

Variation in desiccation tolerance among papaya accessions (*Carica papaya* L.) and its implications for conservation in germplasm banks

Variação na tolerância à dessecação entre acessos de mamoeiro (*Carica papaya* L.) e suas implicações para a conservação em bancos de germoplasma

Variación en la tolerancia a la desecación entre accesiones de papaya (*Carica papaya* L.) y sus implicaciones para la conservación en bancos de germoplasma

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Abstract

Seed conservation in germplasm banks depends on maintaining viability over time, and desiccation tolerance is a key factor determining storage success, particularly in tropical species such as papaya (*Carica papaya* L.). However, information on the variability of this trait among different accessions remains limited, hindering the development of efficient long-term conservation strategies. Therefore, this study aimed to evaluate desiccation tolerance in papaya accessions from the Active Germplasm Bank of Embrapa Cassava and Fruits. The experiment was conducted in a completely randomized design. Initially, seed moisture content and germination were determined. Subsequently, seeds were subjected to drying conditions (silica gel) and moist storage (vermiculite), both in hermetically sealed containers. Of the 17 accessions evaluated, 12 (70.6%) were classified as desiccation tolerant, while 5 (29.4%) were sensitive. The results reveal significant intraspecific variation, with a strong genotype effect on desiccation response. These findings highlight the need for accession-specific conservation strategies to ensure long-term seed viability.

Keywords: Seed viability; Moisture content; Ex situ conservation; Genetic variability.

Resumo

A conservação de sementes em bancos de germoplasma depende da manutenção da viabilidade ao longo do tempo, sendo a tolerância à dessecação um dos principais fatores que determinam o sucesso do armazenamento, especialmente em espécies tropicais como o mamoeiro (*Carica papaya* L.). No entanto, ainda são limitadas as informações sobre a variabilidade dessa característica entre diferentes acessos, o que dificulta a definição de estratégias eficientes de conservação a longo prazo. Assim, o objetivo deste estudo foi avaliar a tolerância à dessecação em acessos de mamoeiro provenientes do Banco Ativo de Germoplasma da Embrapa Mandioca e Fruticultura. O experimento foi conduzido em delineamento inteiramente casualizado, sendo inicialmente determinado o teor de água e a germinação das sementes. Posteriormente, as sementes foram submetidas a condições de secagem (sílica gel) e armazenamento úmido (vermiculita), ambas em recipientes hermeticamente fechados. Dos 17 acessos avaliados, 12 (70,6%) foram classificados como tolerantes à dessecação, enquanto 5 (29,4%) apresentaram sensibilidade. Os resultados evidenciam variação intraespecífica significativa, com forte influência do genótipo sobre a resposta à dessecação. Esses achados indicam a necessidade de estratégias específicas de conservação para cada acesso, visando a manutenção da viabilidade em longo prazo.

Palavras-chave: Viabilidade de sementes; Teor de água; Conservação ex situ; Variabilidade genética.

Resumen

La conservación de semillas en bancos de germoplasma depende del mantenimiento de la viabilidad a lo largo del tiempo, y la tolerancia a la desecación es un factor clave que determina el éxito del almacenamiento, particularmente en especies tropicales como la papaya (*Carica papaya* L.). Sin embargo, la información sobre la variabilidad de esta característica entre diferentes accesiones aún es limitada, lo que dificulta el desarrollo de estrategias eficientes de conservación a largo plazo. Por lo tanto, este estudio tuvo como objetivo evaluar la tolerancia a la desecación en accesiones de papaya del Banco Activo de Germoplasma de Embrapa Mandioca y Fruticultura. El experimento se llevó

a cabo en un diseño completamente al azar. Inicialmente, se determinaron el contenido de humedad de las semillas y la germinación. Posteriormente, las semillas fueron sometidas a condiciones de secado (gel de sílice) y almacenamiento húmedo (vermiculita), ambos en recipientes herméticamente sellados. De las 17 accesiones evaluadas, 12 (70,6%) fueron clasificadas como tolerantes a la desecación, mientras que 5 (29,4%) fueron sensibles. Los resultados revelan una variación intraespecífica significativa, con un fuerte efecto del genotipo sobre la respuesta a la desecación. Estos hallazgos resaltan la necesidad de estrategias de conservación específicas para cada accesión con el fin de garantizar la viabilidad de las semillas a largo plazo.

Palabras clave: Viabilidad de semillas; Contenido de humedad; Conservación ex situ; Variabilidad genética.

1. Introduction

Papaya (*Carica papaya* L.) is a fruit native to tropical regions (Mangolin et al., 2019) and has significant economic importance, being cultivated in several parts of the world. Brazil, India, Mexico, the Dominican Republic, and Indonesia stand out as the main producers (Kuhlcamp et al., 2022). Brazil is one of the leading producers and exporters, with relevance extending beyond the agro-industrial food sector to include pharmacological and medicinal applications (Serafini et al., 2021; FAO, 2021). However, despite its economic and biotechnological importance, there are still limitations related to seed conservation, which directly impact breeding programs and the maintenance of genetic resources.

Papaya is predominantly propagated by seeds; however, germination is often slow, uneven, and irregular due to the occurrence of dormancy (Vale et al., 2020). Even after removal of the sarcotesta, germination remains non-uniform and delayed (Berbert et al., 2008). Furthermore, the physiological classification of papaya seeds regarding desiccation tolerance—whether orthodox or intermediate—remains unclear, making it difficult to establish safe storage conditions, particularly given the variability observed among different accessions.

Maintaining physiological quality is essential for seed conservation in germplasm banks. However, papaya seeds exhibit inconsistent behavior, as although they tolerate desiccation, they may lose viability when stored at low temperatures, such as $-20\text{ }^{\circ}\text{C}$ (Sharmela et al., 2019). This behavior reinforces the uncertainty regarding their physiological classification and highlights limitations in conventional storage protocols, which are largely based on the distinction between orthodox and recalcitrant seeds.

During storage, seeds of various species may undergo accelerated deterioration as a function of moisture content and temperature, affecting physiological and biochemical processes and resulting in significant losses in germplasm conservation (Mahjabin et al., 2015). However, studies evaluating desiccation tolerance considering variability among papaya accessions from germplasm banks are still scarce. This limits the understanding of intraspecific physiological responses and hinders the development of specific protocols for long-term conservation.

In this context, understanding desiccation tolerance in different papaya accessions is essential for developing efficient seed conservation strategies. Considering the importance of this trait for breeding programs and the maintenance of genetic resources, this study is based on the hypothesis that desiccation tolerance varies among accessions and directly influences the efficiency of ex situ conservation. Thus, the objective of this study was to evaluate the desiccation tolerance of seeds from papaya accessions maintained in the Active Germplasm Bank of Embrapa Cassava and Fruits.

2. Methodology

An experimental, laboratory-based study was conducted using a quantitative approach (Risemberg et al., 2026; Pereira et al., 2018). The experiment was conducted in the experimental area of Embrapa Cassava and Fruits, located in Cruz das Almas, Bahia, Brazil ($12^{\circ}40'12''\text{ S}$, $39^{\circ}06'07''\text{ W}$, 220 m altitude). The municipality is situated in the Recôncavo region of Bahia, and according to the Köppen classification, the climate is transitional between Am and Aw types (tropical subhumid to dry), with an

average annual temperature of 23.8 °C, annual precipitation of 1,224 mm concentrated between March and August, and mean relative humidity of 82.3%.

Seeds from 17 hybrid papaya (*Carica papaya* L.) accessions were used, obtained from the Active Germplasm Bank of Embrapa Cassava and Fruits: BGM69, BGM251, BGM175, BGM187, BGM166, BGM23, BGM142, BGM135, BGM46, BGM254, BGM145, BGM257, BGM245, BGM252, BGM246, BGM72 (Solo group), and BGM78 (Solo group).

Fruits were harvested from the Active Germplasm Bank of papaya at Embrapa Cassava and Fruits and transported to the processing unit. They were then transversely sectioned, avoiding damage to the seeds. Seeds were removed using a spoon and transferred to a fine mesh sieve, where the sarcotesta was manually removed by friction under running water.

After sarcotesta removal, the seeds were placed on paper towels to remove excess moisture and subsequently kept on newspaper sheets for two days for drying under ambient conditions.

The desiccation tolerance test was conducted based on a methodology adapted from Pritchard (2004). Initially, seed moisture content was determined using three replicates of 10 seeds by the oven method at 105 °C (Brasil, 2009), and initial germination was assessed using four replicates of 10 seeds.

Two treatments were established: a humid condition, in which seeds were placed in hermetically sealed containers with 200 g of moistened vermiculite (1:2.5 ratio with the addition of 2.5 mL of water), and a dry condition, using 125 g of activated silica gel, also in hermetically sealed containers. Both treatments were maintained at room temperature.

Seeds subjected to silica gel were weighed daily until reaching constant mass, at which point final moisture content was determined. In the humid treatment, containers were opened every three days to allow aeration, and the storage period corresponded to the time required for mass stabilization in the dry treatment. At the end of the storage period, moisture content was again determined by the oven method at 105 °C (Brasil, 2009).

After treatments, germination tests were conducted with four replicates of 10 seeds for each condition. Seeds were sown in moistened vermiculite, in Petri dishes, and maintained in a germination chamber under alternating temperatures of 35 °C/25 °C and a 12-hour photoperiod. Evaluations were carried out daily, and seeds were considered germinated when radicle protrusion reached at least 2 mm.

Germination curves (% emergence vs. days after sowing) of fresh seeds and seeds subjected to drying and humid storage were compared to identify desiccation-tolerant and intolerant accessions.

The following variables were evaluated: germinability (G, %); mean germination time (\bar{t} , days); coefficient of variation of germination time (CV_t , %); mean germination rate (\bar{v} , day⁻¹); uncertainty (I); and synchronization index (Z).

The mean germination time (\bar{t}) was calculated using the expression: $\bar{t} = \sum_{i=1}^k n_i t_i / \sum_{i=1}^k n_i$, where t_i is the time from the beginning of the experiment to the i -th observation, n_i is the number of seeds germinated at time i , and k is the last germination time. The coefficient of variation of germination time (CV_t) was calculated as $CV_t = (s_t / \bar{t}) \times 100$, where s_t is the standard deviation of germination time. The mean germination rate (\bar{v}) was calculated as $\bar{v} = 1 / \bar{t}$. Uncertainty (I) was calculated as $I = -\sum_{i=1}^k f_i \log_2 f_i$, where f_i is the relative frequency of germination, given by $f_i = n_i / \sum_{i=1}^k n_i$. The synchronization index (Z) was calculated as $Z = \sum C_{n,2} / N$, where $C_{n,2} = n_i(n_i - 1) / 2$ and $N = \sum n_i (\sum n_i = 1) / 2$, where $C_{n,2}$ representing the number of pairwise combinations of seeds germinated at time i . Further details of these expressions can be found in Ranal and Santana (2006).

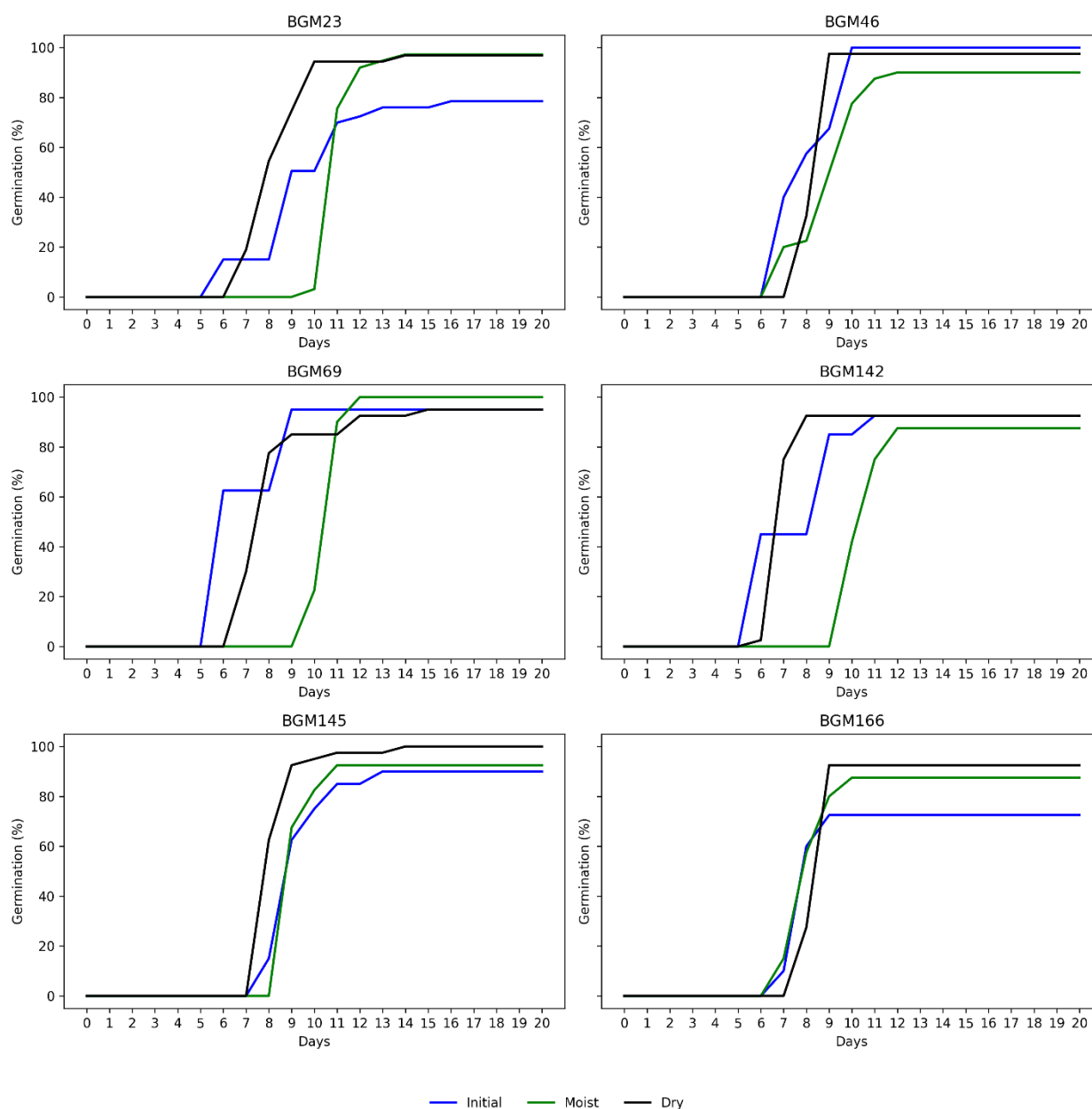
Data were subjected to analysis of variance (ANOVA) using the F-test. Substrate means were compared using the F-test, and temperature regime means were compared using Tukey's test, both at a 5% probability level. Germination data were transformed using arcsine $\sqrt{(x/100)}$ to meet the assumptions of ANOVA.

3. Results

3.1 Germination curves

Among the 17 accessions evaluated, 12 were classified as desiccation-tolerant (BGM23, BGM46, BGM69, BGM142, BGM145, BGM166, BGM187, BGM245, BGM246, BGM251, BGM254, and BGM257), as they did not show a significant reduction in germination after the drying treatment or exhibited performance superior to the control. In contrast, five accessions were considered intolerant (BGM72, BGM78, BGM135, BGM175, and BGM252), showing at least a 20% reduction in germination under dry conditions (Figures 1, 2 and 3).

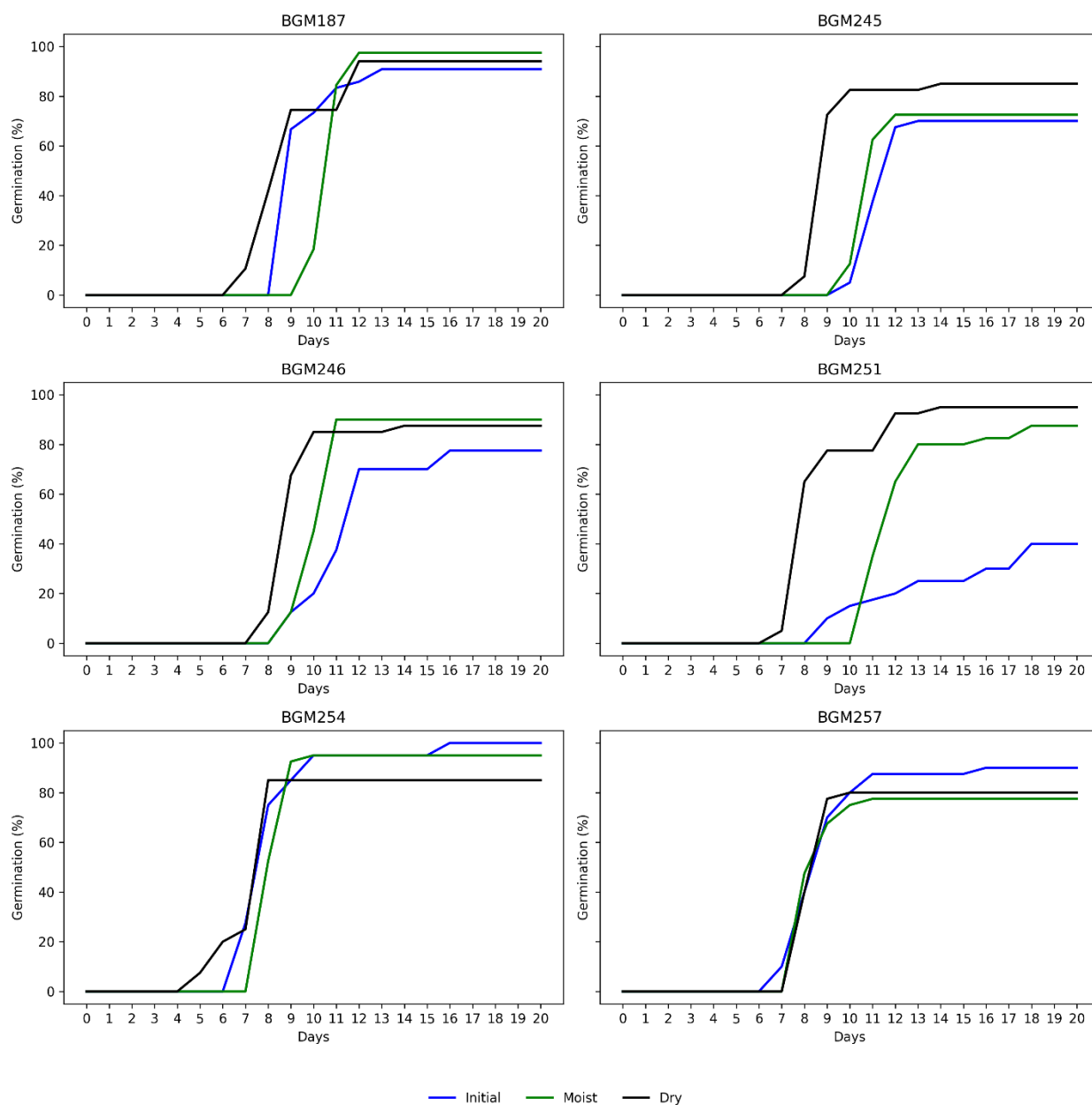
Figure 1 - Germination dynamics (%) of desiccation-tolerant papaya (*Carica papaya* L.) accessions (BGM23, BGM46, BGM69, BGM142, BGM145, and BGM166) under contrasting moisture conditions (initial, moist, and dry) in a 100-seed germination assay. Germination was recorded over time and expressed as cumulative percentage.



Source: Research data (2025).

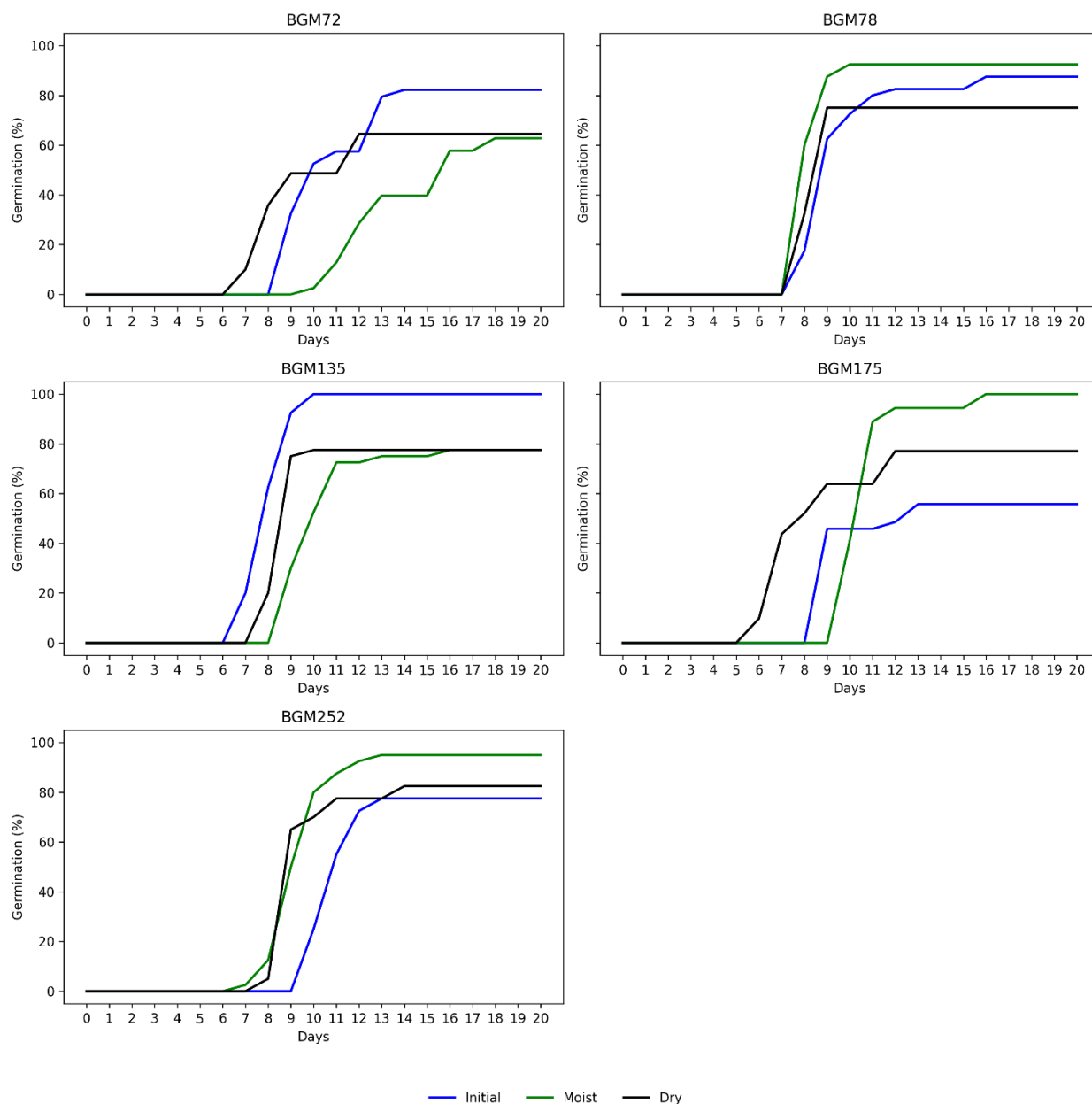
The ability to tolerate desiccation varied among the evaluated accessions, as evidenced by differences in germination curves.

Figure 2 - Germination dynamics (%) of desiccation-tolerant papaya (*Carica papaya* L.) accessions (BGM187, BGM245, BGM246, BGM251, BGM254, and BGM257) under contrasting moisture conditions (initial, moist, and dry) in a 100-seed germination assay. Germination was recorded over time and expressed as cumulative percentage.



Source: Research data (2025).

Figure 3 - Germination dynamics (%) of desiccation-intolerant papaya (*Carica papaya* L.) accessions (BGM72, BGM78, BGM135, BGM175, and BGM252) under contrasting moisture conditions (initial, moist, and dry) in a 100-seed germination assay. Germination was recorded over time and expressed as cumulative percentage.



Source: Research data (2025).

3.2 Ex situ conservation and implications for germplasm storage

The variability observed in desiccation tolerance among *Carica papaya* accessions indicates that seed physiological behavior is not uniform, which limits the application of generalized storage protocols in germplasm banks. Although some accessions maintained viability after desiccation, suggesting behavior consistent with orthodox seeds, the significant reduction in germination observed in other accessions characterizes an intermediate pattern. This pattern has already been described for tropical species with partial sensitivity to desiccation and storage at low temperatures (Ellis et al., 1990; Walters, 2015).

This behavior demonstrates that the physiological classification of papaya seeds cannot be established uniformly for the species and must consider intraspecific variability associated with genotype. Seeds with intermediate behavior exhibit partial

tolerance to water loss but are sensitive to conventional storage conditions, especially under low temperature and low moisture content, which reduces their longevity (Walters, 2015; Ballesteros et al., 2021).

Therefore, ex situ conservation strategies should consider specific parameters for each accession, particularly critical moisture content and storage temperature, which are key factors for maintaining viability and physiological integrity over time. The adoption of inadequate conditions may accelerate deterioration and result in loss of viability and conserved genetic variability.

In this context, the results obtained have direct implications for germplasm bank management, as they highlight the need for differentiated protocols for papaya seeds. The absence of such an approach may compromise long-term conservation and negatively impact breeding programs, which depend on the availability of viable and genetically representative material.

3.3 Germination indices

For the initial, moist, and dry treatments, the mean moisture contents were 8.95%, 59.22%, and 6.58%, respectively. No statistically significant differences were observed for germination, coefficient of variation of germination time, and synchronization index.

In this study, moisture content did not influence germination percentage; however, it is one of the key factors determining seed conservation. Seed longevity can be extended by reducing moisture content through drying and by modifying storage conditions (Venturini et al., 2012).

Moisture content is a critical factor for papaya seed storage, as high moisture levels can rapidly reduce storage longevity. In this species, seed longevity is reduced by half for each 1% increase in seed moisture content (Zulhisyam et al., 2013). A study by Bass (1975) demonstrated that papaya seeds dried and stored in hermetic packaging at 5 °C can remain viable for approximately six years.

Regarding mean germination time, the dry treatment was statistically lower than the other treatments, indicating faster germination (Table 1).

The mean germination rate in the dry treatment was higher than in the moist treatment, indicating faster germination in seeds subjected to desiccation.

Uncertainty (I) is related to the distribution of relative germination frequency over time. Low values of I indicate that germination is concentrated within a specific time interval. For this index, moist and dry treatments showed higher values than the initial treatment, with no statistical difference between them (Table 1).

Table 1 - Mean values of germinability (G, %); mean germination time (\bar{t} , days); coefficient of variation of germination time (CV_t , %); mean germination rate (\bar{v} , day⁻¹); uncertainty (I); and synchronization index (Z) as a function of the treatments applied to papaya seeds.

Treatments	G	\bar{t}	CV_t	\bar{v}	I	Z
Initial	82.17 a	7.43 a	20.03 a	0.14 a	1.29 a	0.40 a
Moist	87.49 a	8.17 a	25.46 a	0.13 b	1.10 b	0.41 a
Dry	86.66 a	6.53 b	26.07 a	0.16 a	0.96 b	0.42 a

Means followed by the same lowercase letters in the columns do not differ statistically from each other according to Tukey's test at the 5% probability level. Source: Research data (2025).

For the initial, moist, and dry treatments, the mean moisture contents were 8.95%, 59.22%, and 6.58%, respectively. No statistically significant differences were observed for germinability, coefficient of variation of germination time, and

synchronization index. For mean germination time, the dry treatment showed lower values than the other treatments, indicating faster germination (Table 1).

The mean germination rate was higher in the dry treatment compared to the moist treatment. Uncertainty values indicated differences among treatments, with moist and dry treatments showing higher values than the initial treatment, with no statistical difference between them (Table 1).

4. Discussion

The predominance of desiccation-tolerant accessions suggests that a portion of papaya seeds exhibits behavior consistent with orthodox seeds, at least under the conditions evaluated. However, the occurrence of sensitive accessions indicates that this behavior is not uniform, revealing significant intraspecific variability associated with genotype.

Similar results have been reported in the literature, where papaya seeds show tolerance to desiccation up to certain moisture content levels without immediate loss of viability (Lopes & Souza, 2008). On the other hand, the existence of contrasting responses among seed lots and accessions reinforces the difficulty of establishing a single physiological classification for the species.

Moisture content is one of the main factors influencing seed conservation, and its reduction is generally associated with increased longevity under appropriate storage conditions (Venturini et al., 2012). However, in tropical species, this relationship may not be linear, particularly in seeds with intermediate characteristics.

Studies indicate that papaya seeds may exhibit a significant reduction in longevity with increasing moisture content, with marked decreases in storage time reported even with small variations in this parameter (Zulhisyam et al., 2013). Conversely, adequate drying and storage conditions can maintain seed viability for several years (Bass, 1975).

The absence of a consistent grouping pattern among accessions indicates high physiological variability, which hampers the formation of homogeneous groups based on the variables analyzed. This variability highlights the need to expand the number of accessions in future studies to improve the understanding of seed physiological behavior.

Additionally, the literature reports inconsistencies in the classification of desiccation tolerance in seeds of the genus *Carica*, which is still considered uncertain in international databases, reinforcing the need for experimental studies aimed at defining tolerance limits to moisture content and storage conditions.

Thus, although most of the evaluated accessions exhibited behavior consistent with orthodox seeds, the results indicate that desiccation tolerance in papaya seeds cannot be generalized, being strongly influenced by genotype and by drying and storage conditions.

5. Conclusion

Desiccation tolerance in papaya seeds varies among accessions and is strongly influenced by genotype.

Most accessions exhibited behavior consistent with orthodox seeds; however, the presence of sensitive accessions indicates that this characteristic cannot be generalized for the species.

The results highlight the need to develop accession-specific conservation protocols to ensure the maintenance of viability and genetic variability in germplasm banks.

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