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CORN SEEDS STORED UNDER VARYING STORAGE CONDITIONS

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KEYWORDS

packaging; *Zea mays*; hermetic; controlled environment.

ABSTRACT

The seed deterioration process during storage is inevitable, but it can be slowed down using packaging that reduces the influence of the external environment on stored corn seeds. Therefore, this study aimed to evaluate the physiological quality of corn seeds stored in different packages and subjected to storage conditions in the central region of Brazil. Thirty-seven corn genotypes were analyzed in three storage environments: multiwall paper, 10 °C temperature, and 40% relative air humidity; multiwall paper under uncontrolled conditions; and hermetic packaging under uncontrolled conditions. The results of germination, water content, electrical conductivity, accelerated aging, soilless cold test, and field emergence test were used. Physiological quality assessments indicated that storage under conditions of 10 °C temperature and 40% relative air humidity is more efficient in preserving corn seeds' physiological quality than packaging in an uncontrolled environment.

INTRODUCTION

The projected grain production in Brazil for the 2022/23 crop season is 312.5 million tons, with corn contributing to approximately 40% of the total (Alves et al., 2020; Conab, 2023). The utilization of high-quality seeds, characterized by increased tolerance to adverse conditions, is essential for establishing a uniform crop field that yields high productivity. It is crucial to attain the targeted result of 93.4 million tons of corn grains by the end of the crop season. In addition to production in the field, other post-harvest activities are relevant to maintain seed quality until it reaches the producer, such as storage during the off-season.

Storage plays a crucial role in maintaining the viability and vigor of corn seeds. Particularly noteworthy is the use of packaging that mitigates the impact of the external environment, which can influence respiration and lead to the subsequent deterioration of the seeds (Capilheira et al., 2020).

Packaging has several functions in the seed market, such as separation and identification of seeds, ease of transport and storage, and protection of seeds against attack by organisms and environmental variations (Coradi et al., 2020). Therefore, packaging must present good resistance to transport, porosity or impermeability, flexibility or rigidity, durability, ease of printing, transparency or opacity, and resistance to insects and rodents (Bakhtavar et al., 2019).

Impermeable packaging is a barrier, preventing moisture exchange between the seed and the environment. It exhibits other crucial characteristics, such as minimizing oxygen availability due to seed respiration. This, in turn, mitigates the decline in dry matter, deters insect proliferation, and preserves the physiological quality of the seeds over extended storage periods (Ferreira & Bazzo, 2020).

Polyethylene (Jaques et al., 2022) or hermetic packaging (Capilheira et al., 2019; Capilheira et al., 2020; Hornke et al., 2020) has been used in several studies to preserve the physiological seed quality. Considering these aspects, this study aimed to evaluate the physiological quality of corn seeds stored in different packaging and subjected to storage conditions in the central region of Brazil.

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MATERIAL AND METHODS

This experiment was conducted using 37 corn genotypes stored in three environments and two types of packaging (multiwall paper and hermetic packaging) for 180 days. The samples comprised 2 kg of seed from each genotype, previously treated in the company that supplied the seeds.

In the first storage condition, the 37 genotypes were packaged in multiwall paper packaging and stored in a cold room (10 °C and 40% relative humidity).

In the second storage condition, the 37 corn seed genotypes were packaged in multiwall paper packaging and stored under uncontrolled environmental conditions. In the third storage condition, the genotypes were packed in hermetic packaging and stored under uncontrolled environmental conditions. The environment consisted of a warehouse in the region of Itumbiara/GO, with a mean annual temperature of 25 °C and a relative humidity of 62% (ClimateData, 2023).

Sensors were added inside the packages to record temperature and relative humidity values during the experimental period. The data is shown in Figure 1. The five evaluations were carried out every 45 days, totaling 180 days of storage.

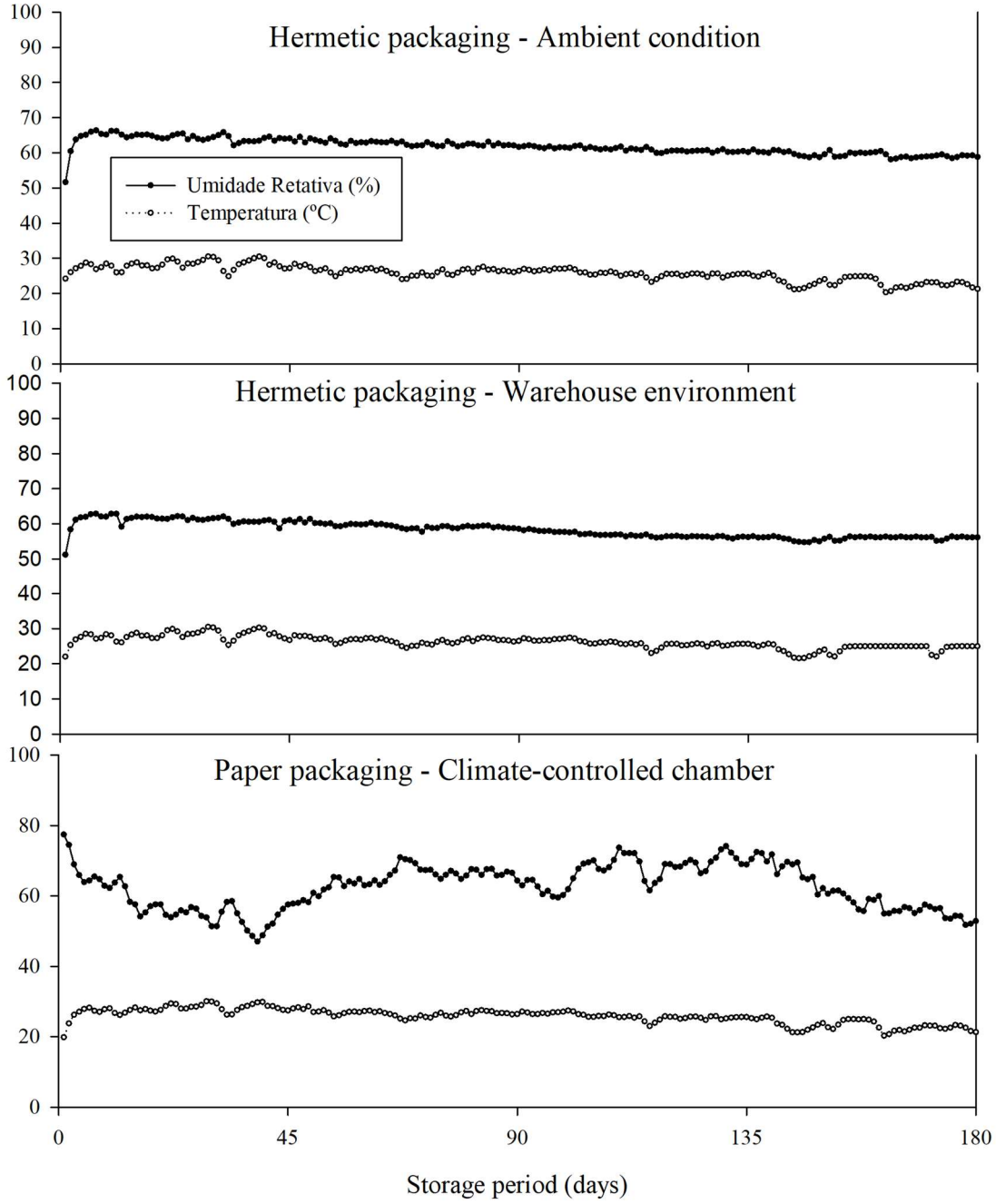

FIGURE 1. Variations in temperature and relative humidity inside packages stored in three different environments.

Corn lots were subjected to the following tests to characterize the physiological quality during storage:

Water content: The oven method with forced-air circulation at 105 ± 3 °C for 24 hours was used to obtain results under the Rules for Seed Testing (RAS) (Brasil, 2009).

Germination test: Four replications of 50 seeds were moistened on Germitest paper rolls, according to the methodology described in the Rules for Seed Testing (RAS), at 25 °C. Counts were conducted four and seven days after the test was set up (Brasil, 2009).

Electrical conductivity: Four replications of 50 seeds were weighed on a 0.001-g precision scale and placed for soaking in plastic cups (200 mL capacity) containing 75 mL of deionized water. Readings were taken in 24 hours at a temperature of 20 °C using a digital conductivity meter. The results were expressed in $\mu S\ cm^{-1}\ g^{-1}$ of seeds (Vieira & Krzyzanowski, 2020).

Accelerated aging test: The methodology was adapted from Marcos-Filho (2020). Four replications were distributed on aluminum screens suspended inside adapted Gerbox plastic boxes (mini chambers) with 40 mL of water. The Gerbox boxes were maintained in a BOD at a temperature of 42 °C for 72 hours. After this period, the same procedure adopted for the germination test was followed, with evaluation four days after sowing. The results were expressed as a percentage of normal seedlings.

Soilless cold test: Four samples with four subsamples of 50 seeds on Germitest paper rolls moistened with distilled water were used. After sowing, the rolls were placed in transparent polyethylene bags and kept at 10 °C for seven days (Cícero & Vieira, 1994). Subsequently, the rolls were removed from the polyethylene bags, transferred to a germinator at a temperature of 25 °C, and evaluated on the fourth day after the test was set up.

Field emergence: Samples with four subsamples of 50 seeds were used. Sowing was carried out in beds containing a sandy loam-textured Ultisol. Irrigation was performed manually when necessary. The seeds were distributed in a row at a depth of 3 cm, and the final evaluation was carried out 21 days after sowing by counting the emerging seedlings. The results were expressed as a percentage of emerged seedlings.

Experimental design and statistical analysis

A completely randomized experimental design was used with four replications, distributed in a split-plot arrangement (2x3x4), with two vigor levels in the main plot, three subplot storage conditions, and four sub-subplot storage periods.

Germination, accelerated aging, cold test, and field emergence data were subjected to arcsine transformation before analysis of variance.

The data were subjected to analysis of variance, and when significant, the means were compared by the Tukey test at a 5% probability level ($p \leq 0.05$). The Sisvar program was used to carry out the statistical procedure.

RESULTS AND DISCUSSION

No significant interaction was observed between lots, environments, and storage period for the variable water content. The mean seed water content for most genotypes ranged from 10 to 12%, with no changes between different storage conditions during the storage period.

The relative air humidity is directly related to seed water content, in addition to controlling the occurrence of the different metabolic processes it can undergo, mainly the degradation of reserves with increased respiratory activity (Lima et al., 2021).

Genotype 51 showed a variation of 1% for the water content variable (Figure 2), with 12.72%, although within acceptable storage standards.

The analysis of variance for the other tested variables showed a significant interaction. Germination in all genotypes showed an interaction between lots, environment, and storage period.

The cold storage conditions resulted in a drop in germination percentage over the 180 days of storage for most of the genotypes under study (Figure 2A).

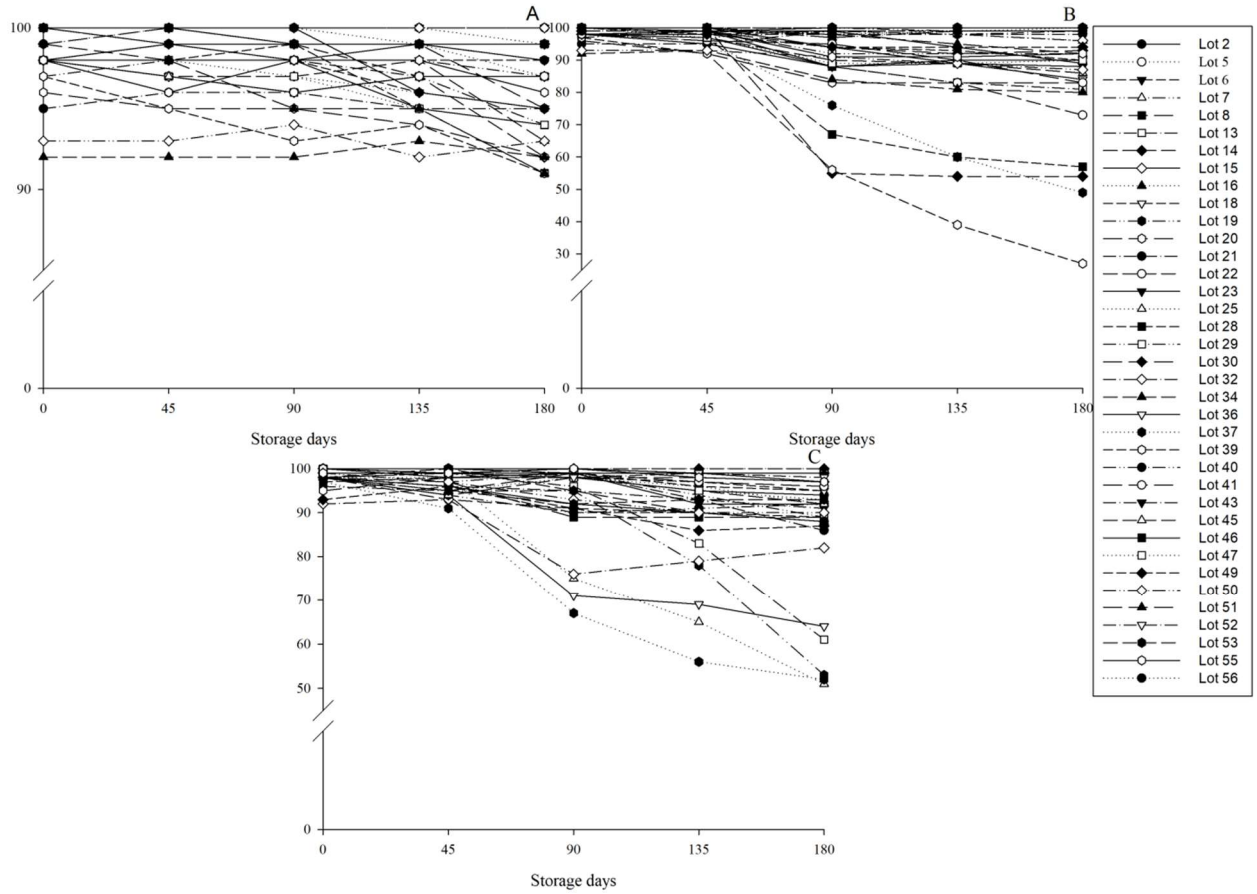

FIGURE 2. Germination of 37 corn genotypes stored in a cold room (A), hermetic packaging and storage under uncontrolled environmental conditions (B), and paper packaging and storage under uncontrolled environmental conditions (C) for 180 days.

The comparison between the germination of corn seeds stored in a cold room and other storage conditions showed the positive influence of the controlled environment conditions (temperature and relative humidity) on seed quality throughout the storage period. It supports the assertion by Oliveira et al. (2011), indicating that the cold room is deemed the optimal environment for seed storage, even when utilizing diverse packaging methods such as Tetra Pak® and cotton bags. The reduced temperature in the storage environment diminishes the activity of enzymes associated with respiration, a critical process that contributes significantly to the loss of seed viability (Harrington, 1972; Cavalcante et al., 2023).

Seeds from four of the five low-vigor genotypes (lots 14, 28, 34, 37, and 39) packed in hermetic packaging and stored in an uncontrolled environment showed a drop in germination after 90 days of storage (Figure 2B). According to the Ministry of Agriculture, Livestock, and Food Supply (MAPA), the minimum value established for the commercialization of corn seeds in Brazil is 85% germination (Brasil, 2013).

The percentage of germination decreased after 90 days of storage, as in a natural process of seed deterioration, especially for eight of the evaluated genotypes (lots 13, 14, 20, 22, 28, 34, 37, and 39), of which 88% are identified as low-vigor lots.

Ten genotypes (lots 13, 14, 20, 22, 28, 34, 36, 37, 39, and 41) showed less than 85% germination after 180 days of storage, making the seeds unviable for commercialization (Brasil, 2013).

The decrease in germination over the 180 days can also be attributed to the chemical treatment performed on the corn seeds (Figure 2A), as the number of abnormal seedlings and the type of abnormality were characterized as phytotoxicity and a high level of deterioration (data not shown). The reduction in the percentage of germination was also observed in corn seeds packed in paper packaging (Figure 2B) and stored under uncontrolled environmental conditions (Figure 2C).

Inadequate chemical treatment can lead to seedling deformations and seed death in more severe cases (Chauhan et al., 2013; Okereke et al., 2023). Hence, it is crucial to adhere to precise guidelines regarding dosage, application of chemical products, and the selection of suitable products tailored to each species. This approach is essential for minimizing the risks of phytotoxicity and ensuring the successful establishment of plants. The behavior of low-vigor genotypes over the 180 days of storage compared to the other genotypes responded unfavorably to local storage conditions and may be combined with the existing chemical treatment of corn seeds.

Classifying seeds into different levels of vigor helps to separate lots, which are more or less vigorous. Thus, seeds with high vigor have a higher chance of establishment with rapid emergence and expressing high yield (Pimentel et al., 2018).

The germination test has less sensitivity for evaluating the level of deterioration in seed lots. Therefore, vigor tests can provide valuable sensitivity, enabling a comparative analysis of the impact of storage conditions on seed deterioration.

The assessment of vigor using the cold test showed a significant effect for the different tested levels, with the

storage condition in a cold room resulting in the best conditioning response of corn seeds over the 180 days of storage compared to other conditions (Figure 3A).

Only one genotype showed inferior behavior (lot 39), identified as a low-vigor genotype, which also occurred in the other analyses.

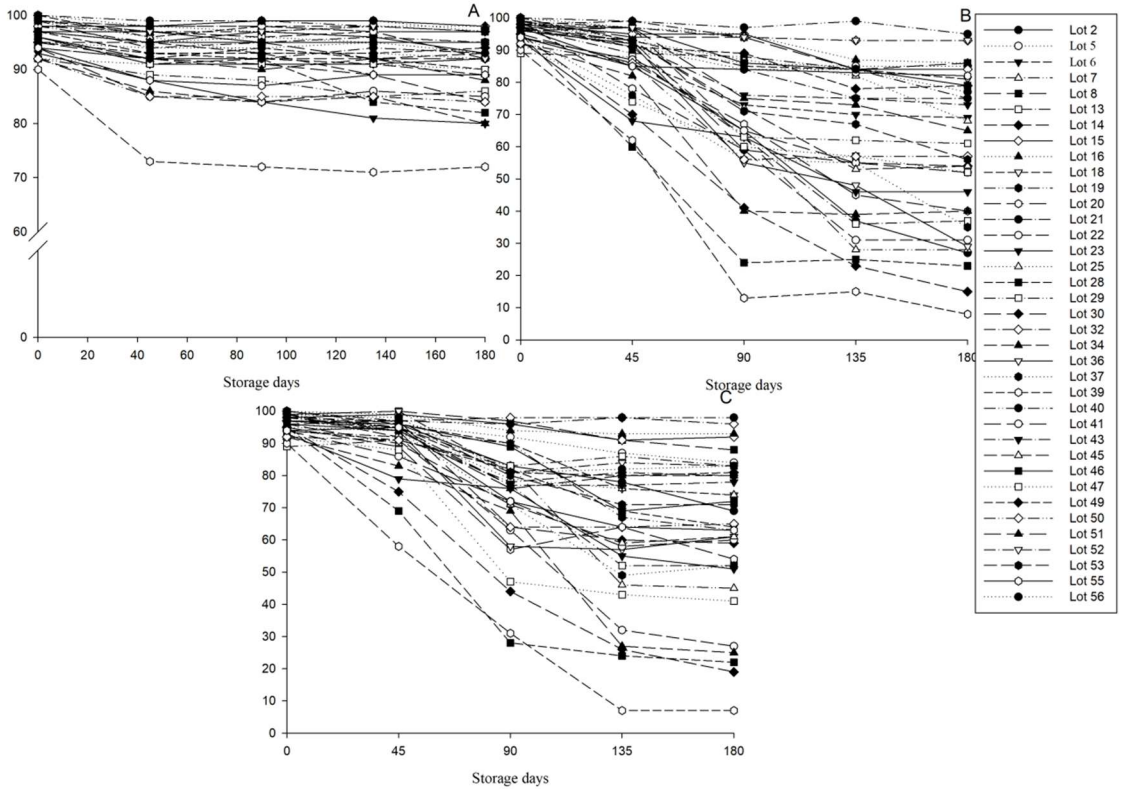

FIGURE 3. Cold test of corn seeds stored in a cold room (A), hermetic packaging and storage under uncontrolled environmental conditions (B), and paper packaging and storage under uncontrolled environmental conditions (C) for 180 days.

Optimizing temperature and relative humidity within the storage environment and elevated germination rates promote the establishment of genotypes demonstrating high performance in low-temperature conditions. These genotypes exhibit robust resilience to abiotic stress conditions in the field, yielding consistent and homogeneous emergence in soils characterized by low temperatures (Carvalho et al., 2015).

Despite the fluctuations observed in the percentage in the cold test during storage (Figure 3B), two genotypes (lots 28 and 39) were noteworthy for their low vigor, exhibiting levels below 60% after 45 days of storage.

Nine lots (14, 22, 28, 30, 34, 36, 37, 39, and 50) reached below 60% after 90 days of storage.

Eighteen lots had less than 60% vigor in the last storage period (180 days).

Low-vigor lot deterioration is more evident with storage due to the deleterious processes that occur with higher intensity than high-vigor lots, standing out the increase in cell respiration (decrease in O_2 intake or increase in CO_2 release) and synthesis of ATP with the mobilization of reserves and accumulation of reactive oxygen species (Capilheira et al., 2019; Teixeira et al., 2020). Storage for more than 45 days under uncontrolled conditions contributes to the formation of abnormal seedlings, low germination, and a higher number of dead seeds.

The analysis of variance conducted to assess seed vigor through the cold test unveiled a significant interaction among seeds stored in paper packaging exposed to uncontrolled environmental conditions (Figure 3C). This is likely attributed to the influence of the environment and the non-interference of packaging regarding climate variations in the stored location.

One particular genotype (lot 39) distinguishes itself with low vigor, registering a percentage of vigor below 60% after 45 days of storage, the lowest observed during this period. The number of genotypes with low vigor increased considerably after 90 days of storage. Seeds undergo a series of chemical, physical, biochemical, and biological changes, and the speed at which these processes occur directly depends on the type of packaging chosen for storage (Jaques et al., 2022).

The electrical conductivity test was not sensitive to separate lots at different levels of corn seed vigor.

Analysis of variance for the accelerated aging test revealed an interaction between lots, environment, and storage period.

The genotypes stored in the cold room showed higher stability over the 180 days of storage than the other conditions (Figure 4A). The controlled conditions of the cold room, where relative air humidity and temperature are maintained, reduce seed metabolism. This reduction significantly enhances the storage potential for most tested genotypes (Bakhtavar et al., 2019).

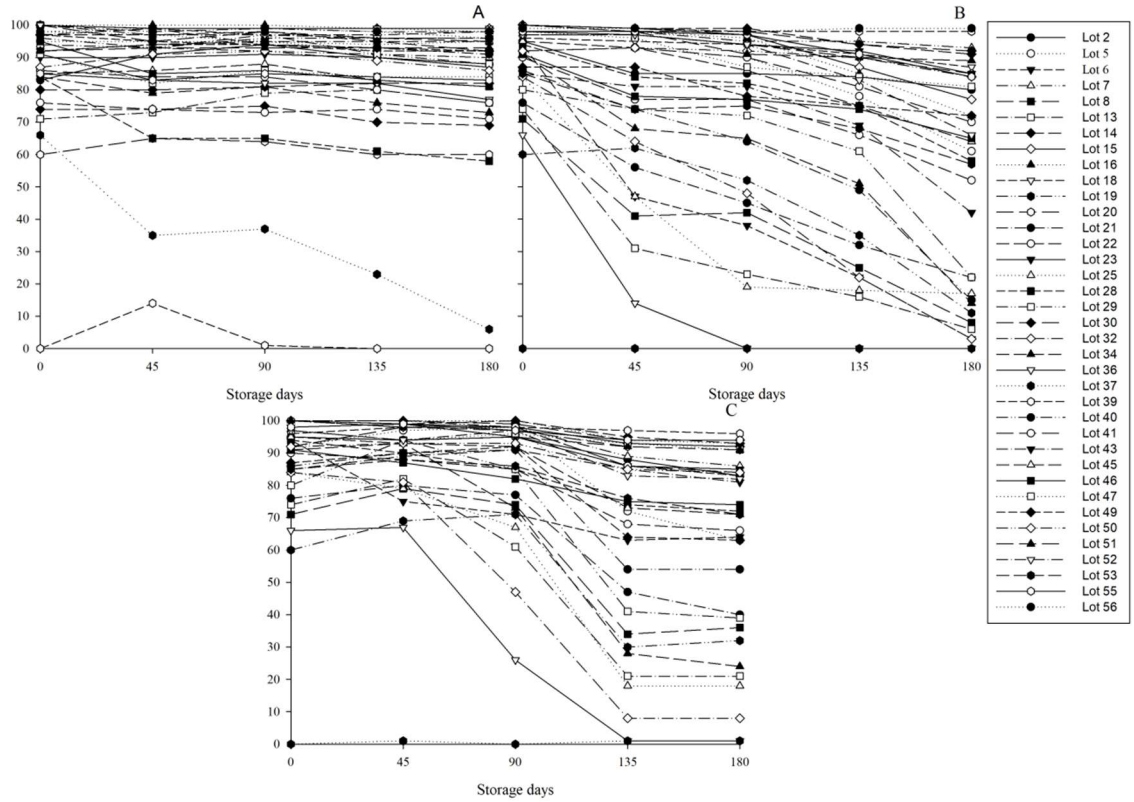

FIGURE 4. Accelerated aging test of corn seeds packed in a cold room (A), hermetic packaging and storage under uncontrolled environmental conditions (B), and paper packaging and storage under uncontrolled environmental conditions (C) for 180 days.

Assessments of the physiological quality of corn have shown that the higher the germination rates, the greater the initial development of seedlings (Sena et al., 2015). Seeds with high physiological performance have fast and stable metabolic processes and, therefore, a faster and more uniform emission from the primary root in the germination process (Queiroz et al., 2019). The physiological quality of seeds enables the selection of genotypes with vigor at levels of 90% until the final period of 180 days (Figure 4A), two of which were classified as low-vigor lots (37 and 39). It confirms that the genetic attribute of seed quality significantly influences storage potential. Low-vigor seeds will have their storage potential compromised over time, even under the best environmental conditions.

The accelerated aging test results for seeds packed in hermetic packaging and stored in an uncontrolled environment differed from those under cold room conditions (Figure 4B). In this condition, some of the lots showed a drop in vigor after 45 days of storage (lots 13, 20, 22, 37, and 39).

High-vigor lots have a higher capacity to withstand an uncontrolled storage condition, becoming dependent on the genetic material compared to low-vigor lots (Koch et al., 2022).

Seeds packed in paper packaging and stored under uncontrolled environmental conditions (Figure 4C) showed low-vigor lots compared to the hermetic condition.

The correlation coefficient of 0.74 obtained for the variable accelerated aging was the most representative when selecting different seed lots using the vigor test (Table 1). Electrical conductivity was the least significant test. It may occur due to the effect of the product used in the chemical treatment of seeds, although the product used was the same in all evaluated lots.

TABLE 1. Pearson's correlation coefficient for the analyzed variables.

	Water content	Germination	Cold test	Electrical conductivity	Accelerated aging	Field emergence
Water content						
Germination	0.0256 ^{ns}					
Cold test	0.0533 **	0.0753*				
Electrical conductivity	0.0410 ^{ns}	-0.274*	-0.343*			
Accelerated aging	0.0554 *	0.692 *	0.741*	-0.311*		
Field emergence	0.0642 *	0.586 *	0.726*	-0.360*	0.612*	

Chemical seed treatment has several benefits, including protection against insects, fungi, and bacteria during storage and the period between sowing and seedling establishment. The use of underdoses or overdoses can cause damage to physiological quality (Chauhan et al., 2013; Okereke et al., 2023). It also influences the integrity of cell membranes and the initial germination stage.

The analysis of variance revealed a significant interaction, with the electrical conductivity test showing a significant interaction at 1% probability between lots, environment, and storage period in the cold room for all genotypes (Figure 5). However, separating lots into different corn seed vigor levels was not sensitive. The behavior of the genotypes for the three storage conditions was similar throughout the storage period, with a positive linear trend for all genotypes, regardless of the vigor level (high or low).

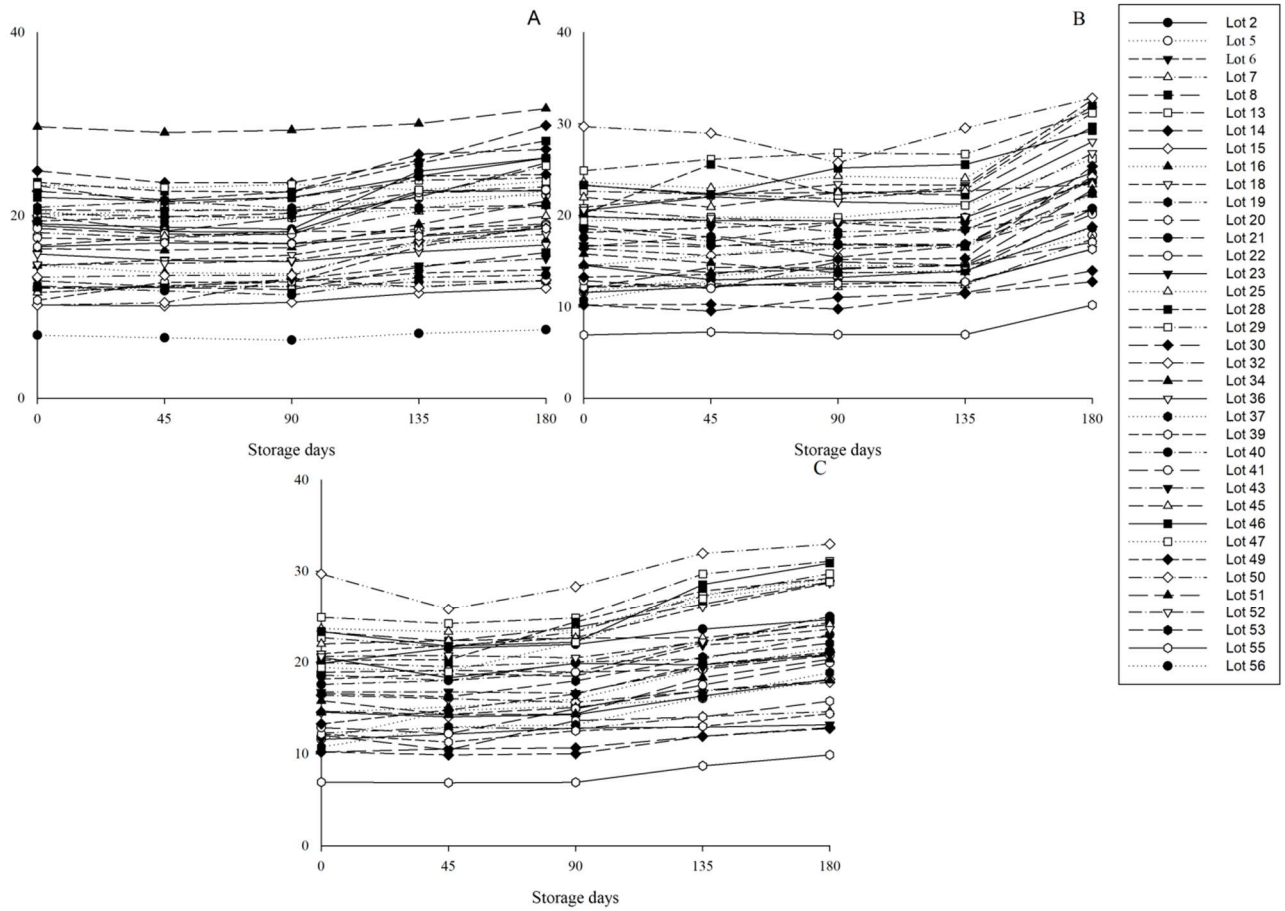

FIGURE 5. Electrical conductivity of corn seeds packed in a cold room (A), hermetic packaging and storage under uncontrolled environmental conditions (B), and paper packaging and storage under uncontrolled environmental conditions (C) for 180 days.

The analysis of variance in the field emergency test revealed interaction for the analyzed factors. Field emergence from hermetic packaging and storage under uncontrolled environmental conditions showed behavior similar to that of the seeds in the cold room. However, lots 13 and 14 showed signs of a drop in vigor at 45 days (Figure 6).

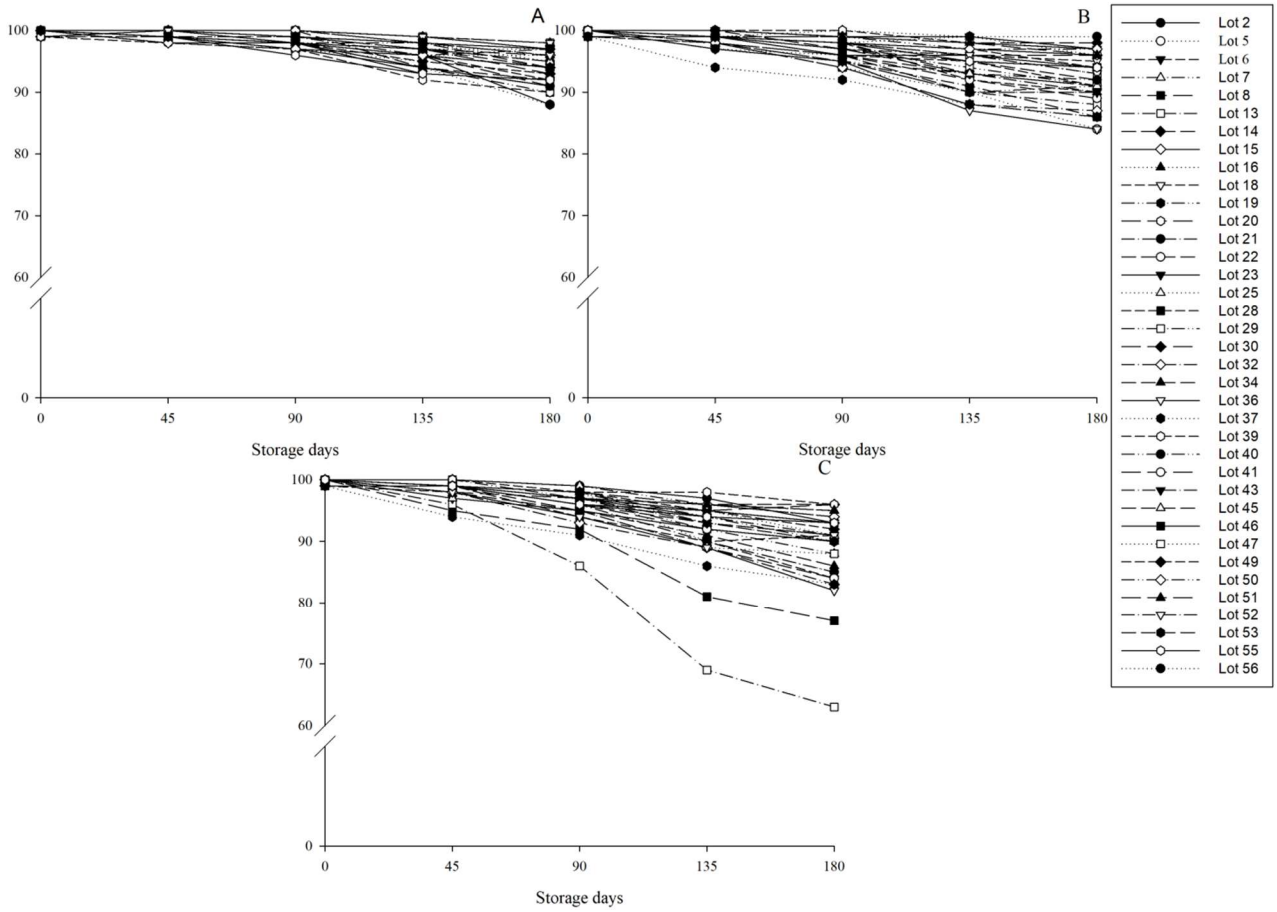

FIGURE 6. Field emergence for corn seeds packed in a cold room (A), hermetic packaging and storage under uncontrolled environmental conditions (B), and paper packaging and storage under uncontrolled environmental conditions (C) for 180 days.

Seeds packed in hermetic packaging showed better results when compared to the responses of seeds packed in paper packaging (Figure 6). The cold storage presented the highest potential for genotypes compared to other storage conditions throughout the entire research period.

The concern about obtaining control of the environment (temperature and relative humidity) in cold rooms causes the seeds to reduce their metabolism, thus prolonging their physiological quality during the storage period.

Hornke et al. (2020) concluded that onion seeds maintained their physiological quality when stored in impermeable packaging for 360 days, regardless of the environment. The physiological seed quality was maintained in other packages when stored in cold or cold-dry rooms, with viability and vigor above 80% up to 180 days of storage.

According to Pessoa (1996), the ideal water content for corn seeds in vacuum storage should be at most 8.0%. Vacuum storage under this environmental condition at an 8.0% humidity maintained the best results for emergence practically throughout the storage period. An alternative to obtain higher storage potential for corn seeds in hermetic packaging would be to change the water content of seeds by 1 to 2% below that used in this test.

CONCLUSIONS

Storage conditions in a cold room with controlled temperature and relative humidity showed the best results in maintaining the physiological quality of corn seeds in the region where the test was conducted. Storage at 10 °C temperature and 40% relative humidity is more efficient for preserving the physiological quality of corn seeds compared to other packaging conditions in an uncontrolled environment.

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