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Original Article

Influence of alternative packaging on the storage and quality of jatobá seeds (*Hymenaea courbaril* L.)

Influência de embalagens alternativas no armazenamento e na qualidade de sementes de jatobá ((*Hymenaea courbaril* L.)

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Abstract

Jatobá (*Hymenaea courbaril* L.) is a tree species of the Fabaceae family with great socio-environmental importance Although the economic exploitation of this crop is increasing mainly in the Amazon region, the collection of information is still limited, especially related to the processing and quality of seeds. The objective of this research was to evaluate the influence of packaging types on the physical properties and physiological quality of jatobá seeds during storage. The treatments consisted of three types of packaging (PET bottle, plastic bag packaging and kraft paper packaging) and five storage periods (0, 2, 4, 6 and 8 months). Every two months, tests were carried out to evaluate the physical properties of the seeds: water content, mass of 100 seeds, mass loss, size and shape, sphericity, roundness, apparent specific mass, unitary specific mass, porosity and physiological quality: germination test, first count, electrical conductivity and accelerated aging. During the storage period, the water content of the seeds ranged from 8.9 to 9.7% (b.u). Among the main results, it can be seen that the PET packaging had the best performance during storage, for physical properties and physiological quality. Seeds can be stored for eight months without significantly losing viability and vigor.

Keywords: Fabaceae, forest species, deterioration, conservation, germination, longevity, orthodox seeds.

Resumo

Jatobá (*Hymenaea courbaril* L.) é uma espécie arbórea da família Fabaceae com grande importância socioambiental embora a exploração econômica desta cultura esteja aumentando principalmente na região amazônica, a coleta de informações ainda é limitada, principalmente relacionadas ao processamento e à qualidade das sementes. O objetivo desta pesquisa foi avaliar a influência dos tipos de embalagem nas propriedades físicas e na qualidade fisiológica de sementes de jatobá durante o armazenamento. Utilizou-se o delineamento inteiramente casualizado (DIC), em esquema fatorial 5 x 3, com quatro repetições. Os tratamentos foram constituídos por três tipos de embalagem (garrafa PET, embalagem de saco plástico e embalagem de papel kraft) e cinco períodos de armazenamento (0, 2, 4, 6 e 8 meses). As embalagens com os tratamentos foram colocadas em sala com temperatura de 21 ± 2 °C e umidade relativa média de 68%. A cada dois meses, foram realizados ensaios para avaliar as propriedades físicas das sementes: teor de água, massa de 100 sementes, perda de massa, tamanho e forma, esfericidade, circularidade, massa específica aparente, massa específica unitária, porosidade e qualidade fisiológica: teste de germinação, primeira contagem, condutividade elétrica e envelhecimento acelerado. Durante o período de armazenamento, o teor de água das sementes variou de 8,9 a 9,7% (bu). Dentre os principais resultados, pode-se observar que a embalagem PET apresentou o melhor desempenho durante o armazenamento, para propriedades físicas e qualidade fisiológica. As sementes podem ser armazenadas por oito meses sem perda significativa de viabilidade e vigor.

Palavras-chave: Fabaceae, espécies florestais, deterioração, conservação, germinação, longevidade, sementes ortodoxas.

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1. Introduction

Jatobá (*Hymenaea courbaril* L.), belonging to the Fabaceae family and the Caesalpineaceae subfamily, is a large tree species with a wide geographic distribution throughout the country. It is considered highly versatile because, in addition to providing good quality wood, it can also be used for medicinal, food and craft purposes. In addition, it is widely used in agroforestry systems and in the recovery of degraded areas (Souza and Lima, 2012).

Jatobá, which is part of a series of forest species that have been requested for reforestation and recovery of degraded areas, has great potential for expansion in the Amazon region, and technical information related to its cultivation is necessary for its inclusion in reforestation projects, including information related to the characteristics of the seeds.

The presence of dormancy in seeds, common in several forest species, is considered an evolutionary mechanism of spatial-temporal distribution of seed germination, which helps in the perpetuation of the species. However, in the production of seedlings, this mechanism needs to be overcome in order to standardize production, requiring knowledge about the type of dormancy and ways to overcome it (Baskin and Baskin, 2004; Penfield, 2017).

Another fundamentally important characteristic is the physiological behavior of seeds in terms of tolerance to desiccation and storage. Seeds can be classified as: orthodox, when they tolerate desiccation down to low water contents of 2-5% and storage at low temperatures down to around -20°C; recalcitrant seeds, which do not tolerate desiccation at low water contents and storage at low temperatures; and intermediate seeds, which allow a reduction in water content of up to 7-10% and do not tolerate storage at low temperatures for prolonged periods (Carvalho et al., 2006).

According to Carvalho et al. (2006), jatobá seeds are classified as orthodox. This characteristic is extremely important because reducing the water content of the seeds reduces the metabolic activity controlled by the speed of stress and reduces the possibility of creating a microclimate favorable to the development of insects and microorganisms, preserving the quality of the product. However, even with the reduction in water content, if storage is not carried out correctly, there may be a high risk of loss of the product over time, considering that the seeds are hygroscopic, that is, they tend to come into equilibrium with the environment, gaining or losing water.

In this context, the choice of the type of packaging can be decisive in the final quality of the seeds, having the function of serving as a barrier for gas exchange between the seeds and the environment, contributing to maintaining the quality of the seeds. The packaging guarantees several benefits such as product protection, ease of identification and separation of batches, but it also represents costs, which may vary according to the type of packaging used.

The use of alternative packaging such as PET bottles, which guarantee protection and safety for the product, facilitate internal visualization and can be reused after cleaning, preventing them from being discarded into the environment after primary use; plastic bag packaging, which is easy to buy and offers some protection, in addition to easy visualization of the contents; and also the Kraft paper bag, which is reasonably affordable and from a renewable source, which can be recycled, ensuring greater sustainability, are some of the alternatives that can be used to store forest seeds.

In view of this, research related to the effect of using different packaging and storage times on maintaining the physical properties and physiological quality of forest seeds is relevant to ensure the standardization of more appropriate storage methodologies, so as not to affect the availability of quality seeds in the off-season, ensuring stability in the market.

2. Materials and Methods

2.1. Implementation of the experiment

The experiment was carried out at the Didactic Laboratory of Seed Analysis (LABSEM) of the Institute of Agricultural Sciences (ICA), of the Federal Rural University of Amazonia (UFRA), Campus Belém. The city is located at latitude 01º27'21 South " and 48º30'16" West longitude, with an Af climate (Köppen classification) with an average annual occurrence of 3,000 to 4,000 mm (Alvares et al., 2013), average annual temperature and relative humidity of 26.4°C and 84%, respectively.

2.2. Characterization of the raw material

The seeds used were provided by the Carajás Flona Extractive Cooperative – COOEX, collected in November 2021 from several matrices in the Carajás National Forest, in the municipality of Parauapebas, which is located at an altitude of 168 meters, in the following geographical coordinates: 6° 4' 15'' S and 49° 54' 15'' W, belonging to the Mesoregion of Southeast Pará.

According to the information passed on by the cooperative in relation to the procedures carried out until the seeds are sold, they were: Collection of the fruits after dispersion by the matrices, then the processing was carried out, which consists of breaking the fruits and washing the seeds in running water to remove the pulp that coats them. After cleaning the seeds, they were laid out on a tarp to dry in the shade under natural ventilation, this process lasts an average of three days, and at the end of drying the seeds were conditioned in polypropylene packaging and stored in a room at room temperature.

As soon as the seeds arrived at the laboratory, the water content of the lot was determined, where the result obtained was 8.9% (b.u), a value considered adequate for the storage of orthodox seeds. In addition to determining the water content of the lot, a classification was also carried out, where damaged seeds were discarded, however, the number of discarded seeds was not significant, which demonstrated the high level of quality of the lot.

In addition to the seeds, the packages used in the experiment were: five-liter blue PET bottles that were previously used for bottling mineral water; plastic bag packaging (polyethylene) with a capacity of five kg and a thickness of 0.06 mm or 60 µm; packaging in kraft paper bag with a capacity of five kg with a grammage of 80 g/m^2.

2.3. Experimental design

A completely randomized design (DIC) was used, in a 5 x 3 factorial scheme, with four replications, totaling 60 plots. The treatments consisted of five storage periods (0, 2, 4, 6 and 8 months) and three types of packaging (PET bottle, plastic bag and kraft paper packaging).

The seeds, after being packed in different packages, were placed on a laboratory shelf in an adapted storage room, using an air conditioner with a temperature of 21 ± 2 °C and an average relative humidity of 68%.

Due to the integumentary dormancy present in the seeds, it was necessary to perform the dormancy-breaking procedure for the physiological tests, for which the integument was mechanically scarified in the region opposite the hilum, with the aid of no immersion in distilled water for 48 hours. Before and after scarification, asepsis was performed with 1% sodium hypochlorite, and asepsis with detergent at the end of the immersion period (soaking) (Brasil, 2009).

Every two months, including time zero, tests were performed to evaluate the physical properties, namely: water content, mass of 100 seeds, mass loss during storage, size and shape, sphericity and circularity, apparent specific mass, unit specific mass and porosity; physiological quality: germination, first count, germination speed index, mean time of germination speed, seedling length, seedling dry mass, electrical conductivity and accelerated aging.

2.4. Physical analyzes

2.4.1. Seed water content

Seed water content was evaluated by gravimetry, using an Odontobrás EL 1.2 oven at 105 ± 1 °C, for 24 hours, with four replications of 10 seeds for each treatment including zero storage time (Brasil, 2009).

2.4.2. Mass of 100 seeds

The mass of 100 seeds chosen at random was measured on a scale from Marte, model AS5500C with precision of 0.01 g. This procedure occurred with 4 repetitions for each treatment.

2.4.3. Mass loss during storage

Weight loss was defined by weighing four replicates of 25 seeds for each treatment, including zero storage time.

2.4.4. Size and shape

The seed size was determined by measuring the dimensions of the orthogonal axes: major axis (a), medium axis (b) and minor axis (c) as illustrated in Figure 1, measured with the aid of a ZAAS digital caliper, model ZAAS- 1.0004. Due to the high variation in the shape of the seeds of the species, four replications of 100 seeds were used for each treatment (Souza and Segato, 2016).

2.4.5. Sphericity and circularity

The sphericity was calculated using the equation suggested by Mohsenin (1980), (Equation 1):

$$S = \frac{\left(a\,x\,b\,x\,c\right)^{1/3}}{a} x100 \tag{1}$$

On what: S - sphericity, %; a - major axis, (mm); b - middle axis (mm); c - minor axis (mm).

The circularity of the seeds was calculated by Equation 2.

$$C = \frac{b}{a} x100 \tag{2}$$

On what: C - circularity, %;

2.4.6. Apparent specific mass

The determination of apparent specific mass was performed by weighing the seeds in a cylinder of known volume on a scale from Marte brand, model AS5500C with precision of 0.01g. using Equation 3:

$$\rho_{ap} = \frac{m}{V} \tag{3}$$

On what: ρ_{ap} = apparent specific mass, kg m^{-3}; m = product mass, kg; V = container volume, m^3.

2.4.7. Unit specific mass

To determine the unit specific mass, four replicates of 100 seeds were used for each treatment. The seeds were

Figure 1. Schematic drawing of the dimensions of the jatoba seed. Source: The author (2023).

weighed individually on an analytical scale Weblabor model M25Ai, with precision of 0.001g, and the orthogonal axes (a, b and c) measured with the aid of a caliper, these data were inserted in Equation 4, to obtain the individual volume of the seeds according to the expression suggested by Mohsenin (1978). The unit specific mass was calculated by dividing the mass of each seed by its respective volume, in Kg.m^{-3} (Equation 5).

$$V = \frac{\pi(abc)}{6} \tag{4}$$

$$\rho_u = \frac{m}{V} \tag{5}$$

On what: ρ_u = unit specific mass, kg m^{-3}; m = individual mass of each seed, kg; V = individual volume of each seed, m^{-3}.

2.4.8. Porosity

The porosity was estimated using Equation 6, suggested by Mohsenin (1978), in which it is the result of the relationship between the apparent specific mass and the unitary specific mass:

$$\varepsilon = 1 - \left(\frac{\rho_{ap}}{\rho_u}\right) * 100 \tag{6}$$

On what: ε = porosity, %; ρ_{ap} = apparent specific mass, kg m^{-3}; e ρ_u = unit specific mass, kg m^{-3}.

2.5. Physiological analyzes

2.5.1. Germination

The germination test (Figure 2) was mounted on rolls of germitest paper, with three leaves each, moistened with water equivalent to three times its original weight. Four repetitions of 25 seeds were used for each treatment, placed in a Marqlabor Mangelsdorf germinator, model maq-c6m, at a temperature of 25 ºC.

Due to the period of 28 days required for the germination test, there was a need to change the papers to avoid disintegration of the rolls, so the change was standardized on the fourteenth day. At the end, the number of normal seedlings on the 28th (twenty-eighth) day after test implementation was counted (Brasil, 2009).

2.5.2. First count

It was conducted together with the germination test, and considering the percentage of normal seedlings present on the 21st (twenty-first) day after the start of the test.

2.5.3. Germination speed index

Conducted together with the germination test, recording the number of seeds with radicle emission each day, until the last count.

The IVG was calculated according to the formula proposed by Maguire (1962), (Equation 7).

$$IVG = \frac{G1}{N1} + \frac{G2}{N2} \cdots \frac{Gn}{Nn} \tag{7}$$

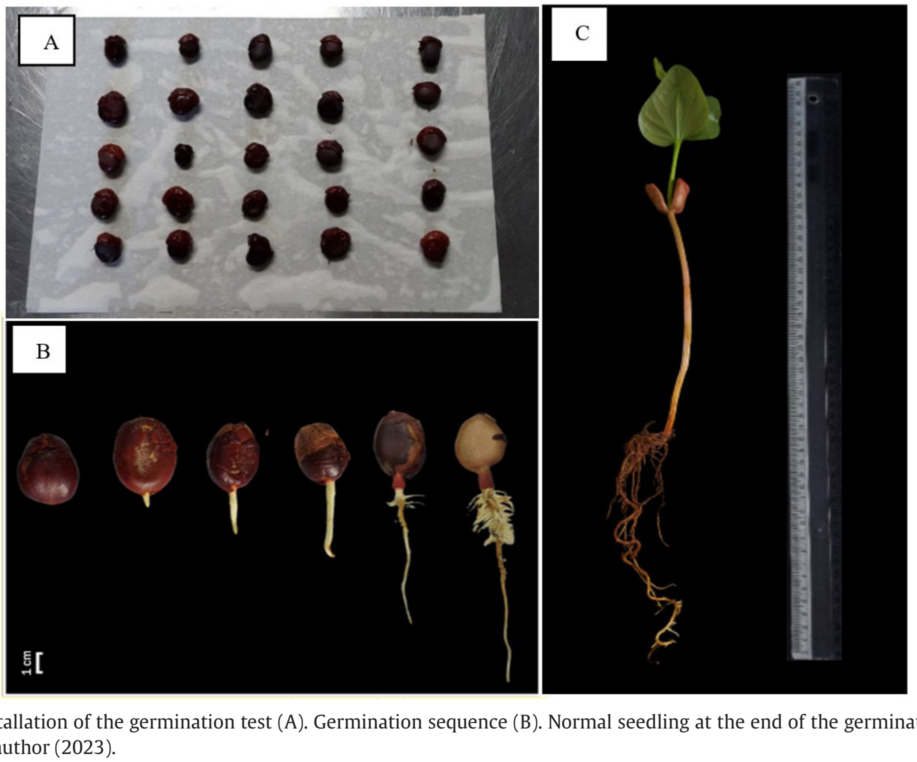

Figure 2. Installation of the germination test (A). Germination sequence (B). Normal seedling at the end of the germination test (C). Source: The author (2023).

Where: IVG = germination speed index; G = number of seedlings germinated in the day 1, 2, 3, ...n; N = number of days.

2.5.4. Average germination speed time

The mean germination speed values were obtained through the formula mentioned by Labouriau and Valadares (1976), (Equation 8).

$$tG = \left(\sum ni\,ti\right) / \sum ni \quad (8)$$

Where: tG = average germination time, in days; Ni = number of seeds germinated on the ith day; Ti = time, in days.

Calculations of average germination speed were performed according to the formula cited by Labouriau and Valadares (1976), (Equation 9).

$$VG = 1 / tG \quad (9)$$

Where: VG = average germination speed, in days; tG = average germination time, in days.

2.5.5. Seedling length

In germitest paper rolls, with three leaves each, moistened with water equivalent to three times its original weight, four replications of 10 seeds were used for each treatment, conditioned in a Marqlabor Mangelsdorf germinator, model maq-c6m, under a temperature of 25ºC and photoperiod of 12 hours. At the end of the test, on the 28th day, the average length of seedlings considered normal was determined with the aid of a millimeter ruler, the results being expressed in centimeters (cm) per seedling.

2.5.6. Dry mass of seedlings

After determining the seedling length, the dry mass was determined, drying the normal seedlings of each repetition in an oven with forced air circulation, Marq Labor, set at 65 °C, for 48 hours. After drying the seedlings, the material was weighed on a scale with a precision of 0.001 from the Weblabor brand, model M25Ai. The results were expressed in grams per seedling (Nakagawa, 1999).

2.5.7. Electric conductivity

Four repetitions of 10 scarified seeds of each treatment were used, placed in containers with a volumetric capacity of 200 ml. After determining the mass of each repetition, 75 ml of distilled water was added to each of the containers, which were kept in a B.O.D type chamber by Solab, model SL224, at a temperature of 25 ± 2ºC, for 24 hours. After this period, the reading of the electrical conductivity was carried out using a bench conductivity meter from Gehaka, model CG 1800. The result is in µS/cm/g, as the reading value is divided by the mass of seeds of each repetition.

2.5.8. Accelerated aging

For each treatment, 25 seeds were distributed per repetition on the surface of a metallic screen fixed inside a plastic box - gerbox, containing 40 ml of distilled water, maintained at 42ºC and 100% relative humidity, for 48 hours in a type B.O.D. from the brand Eletrolab model EL202/4LED (Krzyzanowski and Vieira, 1999). After this period, the seeds were submitted to the germination test, previously described in item 4.4.2, to determine the percentage of normal seedlings on the 21st day after mounting the test.

2.6. Statistical analyzes

For statistical analyses, the data were subjected to analysis of variance (ANOVA), and Tukey's test at 5% probability for types of packaging and regression analysis for storage time, using the SISVAR 5.6 analysis software (Ferreira, 2019).

3. Results and Discussion

Analysis of variance on the physical properties of jatobá seeds (Tables 1 and 2) revealed that the type of packaging significantly influenced only the apparent specific mass (ρap) and unitary specific mass (ρu), while the time factor of storage significantly influenced the mass of 100 seeds (MCS), mass loss (PM), apparent mass (ρap), apparent unit mass (ρu) and porosity.

As for the ExT interaction, a significant difference was observed at 5% probability by the F test, only for water content (TA) and apparent specific mass (ρ_{ap}) (Tables 1 and 2).

As for the experimental precision (Tables 1 and 2), it can be seen that all values of the coefficient of variation of the physical properties of jatobá seeds stored over eight months are classified as low (less than 10%), with the exception of porosity that was classified as medium (between 10-20%), according to criteria by Pimentel Gomes (Pimentel, 1990). Thus, it can be stated that the experimental precision for the physical properties of jatobá seeds was considered good.

It was observed through analysis of variance on the physiological quality of jatobá seeds that the packaging significantly influenced only the radicle length (CRA), total dry matter (MST), germination speed index (IVG), average germination speed (VG) and average germination time (TG), while the storage time factor significantly influenced radicle length (CRA), shoot length (CPA), height, total dry matter (MST), shoot dry matter MSPA, first count of normal seedlings (PC), germination speed index (IVG) mean germination speed (VG), electrical conductivity (EC) and accelerated aging (AE).

As for the E x T interaction, a significant difference was observed at 1% probability by the F test, for total dry matter (MST), germination speed index (IVG), average germination time (TG) and average germination speed germination (VG). And at 5% probability for seedling height.

As for experimental precision, it can be seen that the coefficient of variation of physiological quality values for the variables of jatobá seeds stored over eight months are classified in the vast majority as low (less than 10%), while seedling height, total dry matter (MSPA) and electrical conductivity (EC) were classified as medium (between 10-20%), and only total dry matter and radicle dry matter (SARM) as high (20 -30%) according to criteria by Pimentel

Table 1. Analysis of variance of physical properties of jatoba seeds submitted to storage in different types of packaging.

Variation factor	G.L	QM					
		TA	Axis A	Axis B	Axis C	Mass	MCS
		(%)	(cm)	(cm)	(cm)	(g)	(g)
Packaging (E)	2	0.626 ns	0.196 ns	0.116 ns	0.044 ns	0.032 ns	33.054 ns
Time (T)	4	0.538 ns	0.084 ns	0.179 ns	0.092 ns	0.113 ns	558.613*
E*T	8	1.417**	0.162 ns	0.219 ns	0.029 ns	0.074 ns	302.962 ns
Error	45	0.363	0.322	0.231	0.068	0.61	173.356
CV%	-	-	2.1	2.4	1.8	4.7	2.5

Source: the author (2023). **Significant at 1% probability; *Significant at 5% probability by F test. ns Not significant. Water content (TA); Major axis of the seed (Axis A); Average seed axis (Axis B); Seed Minor Axis (Axis C); Seed mass (Mass) and Mass of 100 seeds (MCS).

Table 2. Analysis of variance of physical properties of jatoba seeds submitted to storage in different types of packaging.

Variation factor	G.L	QM					
		PM	Circ.	Sphe.	Ρap	ρu	Porosity
		(g)	(%)	(%)	(Kg m^{-3})	(Kg m^{-3})	(%)
Packaging (E)	2	36.863 ns	0.133 ns	1.007 ns	3854.79**	25209.37*	17.21 ns
Time (T)	4	409.378**	2.781 ns	0.718 ns	114722.12**	86168.28**	100.57**
E*T	8	44.359 ns	3.354 ns	0.565 ns	10832.31**	13315.80 ns	14.83 ns
Error	45	23.38	2.475	0.797	323.47	7001.31	21.98
CV%	-	3.6	2.0	1.2	1.7	5.7	17.1

Source: the author (2023). **Significant at 1% probability; *Significant at 5% probability by F test, ns Not significant. Mass loss (PM); Circularity (Circ.); Sphericity (Sphe.); Apparent specific mass ($ñ_{ap}$); Specific unitary mass ($ñ_u$) and porosity.

Gomes (Pimentel, 1990). Thus, it can be stated that the experimental precision for the physiological quality of jatobá seeds was considered good.

The average values of water content of the jatobá seeds for the E x T interaction can be observed (Table 3), in which at four months of storage there was a significant difference for this characteristic between the packages used, and the kraft paper presented the highest average value for water content, while after eight months of storage, the plastic packaging differed statistically from the others, presenting the highest average value for water content.

The highest average value for water content in jatobá seeds after four months of storage may have occurred due to the fact that the kraft packaging is made of paper and, due to this, has a higher permeability rate than the water value. While after eight months of storage, the highest average value of water content for the plastic bag packaging may have occurred due to its location in the storage room and its having been subject to more humid areas, for example, in the part closest to the door, which may have been opened more times in a given period, since the seeds used by the laboratory are also stored in the same environment (Table 3).

The maintenance of the physiological quality of seeds is largely dependent on the initial water content of a seed lot, as well as the environmental conditions of the place where it will be stored (Marcos Filho, 2015). The water content of the seed influences its physical characteristics, being necessary to determine during the storage period (Carvalho and Nakagawa, 2012). The plastic and kraft packages were the ones that had the most oscillations in the water content during storage, this is probably due to the fact that their permeability and gas exchange with the environment are greater than the PET packaging.

It is possible to observe the average values of apparent specific mass of the jatobá seeds for the E x T interaction (Table 4) in which at six months of storage a significant difference was detected for this variable between the packages used, where the PET package had the highest average value in relation to kraft paper and plastic. While after eight months of storage, the plastic packaging differed statistically, showing an average value of apparent specific mass lower than the other packaging used. Evaluating each type of packaging separately over time, it is observed that there was a statistical difference between storage periods.

This shows that there was a reduction in the apparent specific mass over time for all packages, but the PET package had, in general, the smallest reduction (Table 4). The fact that the PET package had a better performance for the apparent mass loss variable (ρap) may be related to its characteristics regarding resistance to gas exchange with the medium, and may better preserve the physiological quality of the seeds by delaying the natural process of deterioration, which is responsible for the consumption of reserves. The specific mass is widely used in the evaluation of grain quality, the higher the value the better the quality

Table 3. Mean values for water content (% b.u) applied to jatobá seeds stored in different packages for the package x time interaction.

Packaging	Storage time (months)				
	0	**2**	**4**	**6**	**8**
PET	8.94 Aa	8.83 Aa	7.84 Ba	8.56 Aa	8.44 Bba
Plastic	8.94 Aa	8.13 Aa	8.75 Bba	9.22 Aa	9.31 Aa
Kraft	8.94 Ab	8.11 Aa	9.66 Ab	8.32 Aa	8.17 Ba
Averages	8.94	8.36	8.75	8.70	8.64

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

Table 4. Average values for Apparent Specific Mass (ρ_{ap}) applied to jatobá seeds stored in different packages for the packaging x time interaction.

Packaging	Storage time (months)				
	0	**2**	**4**	**6**	**8**
PET	1211.13 Aa	1035.00 Ab	1030.00 Ab	991.00 Ac	1004.00 Ab
Plastic	1211.13 Aa	1054.00 Aa	1..028.00 Ab	952.00 Bc	964.00 Bc
Kraft	1211.13 Aa	1033.00 Ab	1031.00 Ab	949.00 Bc	1004.00 Ab
Averages	1211.13	1040.33	1029.67	964.00	995.33

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

Table 5. Mean values for seedling height (cm) applied to jatobá seeds stored in different packages for the package x time interaction.

Packaging	Storage time (months)				
	0	**2**	**4**	**6**	**8**
PET	43.58 Aa	42.81 Aa	43.02 Aa	47.57 Aa	45.95 Aa
Plastic	43.58 Aa	45.60 Aa	41.82 Aa	45.18 Aa	46.84 Aa
Kraft	43.58 Aa	42.25 Aa	38.43 Bb	45.77 Aa	47.95 Aa
Averages	43.58	43.55	41.09	46...17	46.91

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

(Botelho et al., 2015). This reduction in apparent specific mass over storage time was also verified by Faroni et al. (2005) in corn storage.

The average values for the variable height of jatobá seedling in the E x T interaction present in Table 5, show that with the exception of kraft, which after four months of storage had statistically lower averages both between packages and storage periods, the others did not have statistical difference.

Seedling height was significant in the regression analysis only for kraft packaging with quadratic model adjustment (Figure 3). There are oscillations during the evaluated periods, but the values tend to decrease in the initial months of storage, however from month six they increase again. The shape of the trendline may be related to variations in seed vigor due to the high genetic variability of the lot.

The average values of total dry mass of seedlings (TSM) for the E x T interaction (Table 6), did not have statistical difference between packages or between storage periods, except for plastic packaging in month zero of storage, being statistically lower than in other periods.

The behavior of the variable total dry mass of seedlings can be observed over time for plastic bag packaging (Figure 4). The plastic bag package was better suited to the cubic model. There were oscillations in the packaging data over the analyzed periods, with growth followed by reduction, and this behavior was repeated over time, which justified the use of the model. This behavior followed the pattern of seedling height oscillations, given the fact that they have a strong relationship.

The mean values of the germination speed index for the E x T interaction (Table 7) showed a statistically higher mean for PET packaging in the second month, statistically differing from the other packaging and also in the storage periods. When evaluating the kraft and plastic packaging in relation to the storage periods, it can be stated that there was no difference. This increase in the average value of IVG

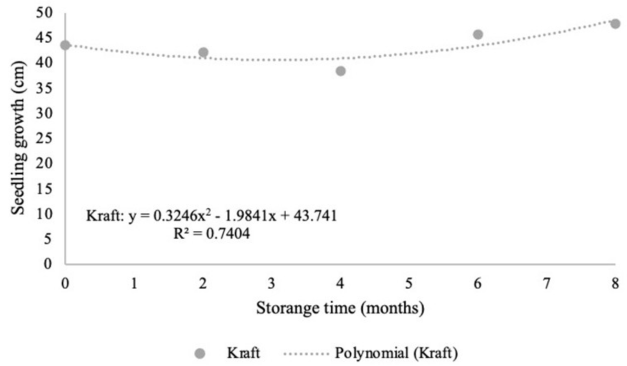

Figure 3. Height of jatobá seedling stored in Kraft paper packaging for eight months of storage. Source: The author (2023).

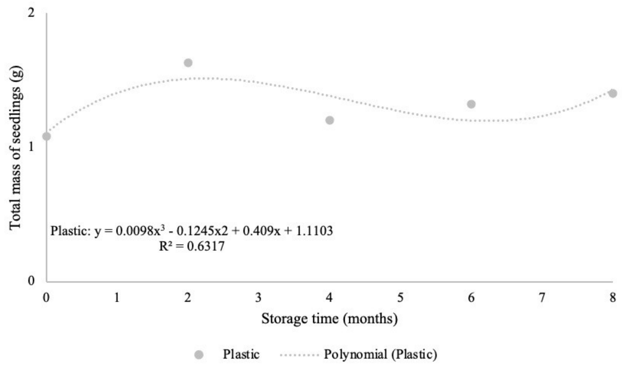

Figure 4. Total dry mass of jatobá seedlings from seeds stored in kraft paper packaging and plastic bag for eight months. Source: The author (2023).

Table 6. Mean values for total seedling mass (g) applied to jatobá seeds stored in different packages for the package x time interaction.

Packaging	Storage time (months)				
	0	2	4	6	8
PET	1.08 Aa	1.44 Aa	1.21 Aa	1.53 Aa	1.30 Aa
Plastic	1.08 Ab	1.63 Aa	1.20 Aa	1.32 Aa	1.40 Aa
Kraft	1.08 Aa	1.42 Aa	1.04 Aa	1.43 Aa	1.37 Aa
Averages	1.08	1.49	1.15	1.43	1.35

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

Table 7. Mean values for the Germination Speed Index (GVI) applied to jatobá seeds stored in different packages for the package x time interaction.

Packaging	Storage time (months)				
	0	2	4	6	8
PET	2.67 Ab	2.94 Aa	2.39 Ab	2.50 Ab	2.60 Ab
Plastic	2.67 Aa	2.63 Ba	2.45 Aa	2.46 Aa	2.56 Aa
Kraft	2.67 Aa	2.64 Ba	2.42 Aa	2.47 Aa	2.64 Aa
Averages	2.67	2.73	2.42	2.47	2.60

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

in the second month of storage may have occurred due to the difference in vigor caused by the genetic variability of the seeds.

The germination speed index (GVI) of jatobá seeds (Table 7) showed a significant difference for the plastic bag packaging in the regression analysis, in which the data matched the quadratic model.

The (IVG) is an important parameter to evaluate seed vigor, and the higher the result, the greater the vigor, since the calculation is based on the average number of seedlings germinated per day (Nakagawa, 1994). According to the data, there was a decrease in the IVG (Table 8), which are probably linked to the variability of the seeds, indicates a reduction in the vigor of the seeds stored during the eight months.

It can be observed the mean values of mean germination time (TG) for the E x T interaction (Table 8), in the period of six months of storage, both the PET packaging and the plastic bag had statistically lower means than the kraft. Evaluating the packages individually over the storage periods, it can be seen that for PET the best averages were at zero and eight months and the lowest average at six months. For Kraft, the lowest average was at four months and for plastic, the highest average was at zero month and the lowest at four months of storage. There was variation in the behavior of the average germination time of each package over time, as shown by the data, and the related factors are not very clear, and may be factors inherent to the seed.

For the mean germination time (TG) variable (Figure 5) there was a significant difference in the regression analysis for the plastic bag, being better represented by the quadratic model. The behavior of the trend line may be linked to the variability of seed vigor within the lot, since the species is not domesticated and the seed lot used was collected from several matrices of the National Forest of Carajás, which means a high genetic variability.

It can be observed the average values of average germination speed (VG) of the jatoba seeds for the E x T interaction (Table 9), that after six months of storage the kraft package presented a statistically lower average than the other packages. When observing the data, it is noticeable that the behavior of this variable had oscillations over time. Regarding the regression analysis, the variable did not fit the tested models. This variable is used to evaluate vigor in seed lots, and can influence plant establishment, that is, the faster it germinates and develops, the lower the risk of suffering from adverse factors in the field (Marcos Filho, 2015).

The oscillations within each package over time for the germination speed index (IVG), average germination time (TG) and average germination speed variables may be related to the characteristics of the seeds of the species. Lima et al. (2008) when analyzing the germination of forest species after storage, identified an increase in the percentage of germination for jatobá over time, and attributed it to a possible difference in the physiological

Table 8. Mean values for mean germination time (TG) applied to jatoba seeds (*Hymenaea courbaril* L.) stored in different packages for the packaging x time interaction.

Packaging	Storage time (months)				
	0	2	4	6	8
PET	9.05 Aa	8.86 Aab	8.79 Aab	8.27 Bb	9.03 Aa
Plastic	9.05 Aa	8.88 Aab	8.64 Ab	8.72 Bab	8.90 Aab
Kraft	9.05 Aab	9.05 Aab	8.79 Ab	9.74 Aab	9.06 Aab
Averages	9.05	8.93	8.74	8.91	9.00

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

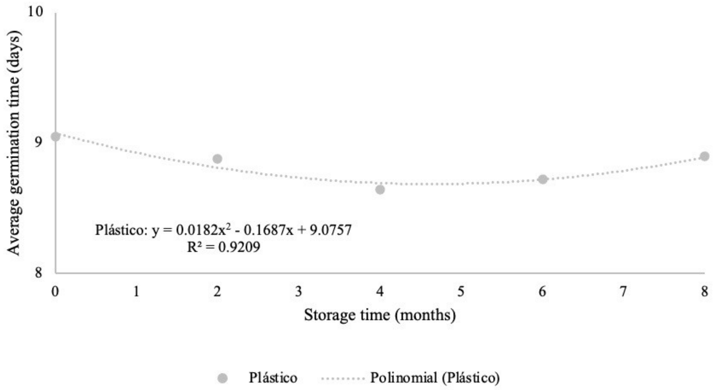

Figure 5. Mean germination time (TG) of jatobá seeds stored in different packages for eight months of storage. Source: The author (2023).

Table 9. Mean values for mean germination speed (VG) applied to jatobá seeds stored in different packages for the package x time interaction.

Packaging	Storage time (months)				
	0	**2**	**4**	**6**	**8**
PET	0.11 Ab	0.12 Aab	0.11 Aab	0.12 Ab	0.11 Ab
Plastic	0.11 Ab	0.11 Aab	0.12 Aa	0.11 Aab	0.11 Ab
Kraft	0.11 Aab	0.11Aab	0.12 Aa	0.10 Bb	0.11 Aab
Averages	0...11	0.11	0.11	0.11	0.11

Source: the author (2023). Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically, according to Tukey's test, at 5% probability.

maturity of the seeds, which shows signs of the behavior of the species. According to Marcos Filho (2015), the decrease in germination speed values is one of the indicators of the reduction in the physiological quality of seeds during storage, as well as the increase in the average germination time and the decrease in the germination speed index.

In the present study, for jatobá seeds, the package that had the best performance statistically in maintaining the physical properties and physiological quality was the PET package. Coradi et al. (2016) when studying physical and chemical characteristics in the storage of jatobá seeds, found that glass and PET packaging performed better, corroborating in part with the result found in this research. It is worth mentioning that the PET packaging guarantees high protection against gases, insects and rodents. In addition, PET is easy to transport and can be reused, which makes it a sustainable alternative that benefits the environment and guarantees good value for money, especially for small seed traders.

Silva et al. (2019) observed that after six months of storage under controlled temperature and humidity conditions, *Caesalpinia ferrea* seeds showed a higher germination percentage for kraft paper packaging compared to polyethylene. Oliveira et al. (2012), when evaluating the storage of tento carolina (*Adenathera pavonina* L.), in two types of packaging (paper bag and plastic bag) observed that there was no difference between them. For the pau-de-jangada species (*Apeibati bourbou* Aubl.) they also did not find a difference between these two types of packaging in an uncontrolled environment (Matos et al., 2008). However, in the study by Ferreira et al, (2010), when assessing *Apeibati bourbou* Aubl., they found that in the storage period of up to 180 days, polyethylene packaging was the most adequate to maintain seed vigor. For *Schinus terebinthifolius*, the best type of packaging for maintaining quality was glass (Oliveira et al., 2018), while for *Geoffroea spinosa*, the best packaging for storing seeds was polyethylene (Souza et al., 2011). These results show the importance of studying forest species, given the diversity of behavior depending on the type of storage.

Even with the statistical difference observed between the treatments, the deterioration of jatobá seeds during the storage period did not occur intensely, possibly due to the characteristics of the seed, such as the fact that it is orthodox and presents tegumentary dormancy, therefore requiring a longer evaluation period than the storage period to determine the behavior of the physiology of jatobá seeds.

Thus, based on the literature and the results obtained in this study, there is a need for further research related to the use of packaging for the storage and preservation of forest seeds, given the importance of understanding the interactions between the properties of the materials used for packaging and the maintenance of the physical-chemical and physiological properties of the seeds during storage, mainly due to the increased demand for forest seeds for reforestation. Future work aimed at identifying the most appropriate types of packaging for forest seeds may address other types of materials that were not addressed in this study, such as biodegradable packaging or packaging with specific additives for certain situations, such as breaking dormancy or controlling phytopathogens.

4. Conclusions

The physical properties and physiological quality of jatobá seeds are significantly influenced by packaging during storage and the packaging that provided greater maintenance of physical properties and physiological quality was the PET packaging.Jatobá seeds can be stored for a period of eight months without significantly losing viability. However, a study with a longer evaluation period would be interesting, aiming at a better understanding of the behavior of jatobá seeds. Given the results of this research on the storage of jatobá seeds in different packages, it is expected that these data can be used by collectors, extractive cooperatives and also by researchers, given their practical viability, as demonstrated by this research.

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Data Availability Statement

The entire data set that supports the results of this study was published in the article itself.

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