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EVALUATION OF THE VIABILITY OF *Genipa infundibuliformis* SEEDS SUBJECTED TO DIFFERENT STORAGE CONDITIONS

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Abstract
Genipa infundibuliformis, commonly known as jenipapo-do-seco, is a species with high potential for food use and ecological restoration. However, there is limited information about its seed storage and germination conditions. This study evaluated storage conditions capable of preserving the viability and germination performance of *G. infundibuliformis* seeds for up to 120 days. In a 2×2×4 factorial design, we tested two packaging types (kraft paper vs. transparent plastic bags), two storage environments (ambient temperature vs. cold storage), and four durations (30, 60, 90, and 120 days). Seedling emergence (%E), the Emergence Speed Index (ESI), and Mean Time to Emergence (MET) were determined in standardized seedbeds. Because distributions violated normality assumptions, nonparametric statistics were used. Transparent plastic bags maintained high %E in most scenarios, with a single exception at 60 days under ambient conditions; they also produced consistently higher ESI, indicating faster and more predictable emergence. Differences in MET depended on the time×environment combination, with the effect of time being more evident on MET and the environment exerting only a modest influence on ESI. Kraft paper performed inconsistently: medians were zero in the cold storage at all time points, and %E collapsed to 0% at 120 days under ambient storage. We conclude that, within a 120-day horizon, packaging type is the primary determinant of germination performance. We recommend standardizing the use of transparent plastic bags for seed lots destined for seedling production. When kraft paper is unavoidable, storage should be restricted to short periods and lot replacement scheduled proactively. Operationally, routine ESI monitoring should be adopted as an early indicator of quality loss, thereby improving predictability, efficiency, and supply security for nurseries and seed banks.

Keywords
Emergence — Seed viability — Restoration — Rubiaceae

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1. Introduction

Among the various native species with high economic potential is the genus *Genipa*, a Neotropical lineage of widely distributed lowland trees in the coffee family, Rubiaceae (Ridley et al., 2024). *Genipa infundibuliformis* Zappi & Semir, known as “jenipapo-do-mato,” is a fruit-bearing forest species found especially in the states of Minas Gerais, São Paulo, Rio de Janeiro, and Espírito Santo; in this last state it has been on the red list of threatened species since 2005 (Santos et al., 2024). As with *Genipa americana*, the most common species of the genus, *G. infundibuliformis* has multiple food uses, such as fresh consumption or processing into sweets and beverages, including liqueurs and juices (Lorenzi, 2013).

In addition to the various ways the fruit is used, *G. infundibuliformis* can also be employed in plantings for ecological restoration projects as a native species attractive to wildlife (Lorenzi, 2013), and consequently in plantings for agroforestry systems (AFS). Despite its potential for multiple uses and the feasibility of incorporating the species into plantings with different purposes, there is little technical-scientific information available; the species remains understudied and underutilized. In contrast, *G. americana*, a morphologically similar species, has attracted greater scientific and institutional interest, especially due to its wide distribution. This interest led Embrapa Coastal Tablelands (Embrapa Tabuleiros

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Costeiros), in 2009, to establish an Active Germplasm Bank (Jenipapo AGB) to conserve its genetic resources (Muniz et al., 2015). Thus, the scarcity of studies and initiatives aimed at the conservation and propagation of *G. infundibuliformis* hampers the development of reproductive technologies and limits nursery seedling production, thereby restricting its large-scale use.

Seed storage is one of the key elements for the sexual reproduction of plant species, being essential for planning sowing and for the year-round production of seedlings in nurseries. Unlike *G. americana*, there are no studies in the literature assessing the best storage conditions for *G. infundibuliformis*. In this context, the present study aimed to identify the storage conditions most suitable for maintaining the viability of jenipapo-do-seco (*Genipa infundibuliformis* Zappi & Semir) seeds, with the goal of expanding information on this species' seeds and providing technical support to facilitate its management and seedling production.

2. Material and Methods

The experiment was conducted at the Forest Seed Analysis Laboratory (LASF) of the Arboretum Program, located in the municipality of Teixeira de Freitas, Bahia. Fruits of *G. infundibuliformis* were collected between August and October 2022 from mother trees designated MTE00-422 and MTE00-425, located in the Extreme South of Bahia (Figure 1), at the maturation stage, with yellow-green coloration. After collection, the fruits were processed to remove the pulp and extract the seeds, which were subsequently dried in an enclosed environment with temperature control provided by an air conditioner for 24 hours. Seed lots from two *Genipa infundibuliformis* mother trees were evaluated: mother tree A (MT-A), from the municipality of Alcobaça, BA, and mother tree B (MT-B), from Itamaraju, BA.

After fruit processing and seed extraction of *G. infundibuliformis*, initial germination (T0) was assessed, in which the seeds were sown without prior storage. Seeds from MA were sown four days after collection, whereas those from MB were sown after eight days, with moisture contents of 48.8% and 61.7%, respectively. Moisture content was determined by the oven method at 105 ± 3 ℃ for 24 hours, in accordance with Ministry of Agriculture standards (BRASIL, 1992).

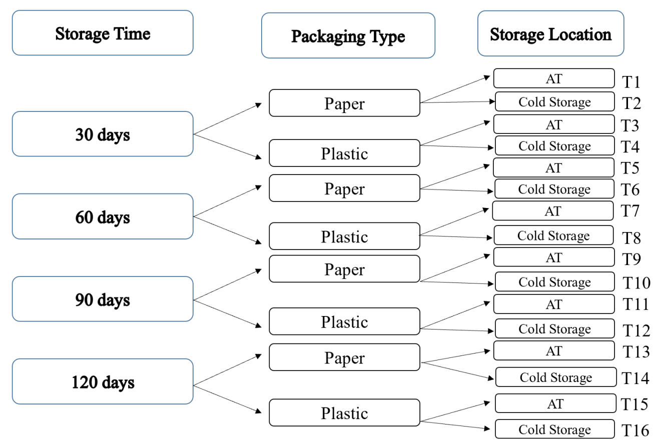
The remaining samples were subjected to experimental storage conditions, varying three factors:

(i) temperature (23 ± 2 ℃, RH 70% — room conditions; or 3 ± 2 ℃, RH 60% — cold storage);

(ii) packaging (kraft paper bag or transparent plastic bag); and

(iii) storage time (30, 60, 90 and 120 days).

These combinations yielded 16 experimental treatments (T1–T16), plus a control (T0), as detailed in Figure 2. Each treatment consisted of four replicates, with 25 seeds per replicate.



Where: AT= Ambient Temperature.

Figure 2. Experimental design of seed storage treatments for *Genipa infundibuliformis*

To assess the viability of the stored seeds, at each storage time the conditioned samples were subjected to an emergence test in sand beds located in a controlled environment with 80% shading. The beds received four daily irrigation cycles to maintain substrate moisture. Emerged seedlings were counted every two or three days after the beginning of emergence and, based on the collected data, the percentage of emerged seeds (E%), the germination speed index (ESI) according to Maguire (1962), and the mean emergence time (MET) according to Labouriau (1983) were determined, as follows:

$$MET = \frac{\sum_{i=1}^{n}(n_i * t_i)}{\sum_{i=1}^{n} n_i}$$

Where:

MET = mean emergence time (days);

n_i = number of seeds that emerged in the interval between consecutive counts;

t_i = time elapsed from sowing to the i-th count.

$$ESI = \left(\frac{E_1}{N_1}\right) + \left(\frac{E_2}{N_2}\right) + \cdots + \left(\frac{E_n}{N_n}\right)$$

Where:

ESI = Emergence Speed Index;

$E_1, E_2, \ldots, E_n$ = number of normal seedlings emerged at the first, second, and n-th count;

$N_1, N_2, \ldots, N_n$ = number of days from sowing to the first, second, ..., n-th count.

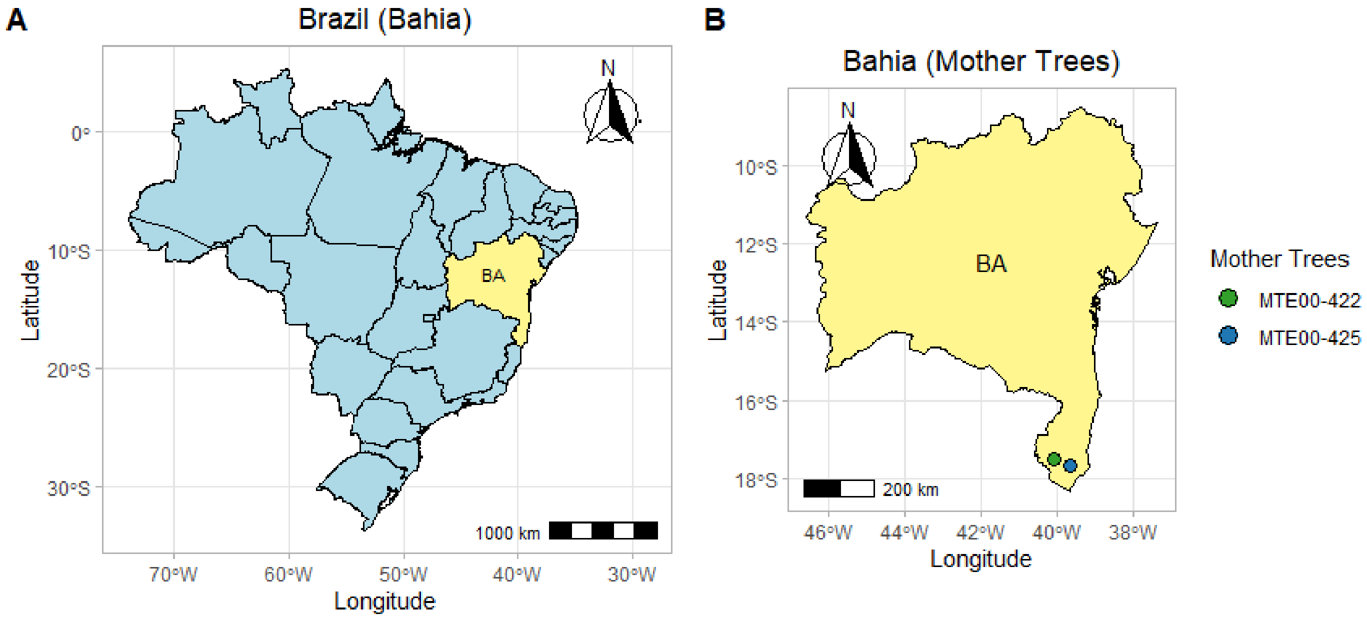


Figure 1. Location Map of *Genipa infundibuliformis* Mother Trees MTE00-422 (MT-A) and MTE00-425 (MT-B) in the Extreme South of Bahia, Brazil.

Statistical analyses were performed in R. Data were organized by storage time (30, 60, 90, and 120 days) and by condition (cold storage or room temperature) to evaluate the effect of packaging type (kraft paper bag vs. transparent plastic bag) on emergence percentage (E%), mean emergence time (MET), and emergence speed index (ESI). Given the violation of parametric assumptions—evidenced by graphical inspection, skewness in descriptive statistics, and the results of normality (Shapiro–Wilk) and homoscedasticity (Cochran and Bartlett) tests—the Mann–Whitney test (Wilcoxon rank-sum) was used for comparisons between independent groups.

To control Type I error in multiple comparisons, the Bonferroni adjustment was applied. Results are presented with adjusted *p*-values, the W statistic, and the indication of significance level: *** ($p < 0.001$), ** ($p < 0.01$), * ($p < 0.05$), and ns (not significant). Only pairwise comparisons with complete data for both packaging categories were included. For variables in which the Kruskal–Wallis test identified statistically significant differences, the Dwass–Steel–Critchlow–Fligner (DSCF) multiple comparisons test was performed to determine which treatments differed significantly from each other. This approach enabled identification of the specific effects of the interactions among packaging type, storage time, and environmental condition on the variables analyzed.

3. Results and Discussion

The distributions of %E, ESI, and MET showed significant departures from normality according to the Shapiro–Wilk test (%E: p = 5.73×10^{-41}; ESI: p = 2.90×10^{-10}; MET: p = 4.64×10^{-11}). Given this violation of assumptions, the data were summarized by the median and interquartile range (IQR), and inferences were based on nonparametric methods. Table 1 summarizes seedling emergence of *G. infundibuliformis* as a function of packaging, time, and storage condition.

In Kraft paper, emergence remained very low throughout the entire period, with medians near zero under both cold storage and ambient temperature; only a slight increase was observed up to 60 days at ambient temperature, followed by a return to zero values. In clear plastic bags, emergence was substantially higher and more variable: high at 30 days under both conditions; a sharp drop at 60 days, especially at ambient temperature; divergence at 90 days (low under cold storage and high at ambient temperature); and a return to high values at 120 days in both conditions. Because the distributions were non-normal and dispersion was high, the description was based on medians and IQR, showing that packaging was the main determinant of performance, with clear plastic bags outperforming Kraft paper at virtually all time points. These findings contrast with Arruda et al. (2017), who did not recommend using plastic bags for storing seeds of *Genipa americana*, a species of the same genus.

Table 1. Descriptive statistics of seedling emergence of *G. infundibuliformis* under different packaging types, times, and storage conditions.

Storage	Time (days)			
	30	60	90	120
Kraft Paper				
Cold Storage	0 [0–0]	0 [0–8.5]	0 [0–0]	0 [0–4]
Ambient Temperature	10 [0–15]	5 [0–33]; 0–88; 33	0 [0–5]	0 [0–0]
Clear Plastic				
Cold Storage	52 [45–68.5]	24 [9.5–40]	10 [4–30]	61.5 [9.5–78]
Ambient Temperature	68 [52–90]	5 [0–27.5]	65 [51–80]	55 [4.75–72]

It is observed that packaging type consistently modulated the seedling emergence of *G. infundibuliformis* over time and across storage conditions. In seven of the eight scenarios evaluated, there was a significant difference between packaging types (Wilcoxon test; $p < 0.001$), with the clear plastic bag performing better; the only exception occurred at 60 days under ambient temperature ($p = 0.422$), when the distributions did not differ (Table 2; Figure 3).

These results (Figure 3 and Table 2) point to the important moisture-control role of clear plastic bags in the storage of recalcitrant seeds. Maintaining moisture in desiccation-sensitive species such as those of the genus *Genipa* may reduce seed germination potential (Arruda et al., 2017).

Table 2. Wilcoxon–Mann–Whitney test results comparing seed viability of *Genipa infundibuliformis* between packaging types (Kraft paper vs. clear plastic bag) across storage times and storage conditions.

Time (days)	Storage	p-value	Significance	Kraft Paper Median (Q1-Q3)	Clear Plastic Median (Q1-Q3)
30	Cold Storage	p<0.001	***	0 (0-0)	52 (45-68.5)
30	Ambient Temperature	p<0.001	***	10 (0-15)	68 (52-90)
60	Cold Storage	p<0.001	***	0 (0-8.5)	24 (9.5-40)
60	Ambient Temperature	0.422	ns	5 (0-33)	5 (0-27.5)
90	Cold Storage	p<0.001	***	0 (0-0)	10 (4-30)
90	Ambient Temperature	p<0.001	***	0 (0-5)	65 (51-80)
120	Cold Storage	p<0.001	***	0 (0-4)	61.5 (9.5-78)
120	Ambient Temperature	p<0.001	***	0 (0-0)	55 (4.75-72)

Legend: ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The temporal pattern was consistent: at 30 days, emergence was high for the clear plastic bag under both conditions (cold storage and ambient temperature); at 60 days, there was a marked reduction - especially at ambient temperature—and the difference between packaging types was no longer detectable under that condition; at 90 days, a strong divergence between conditions emerged (low under cold storage and high at ambient temperature); and at 120 days, emergence again became high for the clear plastic bag under both conditions. Given the non-normality and high dispersion, interpretation was based on medians and the IQR, which underscores the robustness of the effect of the packaging material (Figure 3; Tables 1 and 2).

Figure 3 and Table 2 indicate significant differences (Wilcoxon test; $p < 0.001$) between packaging types in 7 out of 8 scenarios, favoring the clear plastic bag; the exception occurred at 60 days under ambient temperature ($p = 0.422$). By way of magnitude: at 30 days under cold storage, Kraft paper showed 0 (0–0), whereas the clear plastic bag reached 52 (45–68.5); under ambient temperature, the values were 10 (0–15) (Kraft) and 68 (52–90) (clear plastic). At 60 days, the difference persisted under cold storage, 0 (0–8.5) vs. 24 (9.5–40), but not under ambient temperature, where the medians were 5 (0–33) (Kraft) and 5 (0–27.5) (clear plastic). At 90 days, the discrepancy peaked under ambient temperature, 0 (0–5) vs. 65 (51–80); and at 120 days, the clear plastic bag maintained high values under both conditions—61.5 (9.5–78) in cold storage and 55 (4.75–72) at ambient temperature.

From a biological standpoint, the results suggest that the clear plastic bag—by attenuating desiccation and stabilizing moisture—favors the maintenance of germination potential in *Genipa* under the tested regimes. The literature, however, is heterogeneous: studies with species of the same genus report differing effects of plastic on viability, possibly due to intra-/interspecific differences, initial seed moisture, the microenvironment (hypoxia and/or fungi), and the storage protocol (time/temperature). Thus, the findings of this work contrast with reports that discourage plastic for *Genipa* in certain contexts (Arruda et al., 2017) and converge with evidence of higher germination in plastic packaging for other oilseed species, such as safflower (*Carthamus tinctorius* L.) (Menegaes et al., 2020). It is also recognized that the response may be species- and protocol-dependent, as identified by Silva et al. (2014), who found no statistical differences between plastic bags and Kraft paper for the native *Parkia pendula* (Willd.) Benth. ex Walp.

Table 3 presents the mean emergence time in days (MET) for seeds under different combinations of time, packaging type, and storage condition. A clear trend of higher emergence is observed for seeds packaged in clear plastic bags, which showed consistently higher median values and greater dispersion (IQR), whereas seeds stored in Kraft paper bags often had median values of zero, indicating low or no emergence. These results suggest that, for the species evaluated, the use of plastic packaging may favor the maintenance of seed viability during storage.

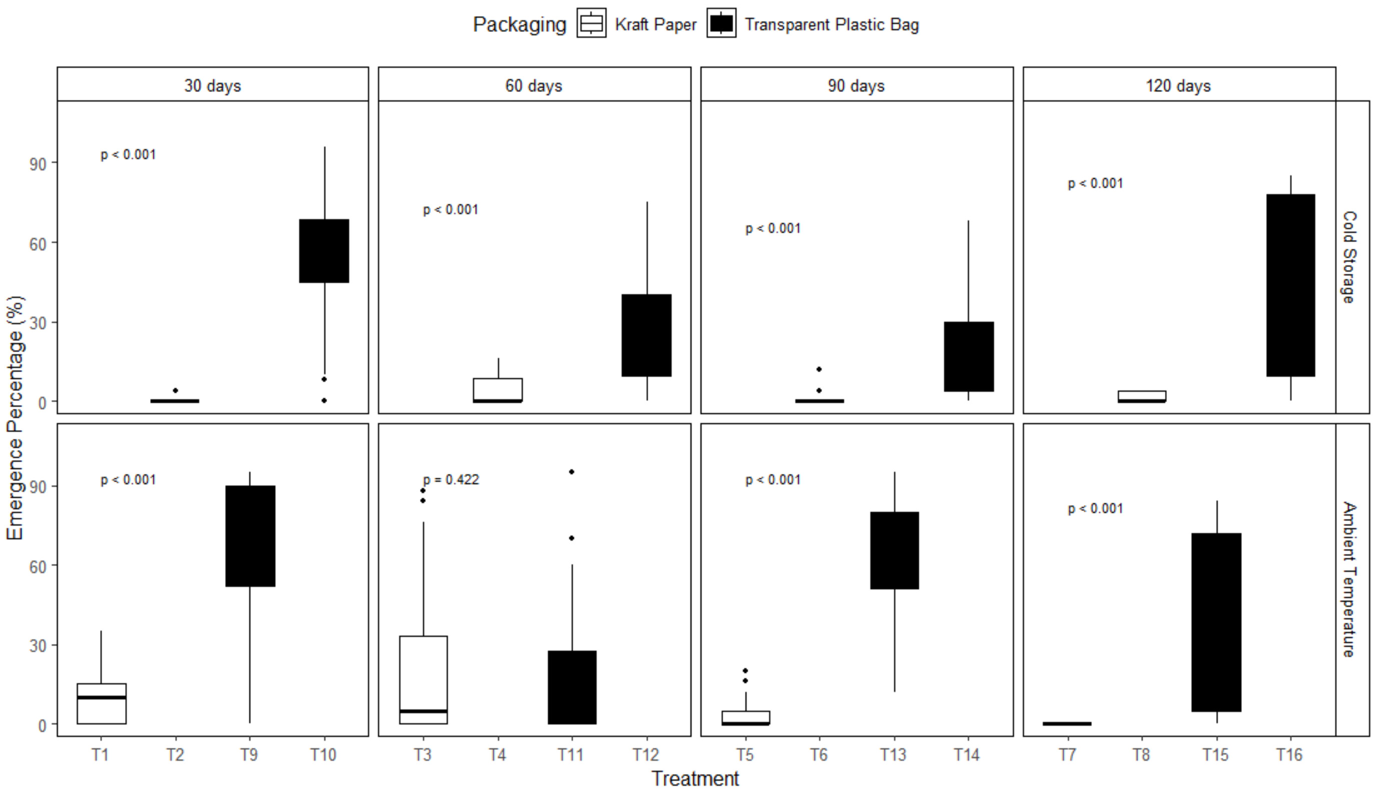


Figure 3. Seedling emergence (%) of *Genipa infundibuliformis* as a function of packaging type, storage time, and storage condition.

Table 3. Descriptive statistics of the mean emergence time (MET) of *G. infundibuliformis* seedlings under different packaging types, times, and storage conditions.

Packaging	Time	Storage	Minimum	Maximum	Median (Q1-Q3)	IQR	Mean ±SD
Kraft Paper	30	CS	0.00	42.00	0.00 (0.00-0.00)	0.00	5.25±14.85
Kraft Paper	30	AT	0.00	59.00	45.50 (33.00-51.00)	18.00	37.25±23.52
Kraft Paper	60	CS	0.00	56.00	0.00 (0.00-51.50)	51.50	20.25±28.01
Kraft Paper	60	AT	0.00	56.00	34.50 (25.12-36.90)	11.78	29.49±19.63
Kraft Paper	90	CS	0.00	43.00	0.00 (0.00-33.00)	0.00	13.62±19.06
Kraft Paper	90	AT	0.00	57.00	39.30 (0.00-42.40)	42.40	27.60±23.52
Kraft Paper	120	CS	0.00	49.00	0.00 (0.00-10.50)	10.50	11.38±21.15
Kraft Paper Bag	120	AT	0.00	0.00	0.00 (0.00-0.00)	0.00	0.00±0.00
Clear Plastic Bag	30	CS	30.40	40.30	36.54 (34.48-39.05)	4.57	36.44±3.42
Clear Plastic Bag	30	AT	30.34	39.45	34.85 (32.75-36.88)	4.13	34.70±3.18
Clear Plastic Bag	60	CS	30.60	47.28	34.18 (33.62-42.77)	9.15	37.67±6.48
Clear Plastic Bag	60	AT	0.00	62.00	40.90 (38.09-50.00)	11.91	39.5±18.31
Clear Plastic Bag	90	CS	30.30	49.85	38.55(36.73-45.69)	8.96	40.30±6.56
Clear Plastic Bag	90	AT	28.20	40.90	33.35 (31.40-35.24)	3.84	33.58±3.97
Clear Plastic Bag	120	CS	29.40	36.00	32.52 (29.6-35.78)	6.18	32.67±3.31
Clear Plastic Bag	120	AT	29.70	34.18	31.36 (30-33.11)	3.11	31.66±1.92

AT: Ambient Temperature; CS: Cold Storage.

The data indicate that packaging type determines the operational viability of *G. infundibuliformis* up to 120 days (Table 3). The clear plastic bag maintained stable median emergence (≈ 31–41%) at all times and under both conditions, with low variability, providing predictability for seedling production. Kraft paper, in turn, was inconsistent: under cold storage the median was 0% at all time points, and even at ambient temperature—although medians were high up to 90 days (≈ 34–46%) - they dropped to 0% at 120 days, alongside greater variability. Thus, for nurseries and seed banks, the practical recommendation is to standardize the use of clear plastic bags and not rely on refrigeration within the 120-day horizon; if Kraft paper is used, limit storage to $\leq$90 days at ambient temperature and plan lot replacement to avoid interruptions in seedling supply.

Figure 4 analysis reveals marked effects of packaging type, time, and storage condition on MET and ESI of *Genipa infundibuliformis* seeds. Overall, cold storage combined with the use of a clear plastic bag provided superior physiological performance of the seeds over the 120-day period for emergence-related parameters.

In Figure 5A, for the MET variable, differences between packaging types were observed under cold storage (CS) at 30 days ($p = 0.010$) and 90 days ($p = 0.009$), with higher MET for the clear plastic bag (i.e., slower emergence). At 60 and 120 days, differences were not detectable ($p = 0.424$; 0.094, respectively). Under ambient temperature (AT), comparisons were not significant at 30, 60, and 90 days ($p = 0.103$; 0.268; 0.562), but were

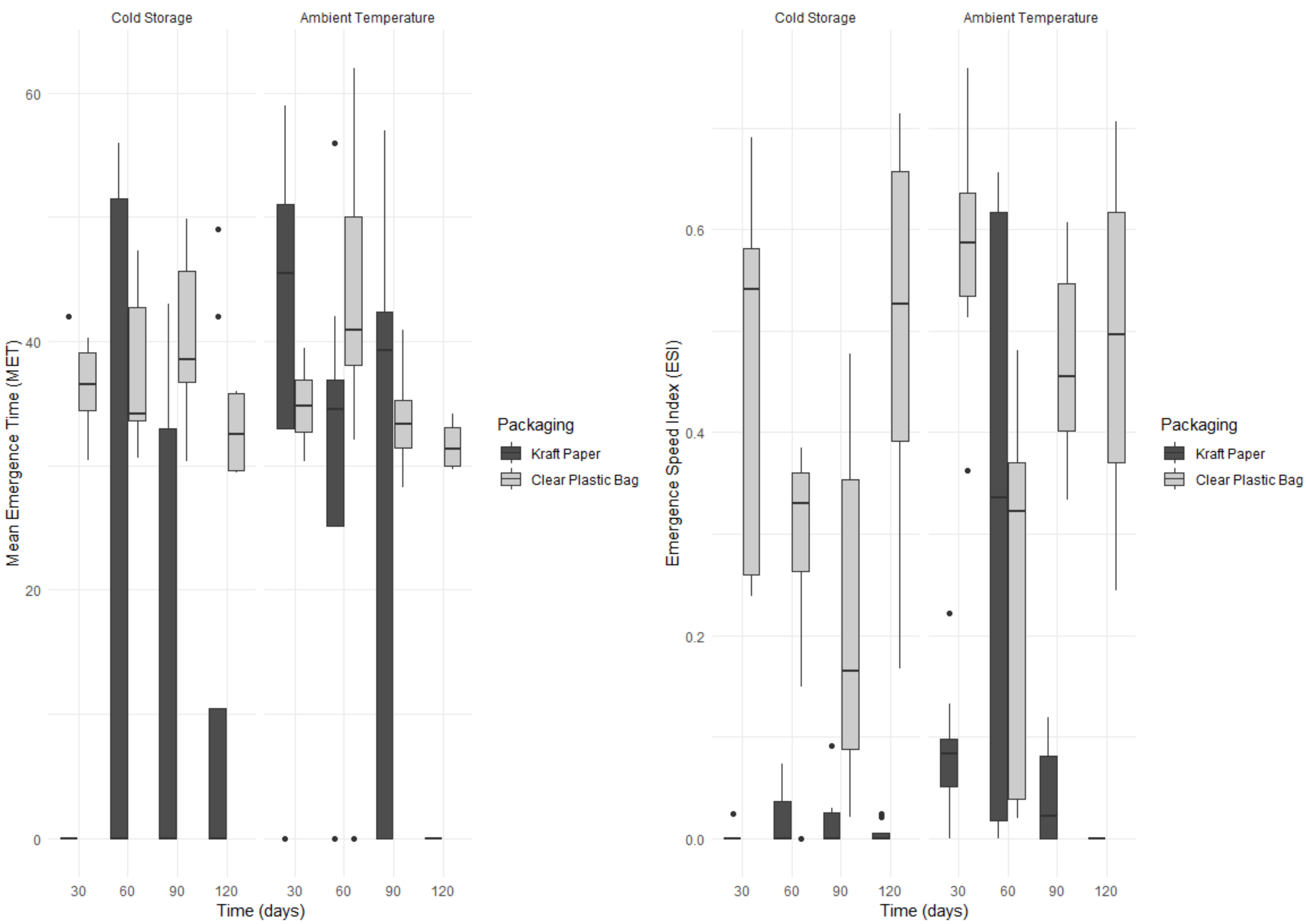


Figure 4. Mean emergence time (MET) and emergence speed index (ESI) of *G. infundibuliformis* seeds stored under different conditions (cold storage and ambient temperature), times (30, 60, 90, and 120 days), and packaging types (Kraft paper and clear plastic bag). Boxplots depict the data distribution.

significant at 120 days ($p < 0.001$), again with higher MET for plastic. Thus, for MET, the packaging effect appears mainly under CS (30 and 90 days) and under AT at 120 days; note that a higher MET implies slower emergence. Up to 120 days, packaging is the decisive factor: the clear plastic bag keeps emergence stable and with lower variability, especially when storage is prolonged (120 days) or under cold storage. Kraft paper shows zero medians in several scenarios (notably under cold storage) and loses performance at 120 days under ambient temperature. Therefore, for nurseries/seed banks, standardizing the use of clear plastic bags provides greater production predictability, whereas refrigeration alone does not compensate for the use of Kraft within the analyzed time frame.

In Figure 5B, for the variable ESI, the transparent plastic bag showed higher ESI than kraft paper under cold storage (CS) at all four time points (30, 60, 90, and 120 days; $p < 0.001$; 0.005; 0.003; < 0.001) and under ambient temperature (AT) at 30, 90, and 120 days ($p < 0.001$), with no difference at 60 days ($p = 0.713$). Practically, plastic speeds up emergence (higher ESI) in most scenarios up to 120 days, supporting its adoption as the standard packaging within this timeframe.

The results in Figures 4 and 5 show that packaging type is the primary determinant of performance, but its effects appear first on emergence speed and only later on the final emergence percentage. For storage of *Genipa infundibuliformis* up to 120 days, standardizing the use of clear plastic bags ensures higher ESI (faster, more predictable emergence) and prevents a drop in %E in the critical scenario. Refrigeration alone does not offset the use of Kraft paper within the studied horizon. In nursery management, monitor ESI as a sensitive indicator of

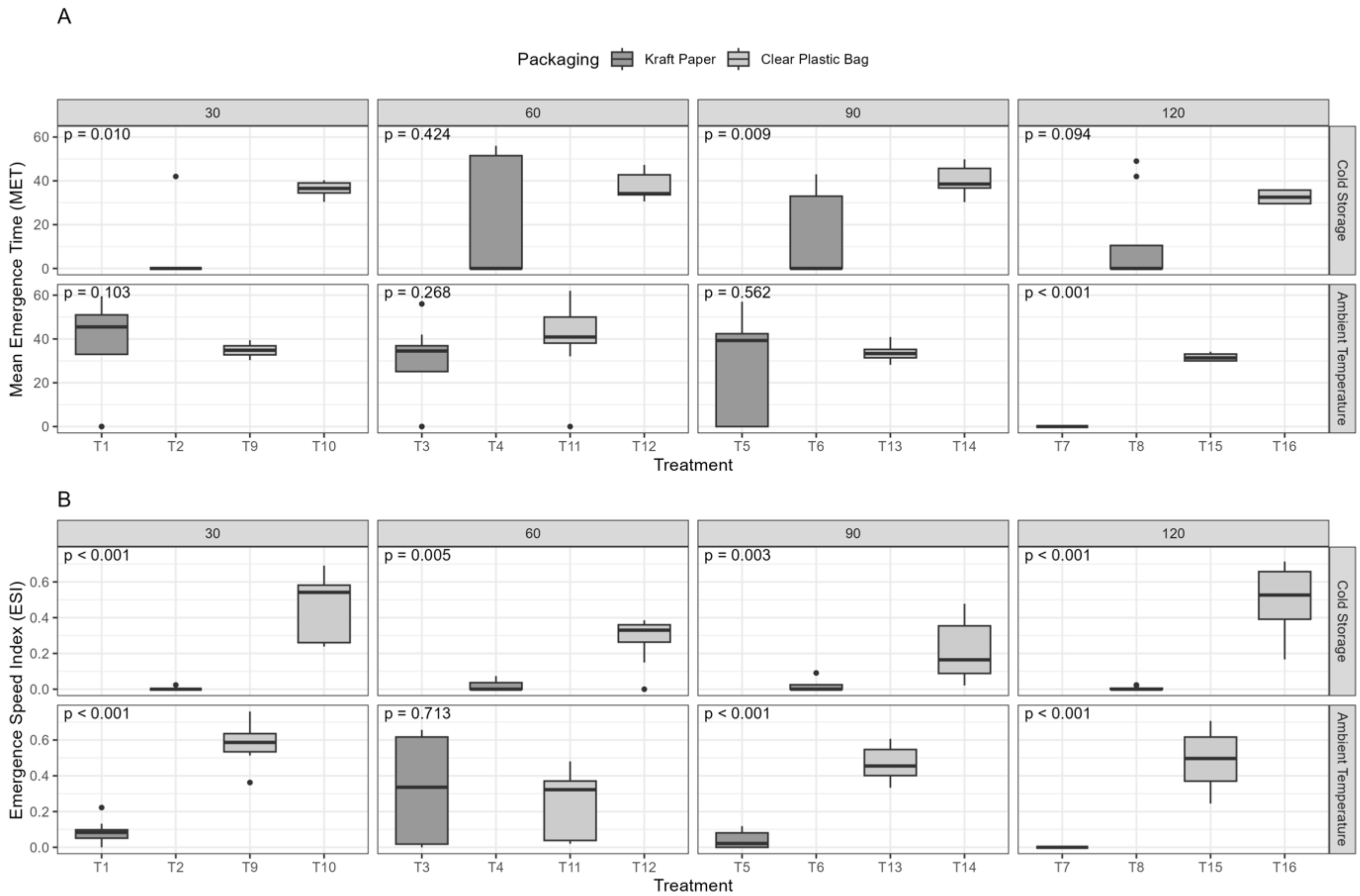


Figure 5. Mean emergence time (MET, A) and emergence speed index (ESI, B) of *Genipa infundibuliformis* seeds stored in Kraft paper or clear plastic bags, evaluated at 30, 60, 90, and 120 days under cold storage (CS) and ambient temperature (AT). Boxplots show the median and Q1–Q3; p-values indicate the Wilcoxon test (comparison between packaging within each panel).

deterioration; sustained declines in ESI signal the need to renew lots before %E also decreases.

The effect of the treatments (combinations of packaging, time, and storage condition) on mean emergence time (MET) and the emergence speed index (ESI) was assessed using the Kruskal–Wallis test, followed by multiple comparisons via the DSCF procedure (Dwass–Steel–Critchlow–Fligner). For MET, an overall difference among treatments was observed ($p < 0.001$), indicating that at least one group differs from the others. After adjustment for multiple comparisons, only three contrasts remained significant: Kraft paper, 30 days, ambient temperature (Treatment 1) versus Kraft paper, 120 days, ambient temperature (Treatment 7); clear plastic bag, 60 days, ambient temperature (Treatment 11) versus Kraft paper, 120 days, ambient temperature (Treatment 7); and clear plastic bag, 90 days, cold storage (Treatment 14) versus Kraft paper, 120 days, ambient temperature (Treatment 7). Considering that a higher MET implies slower emergence, the differences are concentrated in the worst scenario (Kraft paper at 120 days under ambient temperature). Thus, within the 120-day horizon, avoiding Kraft paper under ambient temperature and prioritizing clear plastic bags (both at ambient temperature and under cold storage) increases the predictability and performance of emergence; additional gains attributable to refrigeration are secondary to the choice of packaging.

Similarly, ESI also varied significantly among treatments ($p < 0.001$). Treatment 7 differed from Treatment 1, Treatment 12 (clear plastic bag, 60 days, cold storage), and Treatment 14 (clear plastic bag, 90 days, cold storage), confirming the negative impact of prolonged storage in Kraft paper under ambient temperature on emergence speed. In addition, Treatment 2 (Kraft paper, 30 days, cold storage) differed from Treatments 12 and 14, indicating that using a clear plastic bag under cold storage (60–90 days) increases ESI relative to Kraft paper.

Factor-by-factor analyses (Table 4) reinforce these findings: the Wilcoxon test showed a marked packaging effect for both MET (p = 0.000614) and ESI ($p < 2.2 \times 10^{-16}$); the time factor affected MET (Kruskal–Wallis, p = 0.0051) but not ESI (p = 0.6851); and the storage factor (cold storage vs. ambient temperature) did not change MET (Wilcoxon, p = 0.33) but did influence ESI (p = 0.0301). Taken together, the results highlight packaging as the determinant for MET and ESI, time as critical for MET, and a more modest effect of the storage environment on ESI in *Genipa infundibuliformis*. These patterns align with evidence of higher ESI in seeds packaged in plastic bags (Jeromini et al., 2015) and with reports of physiological changes during storage (Menegaes et al., 2020), whereas studies with other species, such as *Acca sellowiana*, indicate a strong reduction in germination potential and vigor at ambient temperature (Donazzolo et al., 2015), underscoring the species- and protocol-dependent nature of the responses.

Table 4. Results of nonparametric tests for mean emergence time (MET) and emergence speed index (ESI) by factors.

Test	Variable	Factor	p-value	Significance
Wilcoxon	MET	Packaging	0.000614	***
Wilcoxon	ESI	Packaging	$<2.2 \times 10^{-16}$	***
Kruskal-Wallis	MET	Time	0.005095	**
Kruskal-Wallis	ESI	Time	0.685100	ns
Wilcoxon	MET	Storage	0.330000	ns
Wilcoxon	ESI	Storage	0.030088	*

Legend: df = degrees of freedom; ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

To move beyond 120 days, we recommend extending the time window (180, 270, and 360 days) and modeling viability loss using service-life curves (Weibull/AFT or Ellis & Roberts equations), estimating half-life and end-of-use times. Analytically, include “mother tree/lot” as a random effect in mixed models; and monitor and record temperature and relative humidity with data loggers, incorporating these covariates into the models. Test conservation strategies: standardized drying and the Dry Chain, hermetic packaging (PICS/trilaminate) versus conventional/biodegradable plastics, as well as modified atmosphere and vacuum. Explore pre-treatments (priming, GA_3, scarification/coating) to mitigate long-term vigor losses. Finally, conduct cost–benefit evaluations and translate the findings into operational protocols for nurseries and seed banks.

4. Conclusion

Packaging type is the primary determinant of germination performance in *Genipa infundibuliformis* up to 120 days. Clear plastic bags preserve viability and promote faster, more predictable emergence under both cold storage and ambient temperature, whereas Kraft paper shows inconsistent performance and a marked decline under prolonged storage, especially at ambient temperature. In practice, standardize the use of clear plastic bags for seedling production; if Kraft paper is unavoidable, restrict storage to short periods, plan lot replacement, and monitor the ESI as an early indicator of quality loss. These conclusions apply to the species and time frame evaluated and guide management decisions in nurseries and seed banks, prioritizing predictability, efficiency, and operational safety.

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Author Statements

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- ✓ All existing funding sources were acknowledged.
- ✓
- ✓ There is no evidence of plagiarism in this article.

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