

Spondias tuberosa Arr. Câm.: a natural population in Sergipe - contributions to the understanding of genetic variability and conservation of the species

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Research Article

Keywords:

Posted Date: January 8th, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-3835713/v1>

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Additional Declarations: No competing interests reported.

Abstract

The umbuzeiro, a fruit-bearing tree endemic to the Caatinga biome, stands out for its socioeconomic and environmental relevance. Although natural to Sergipe, there is a lack of information about its populations in the state. This study aimed to characterize a natural population of umbu trees in Sergipe, covering individual characteristics to the attributes of their fruits, endocarps, and seedlings. Of the 551 fruits collected from these matrices, the majority had predominantly yellow (62%) with orange (23%) peels. The endocarps, averaging 1.83 cm in length by 1.17 cm in width, significantly influenced the fresh mass of the seedlings, with larger area endocarps associated with greater mass. Endocarps stored for different periods showed no variation in germination rate and speed. These findings not only enrich the understanding of this population but also provide crucial insights for conservation and genetic improvement programs of the species in Sergipe.

Introduction

Cited as a plant for the future in the Northeast region of Brazil, endemic to the region, and listed in the List of Native Species of the Brazilian Flora with Current or Potential Economic Value (Coradin et al. 2018), the umbuzeiro (*Spondias tuberosa* Arr. Câm.) holds significant socio-economic importance, especially through the commercialization of its fruits, known as umbu.

In by-products of umbu, unexplored bioactive compounds such as trigonelline, gallotannins, and polysaccharides have been characterized and quantified in flour. The technological and chemical properties of these co-products have the potential to serve as sources of bioactive compounds for food applications (Cangussu et al. 2021).

Beyond the importance of its fruits, the species also exhibits phytotherapeutic potential due to its cytotoxic properties (Guedes et al. 2020). Umbu tree fruits in Sergipe are sold in open-air markets (Santos et al. 2012) and used in local gastronomy (Lima et al. 2020). However, Sergipe does not contribute to the production and commercialization of the fruits in Brazil (IBGE 2022).

Considering the absence of information about natural populations in Sergipe, the long-term conservation of this species may be at risk, especially considering the significant increase in deforestation in Caatinga areas, as highlighted in the Annual Deforestation Report of Brazil (MapBiomas 2023), particularly in areas within the Caatinga biome, where the umbuzeiro naturally occurs.

In 2022, a total of 2,763 hectares of the biome were deforested in the state, with municipalities such as Poço Redondo (217.38 ha), Nossa Senhora da Glória (226.53 ha), and Monte Alegre de Sergipe (214.54 ha), all located in semi-arid climate regions with the natural occurrence of the umbuzeiro, being among the most affected by this environmental degradation process (MapBiomas 2023). Therefore, the species currently faces challenges for its conservation (Drumond et al. 2016).

Additionally, studies on the diversity and genetic structure of 24 accessions from the Active Germplasm Bank of Embrapa Semiárido, originating from four semi-arid regions, indicate a moderate genetic differentiation among the studied populations, suggesting that genetic variability is moderately structured by region (Santos et al. 2021). This evidence indicates that the genetic diversity of *S. tuberosa* is not uniformly distributed in the

studied regions. Therefore, germplasm from a greater number of populations should be collected to increase the genetic diversity of this species' germplasm bank.

The species is incentivized for the commercialization of its fruits, whether fresh or derived, within the scope of public policies stimulating family farming (Brazil 2021). In 2022, for example, the 14,200 tons of umbu fruit production resulted in approximately 20 million reais in production value, as indicated in the report on Extraction and Forestry Production in Brazil (IBGE 2022). This stimulus to fruit consumption drives the scientific community to develop research on the species. In the context of species occurring in the Caatinga biome, the umbuzeiro stands out in scientific research (Oliveira et al. 2018).

In 2019, four cultivars (BRS 48, BRS 52, BRS 55, and BRS 68) were registered, a result of over 30 years of studies in the Germplasm Bank (BGU) (Ribeiro 2019). This study plays an essential role in the long-term conservation of the umbuzeiro by filling information gaps about a natural population of the species in the state, through a detailed characterization of its trees, fruits, endocarps, and seedlings.

Material and methods

Populacional sampling

The studied population is in a rural area of approximately 45 hectares (10°13'34.98"S; 37°37'56.58"W) in the municipality of Nossa Senhora da Glória, in the Alto Sertão Sergipano region, and is part of the Caatinga biome, characterized by a semi-arid landscape with vegetation adapted to arid climate conditions and nutrient-poor soils (White and Lima 2023). According to the Köppen and Geiger classification, the prevailing meteorological conditions in this region are classified as BSh. The average annual temperature in Nossa Senhora da Glória is 25.1°C, and the annual precipitation is 563 mm (Climate-Data.org 2023) (Fig. 1).

As sampled, trees had a minimum distance of 30 m between them. All mother trees were georeferenced and measured to obtain height, circumference at breast height (CBH) at 1.30 m above the ground, and major and minor diameter of the canopy. CBH was used in the calculation of equivalent diameter (Deq), as many trees had more than one stem.

$$Deq = \sqrt{\sum DAP^2}$$

Where: Deq stands for equivalent diameter of the stem.

$$DAP : CAP/\pi A$$

Biometric analysis of fruits, endocarps, and seedlings.

The fruits (551) were harvested from the matrices in April 2021 and March 2022 and 2023. Intact fruits on the ground and in the tree, canopy were collected, aiming to preserve fruits on the ground and/or in the canopy to ensure regeneration in the area. After collection, the fruits were sanitized with a sodium hypochlorite solution, air-dried, and subjected to image capture using the GroundEye® S800 model equipment.

Subsequently, manual removal of the fruit pulp was carried out to obtain the endocarps. The endocarps were subjected to drying in a shaded environment, weighed, and had their images captured, following the same procedure used for the fruits. Then, the endocarps were stored in paper bags and kept refrigerated at 10°C. The obtained images were processed using the GE program (TBIT, [n. d.]) based on the background color calibration of the images and analyzed to obtain the biometric variables of each fruit and endocarp and the color distribution of the fruits (Fig. 2).

Germination

After the biometric characterization, the endocarps from each matrix were mixed to form the batches used in the experiments (treatment 1 = 5 months; treatment 2 = 17 months; treatment 3 = 28 months of storage) and numbered with a permanent marker. To facilitate seed imbibition and tegumentary dormancy breaking, the removal of the fibrous aril was performed using tweezers, and a cut was made in the internal tegument using a scalpel to facilitate embryo expansion (Marcos-Filho 2005). Subsequently, the endocarps were aseptically treated in a sodium hypochlorite solution (2.5%) for 3 minutes, followed by thorough rinsing with distilled water.

The endocarps were placed on pre-moistened Germitest® paper with distilled water at a volume equivalent to 2.5 times the weight of the paper. The material was placed in a B.O.D. (Biochemical Oxygen Demand) germination chamber maintained at a constant temperature of 30 °C, with a photoperiod of 12 hours.

The experimental design used was completely randomized with four repetitions of 25 endocarps for each treatment. Evaluation was performed every 48 hours for 45 days (Nascimento et al. 2000), considering the emergence of the radicle with a length of 2 mm as evidence of germination. A normal seedling is defined as one that has detached from the endocarp and presents well-developed essential structures: root, hypocotyl, and the first pair of open leaves. As normal seedlings developed, they were removed from the Germitest® paper, weighed to obtain fresh weight, and biometrically characterized in GroundEye®, following the same procedure used for fruits and endocarps.

Data analysis

The dissimilarity between matrices was estimated based on the average Euclidean distance. The data were represented in a dendrogram according to the Unweighted Pair-Group Method Arithmetic Average algorithm - UPGMA (Sneath and Sokal 1973), and the phenotypic characteristics per matrix were represented in a color matrix (heat map).

The variables obtained from the image analyses of fruits, endocarps, and seedlings were analyzed through descriptive statistics. The data were represented using histograms.

To identify the correlation between the size of endocarps and seedlings, a grouping was performed based on the area (cm²) of the endocarps into three size classes, according to the data range. These classes were then correlated with the fresh mass (g) and total length of the seedlings (cm) and subjected to principal component analysis.

The data obtained from the germination test were used to calculate the germination percentage (G%), the germination speed index (GSI) using Maguire's formula (1962), mean germination time (MGT), and mean germination rate (MGR) using Labouriau's formula (1983). The variables were assessed for normal distribution using the Shapiro-Wilk test, homogeneity using the Bartlett test, and subjected to analysis of variance. When differences were detected, these were further explored through polynomial regression analysis ($p < 0.05$). All data analyses were conducted in RStudio (R Core Team 2023).

Results and discussion

Matrices of the population

The studied natural population of umbu trees has an average height of 5.31 m, a smaller crown diameter of 9.02 m, a larger crown diameter of 9.83 m, and a stem diameter of 30.83 cm (Fig. 3).

The matrices showed heights ranging from 4.38 to 6.45 m. Crown diameter measurements varied from 6.42 to 11.25 m for the smaller diameter and from 6.93 to 12.35 m for the larger diameter (Table 1).

Table 1
Geographical location and dendrometric information for 14 matrices of a natural population of umbuzeiros (*Spondias tuberosa* Arr. Câmara) located in Nossa Senhora da Glória, Sergipe: stem diameter (Deq), total height (Ht), major crown diameter (DMA), and minor crown diameter (DME).

Matriz	Geographical coordinates		Dendrometric information			
	Latitude	Longitude	Deq (cm)	Ht (m)	DMA (m)	DME (m)
01	-10.224242°	-37.632607°	53.26	6.25	12.35	11.25
02	-10.224189°	-37.631187°	35.88	6.45	11.10	9.70
03	-10.224315°	-37.630318°	18.24	4.38	6.93	6.42
04	-10.224880°	-37.630009°	17.83	5.50	11.10	10.18
05	-10.224423°	-37.633086°	21.16	4.67	7.40	8.20
06	-10.226070°	-37.630203°	36.06	5.50	10.00	9.50
07	-10.226729°	-37.628901°	32.63	5.00	8.80	8.20
08	-10.226886°	-37.628639°	40.40	6.15	12.20	10.75
09	-10.226334°	-37.628160°	28.30	4.83	12.26	9.00
10	-10.225915°	-37.628010°	21.96	4.61	9.76	9.40
11	-10.225155°	-37.628593°	25.40	4.55	8.20	8.20
12	-01.022525°	-37.634045°	28.50	5.40	9.86	8.96
13	-10.226189°	-37.634709°	28.33	5.08	7.50	6.80
14	-10.226056°	-37.634904°	43.60	5.90	10.10	9.70
Minimum	-	-	17.83	4.38	6.93	6.42
Maximum	-	-	53.26	6.45	12.35	11.25
Mean	-	-	30.83	5.31	9.83	9.02
CV (%)	-	-	33.20	12.85	18.87	15.17

The dendrometric measurements exhibit significant variability among the matrices. The Coefficient of Variation (CV%) indicates the relative dispersion of the data. The stem diameter has a CV of 33.20%, indicating considerable variability. The total height has a CV of 12.85%, indicating moderate variability. The crown diameters have CVs of 18.87% and 15.17%, respectively.

The values found for these variables fall within the ranges reported in the literature for individuals from Bahia, Pernambuco, Piauí, Minas Gerais, Ceará, Paraíba, and Rio Grande do Norte (Kill et al. 2016; Santos 1997; Santos et al. 1999).

The stem diameter was the variable that showed the greatest variation among matrices (17.83 to 53.26 cm; CV 33.20%). Previous studies on umbuzeiro used the base diameter measurement for the stem, making it impossible to compare with the results of this study (Santos 1997; Santos et al. 1999).

Based on dendrometric characteristics and the size of the fruits from each matrix, the presence of genetic dissimilarity is evident, estimated by the average Euclidean distance. The dissimilarity analysis resulted in the formation of three distinct groups in the population: group 1 (matrices 02, 04, 06, 09, 10, 12, and 14), group 2 (matrices 01 and 08), and group 3 (matrices 03, 05, 07, 11, and 13), as illustrated in Fig. 4. Dissimilarity between matrices ranged from 2.99 to 13.69% (range = 33.70%; CV = 55.86%). This analysis highlights phenotypic variability and suggests the existence of genetic diversity in the studied population.

The stem diameter, with the greatest variation among matrices, stands out as a critical variable for dendrometric assessments. The lack of direct comparisons in the literature emphasizes the uniqueness and importance of this measurement.

In this population, matrices 05 and 11 stand out as the most similar to each other in terms of the evaluated characteristics, while matrices 01 and 03 appear as the most divergent for dendrometric and fruit biometry characteristics, compared to the other trees.

Fruit Biometrics

The fruits from the matrices exhibited a range of mean values from 2.47 to 3.51 cm in length and from 2.25 to 2.96 cm for width. Matrix 10 showed mean values for fruit length (3.51 cm) and width (2.96 cm) above the population's average. For the commercialization of fresh fruits, selecting the larger fruits would be advantageous, considering that in this type of market, fruit size along with coloration is attractive to consumers. Consumers often associate these phenotypic characteristics with ripe and more flavorful fruits (Nunes et al. 2021).

In general, the umbu fruits from this natural population had an average length of 2.99 cm and a width of 2.57 cm (Fig. 5). These values are higher than the averages of fruits studied by Uchôa et al. (2020) sold in supermarkets in Teresina, Piauí.

The smallest values for fruit length and width were 1.77 and 1.60 cm, respectively. The largest values were 4.09 and 3.47 cm for length and width, respectively. Similar values are reported in the literature for fruits from Bahia, Paraíba, Piauí, and Rio Grande do Norte (Table 2).

Table 2

Ranges of length and width measurements for umbu fruits (*Spondias tuberosa* Arr. Câmara) from Bahia (BA), Paraíba (PB), and Rio Grande do Norte (RN).

Reference	Season	Procedence		Length (cm)		Width (cm)	
		State	Municipality	Minimum	Maximum	Minimum	Maximum
Costa et al. (2004)	March/April 1998	PB	Juazeirinho	3.32	3.78	2.61	2.88
Costa et al. (2015)	2011 2012	PB; RN	PB: Soledade, Juazeirinho, Campina Grande, Serra Branca, Picuí, Boqueirão, Caturité; RN: Currais Novos, Carnaúba dos Dantas	2.53	4.35	2.47	4.31
Dutra et al. (2017)	March 2016	BA	Anagé, Belo Campo, Brumado, Caraíbas, Macarani	3.39	4.15	3.13	3.71
Menezes et al. (2017)	-	PB	São José de Espinharas	2.89	3.35	2.66	2.78
Pereira et al. (2021)	March/May 2020	PB	São Vicente do Seridó, Queimadas, Boqueirão, Cabaceiras	2.60	6.00	2.30	6.00
Sergipe	April 2021; March 2022; 2023	SE	Nossa Senhora da Glória	2.47	3.51	2.25	2.96

The umbu fruits are of the drupe type, ranging from rounded, ovoid to oblong (Neves and Carvalho 2005). The ratio between length and width of the fruits, close to 1, indicates that morphologically they are rounded or oval, making them more suitable for the pulp industry, as existing machines are suitable for processing fruits with these shapes (Costa et al. 2015).

The analysis of fruit circularity in this population shows that the fruits predominantly have a circular shape (Fig. 6A). Campos et al. (2018) evaluated fruit growth and stated that it is always accompanied by a variation in shape. The author classified fruits in different ripening stages, stating that fully green fruits have a less circular shape, similar to Fig. 6C, while mature fruits have a more circular shape (Fig. 6B). In addition to the

shape, the fruit surface can be smooth when ripe or have four to five small protrusions in its distal portion when fully green (Fig. 6C).

The analyzed fruits from the population showed average skin color composition of 62% yellow, 23% orange, 9% olive, and 5% black (coloration present in small spots on the skins) (Fig. 7). However, according to Lima and Castricine (2019), there are genotypes that may exhibit areas of purplish coloration, generally starting from the peduncle and reaching the middle region of the fruit. In the population analyzed in Sergipe, this coloration was not observed.

The distribution of colors varied according to the ripening stage of the fruits, ranging from predominant green (olive) to orange. Santos et al. (2020) classified umbu fruits based on visual selection into ripening stages: completely green, beginning of pigmentation, predominance of yellowish, completely yellow, and yellow orange. Subsequently, the authors measured pH and soluble solids content. The pH remained stable across different stages, but the soluble solids content varied, with lower levels in green umbus, contrasting with higher values in yellow fruits.

Some fruits appeared entirely orange (100%), while others were nearly entirely yellow (99%). Fruits with a predominance of green also had yellow and/or orange in their color composition. This color combination characterizes fruits at the harvest point, referred to by local communities as "swollen" (Campos et al. 2018). Later, these fruits will progress in ripening, displaying a different color pattern, as they are climacteric fruits (Neves and Carvalho 2005), reaching maturity even after harvest (Batista 2015). According to Campos et al. (2018), fruits with a predominance of yellow and those entirely yellow are considered ripe.

Fruits from extractive systems like umbu should be harvested during a period that allows better preservation of quality for consumption, and color is recognized as an indicator of this ideal point (Lima and Castricini 2019). However, due to high genetic variability, color, and the harvest point (physiological maturity) are not always directly related.

However, color variation is directly related to fruit ripening. Therefore, colorimetry has a direct correlation with soluble solids content, which can aid in the selection of new plants. Additionally, the color of the peel and pulp is one of the most valued attributes by consumers and, as a result, it can include or exclude plants, according to Ferreira et al. (2017).

Therefore, advances in umbu exploitation depend on knowledge and technologies that provide fruits with a quality standard, considering visual and taste aspects (Lima and Castricini 2019).

Biometria dos endocarpos

While fruits are important commercially, endocarps are relevant for seedling production, as propagating the umbu tree by seeds increases the species' variability (Oliveira et al. 2018). However, it has the drawback of taking time for the plants to develop and start producing. Therefore, Fonseca et al. (2019) recommend using seeds for rootstock production, as seed-derived seedlings have an advantage in forming the xilopodium, increasing survival rates in the field (Batista 2015). This way, the characteristics of the mother plant and reproductive precocity are maintained (Oliveira et al. 2018).

Each seed is enclosed in a rigid and lignified endocarp (Fig. 8A) (Fonseca et al. 2019), constituting the dispersal unit of the species, commonly called a stone (Leite et al. 2021) or pyrene (Batista 2015).

In the population of this study, being a natural population, endocarps from the same matrix show significant variation in size (Fig. 8B). This variation among individuals is expected as propagation occurred through sexual reproduction. A considerable variability in endocarp size was also observed by Dutra et al. (2017) in samples for five municipalities in Bahia.

The overall average for the endocarps was 1.83 cm in length and 1.17 cm in width (Fig. 8C). The highest averages are for endocarps from matrix 10, with 2.20 cm in length and 1.53 cm in width, while the lowest averages are from matrix 08, with 1.42 cm in length and 1.00 cm in width, respectively.

Comparing with the measurements of endocarps from Bahia, Minas Gerais, and Rio Grande do Norte (Table 3), it is noticeable that, although they fall within the ranges, the averages in Sergipe are closer to the lower values of the range, both in length and width.

Table 3			
Length and width of endocarps from umbu trees (<i>Spondias tuberosa</i> Arr. Câm.) originating from Bahia (BA) and Minas Gerais (MG).			
Reference	Procedence	Length (cm)	Width (cm)
Dutra et al. (2017)	BA	1.87–2.77	1.14–1.35
Nobre et al. (2017)	MG	2.26	1.66
Rodrigues et al. (2023)	BA	1.32–2.11	0.98–1.44
Sergipe	SE	1.42–2.20	1.00–1.53

Indeed, considering that larger endocarps may contain larger seeds with more stored reserves, they could be recommended for seedling production, even though small size is a desired characteristic for fruit commercialization (Oliveira et al. 2018).

Correlation of endocarp and seedling sizes

The endocarps used in the germination tests, which resulted in normal seedlings, had areas ranging from 0.91 to 2.86 cm². Based on the data range (1.95 cm²), they were grouped into three size classes (Fig. 9).

The seedlings obtained from endocarps of different sizes were analyzed through principal component analysis (PCA) and their fresh mass (g) and total size (cm) (main variables) were correlated with the size of the endocarps. The results are graphically represented in a PCA-biplot in Fig. 10, where the first dimension (Dim1) explains 52.7% of the total variance, and the second dimension (Dim2) explains 42.8%. In the graphical representation, the geometric points correspond to the seedlings, while the colors indicate the size class of the originating endocarp (Oliveira et al. 2018).

It can be observed that endocarps classified as large tend to result in seedlings with significantly greater fresh mass and total size, as indicated by their position in the upper right part of the graph. Medium-sized endocarps, on the other hand, produce seedlings with variable characteristics in terms of fresh mass and total

size. Small-sized endocarps, on the other hand, tend to produce smaller seedlings for both analyzed variables. This observation suggests that larger endocarps may have larger seeds with more stored reserves, which can be utilized in the germination process (Oliveira et al. 2018).

Germination and Storage

The endocarps with different storage periods subjected to the germination test-initiated root protrusion from the sixth day after setting up the experiment. From the thirteenth day onwards, the emergence of the first normal seedlings was observed (Fig. 11A). On the tenth day, the first abnormal seedlings (Fig. 11B) and deteriorated seeds (Fig. 11C) became apparent.

The normal seedlings had an average total length of 11.30 cm (3.79 cm hypocotyl length and 7.51 cm root length) and a fresh weight of 0.32 g. Araújo et al. (2001) reported seedling emergence between 10 and 35 days, with a germination rate of 22.80% for seeds from freshly harvested fruits, while Souza et al. (2022) stated that germination can generally occur within 90 days, with a rate of 30%. The average germination rate in this study, i.e., of endocarps that produced normal seedlings, was 19%.

Considering the low germination performance of freshly harvested umbuzeiro seeds, studies indicate that endocarp storage can improve germination rate and speed. In an analysis of seeds stored for 12 and 24 months, Araújo et al. (2001) found that the longer storage period provided higher germination percentages, representing a practical method to overcome dormancy (Marcos-Filho 2005).

However, in this study, no significant differences were observed among endocarps stored for 5-, 17-, and 28-months regarding germination percentage, germination speed index, and average germination speed. Additionally, no significant differences were identified for the total length and fresh weight of seedlings obtained from endocarps stored for different periods (Table 4).

It is worth noting that the seeds used in Araújo et al.'s (2001) study were also stored at 10°C; however, the material used came exclusively from a single matrix, and it is known that there is a possibility of variation in seed viability and vigor among matrices.

Table 4

Means of the variables percentage of germination (G), germination speed index (GSI), average germination speed (AGS), percentage of abnormal seedlings (AS), percentage of deteriorated seeds (DS), total length of normal seedlings (TLS), and fresh mass of normal seedlings (FMS) derived from endocarps of a natural population of umbu trees (*Spondias tuberosa* Arr. Câm) in Sergipe stored for 05 (T1), 17 (T2), and 28 (T3) months.

Storage (months)	G (%)	GSI	AGS	AS (%)	DS (%)	TLS (cm)	FMS (g)
5	19.00	1.19	0.13	47.00*	16.00*	11.48	0.44
17	10.00	0.58	0.18	16.00*	73.00*	10.11	0.26
28	28.00	1.81	0.25	31.00*	41.00*	12.30	0.27
Mean	19.00	1.19	0.19	31.33	43.33	11.30	0.32
Standard Deviation	9.00	0.62	0.06	15.50	28.57	1.11	0.10
Coefficient of Variation (%)	47.37	51.77	31.53	49.48	65.93	9.80	31.27

Significant at the 1% level of probability by the F-test.

Additionally, the endocarps in this study were subjected to a constant temperature of 30 °C, a value close to the average soil temperature in the Caatinga of Pernambuco, which is 31.02 °C (Dantas et al. 2020). Although species in the Caatinga are known for their tolerance to high temperatures and water scarcity conditions, the germination capacity to withstand extreme soil temperatures and water deficits still needs to be quantified (Dantas et al. 2020).

For the percentage of abnormal seedlings and deteriorated seeds, there was a significant difference in relation to the storage periods. As the percentage of abnormal seedlings decreases, there is a corresponding increase in the percentage of deteriorated seeds (Fig. 12). This analysis suggests that even if the seeds do not deteriorate, they will not give rise to normal seedlings.

It is possible that some seeds, even without showing external signs of deterioration, were internally compromised or unable to generate normal seedlings due to changes induced by the storage period or conditions, or other intrinsic factors related to the parent trees, affecting seed viability, such as genetic factors.

Conclusions

The dendrometric and biometric variability of the fruits indicates genetic dissimilarity among matrices. This variability, coupled with the edaphoclimatic conditions of the studied years, as well as the age of the trees, may contribute to genetic diversity and the formation of distinct groups in the population, as evidenced in the dissimilarity analysis.

The dendrogram generated by the UPGMA method highlights similarities between matrices 05 and 11 and divergences between 01 and 03 for the analyzed characteristics. Matrix 10 stands out with larger fruits, indicating potential for in natura commercialization, and the predominantly circular shape suggests potential for pulp industry.

The average germination rate is 19%, and principal component analysis reveals a positive correlation between the size of the endocarps and seedling development. Endocarps stored for 17 months showed higher percentages of abnormal seedlings and deteriorated seeds, indicating possible effects of storage.

Although no significant differences were observed for the germination rate and speed between the tested storage periods, subtle variations in climatic conditions during the fruit collection years may have contributed to differences in seed viability.

These conclusions provide valuable insights into the genetic variability, dendrometric characteristics, fruit biometrics, germination, and storage of endocarps in the studied population of umbu trees in Sergipe. This information can guide strategies for the management, conservation, and economic utilization of this species in the region.

Declarations

Acknowledgements

We thank the Coordination for the Improvement of Higher Education Personnel—Brazil (CAPES), Federal University of Sergipe, and the Research Group on Conservation, Breeding and Management of Genetic Resources (GENAPLANT).

Author Contributions

NAS conducted the research and wrote the text, VVN and RSM guided the research, revised the text and contributed to the writing of the manuscript, MSOS contributed to obtaining the research data. All authors contributed to the article and approved the submitted version.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

All the authors of this manuscript declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Figures

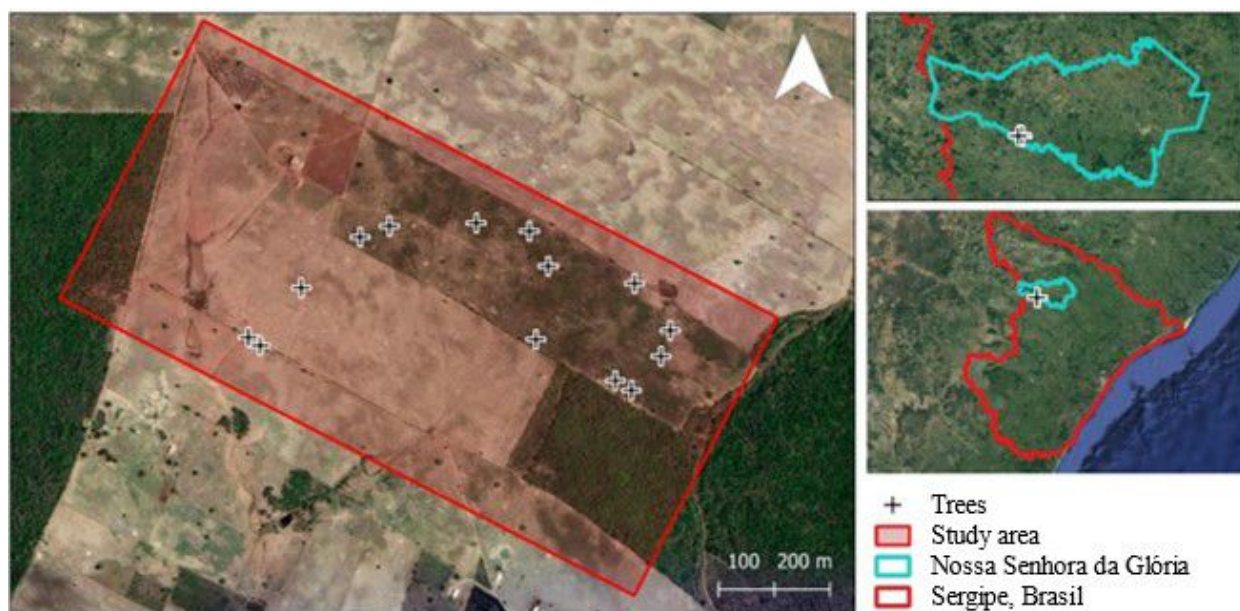


Figure 1

Spatial distribution of umbuzeiros (*Spondias tuberosa* Arr. Câmara) in a natural population located in Nossa Senhora da Glória, Sergipe. Images: Google Satellite.

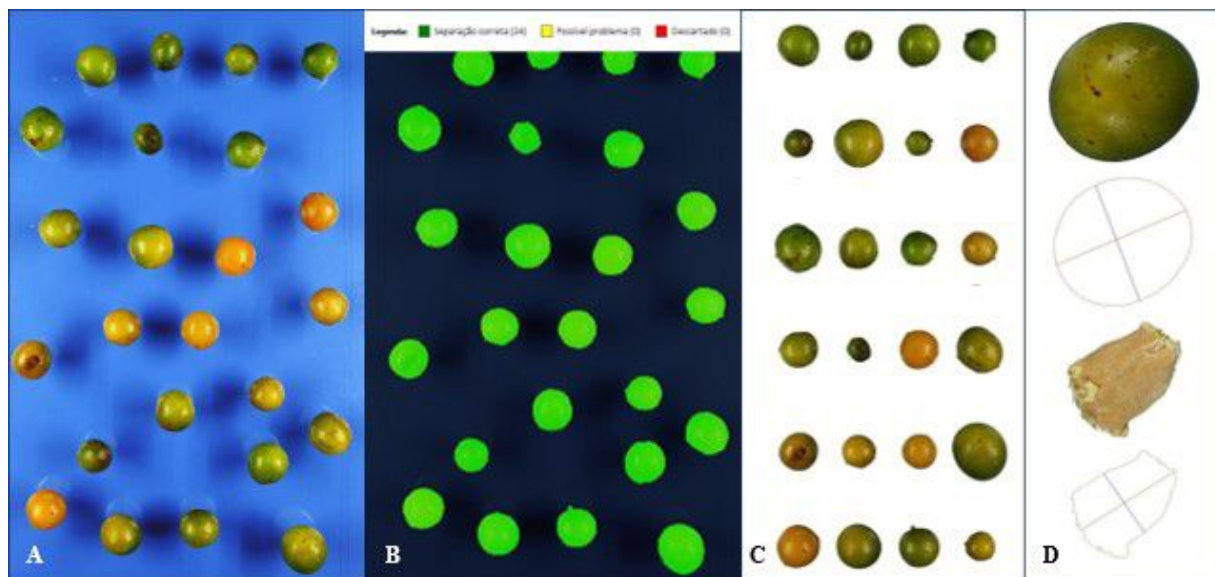


Figure 2

Processing and analysis of images of umbuzeiro fruits (*Spondias tuberosa* Arr. Câmara) in the GE program: image of the fruits on the capture tray (A); calibrated background color (B); processed image (C); models for obtaining biometric variables of fruits and endocarps (D).

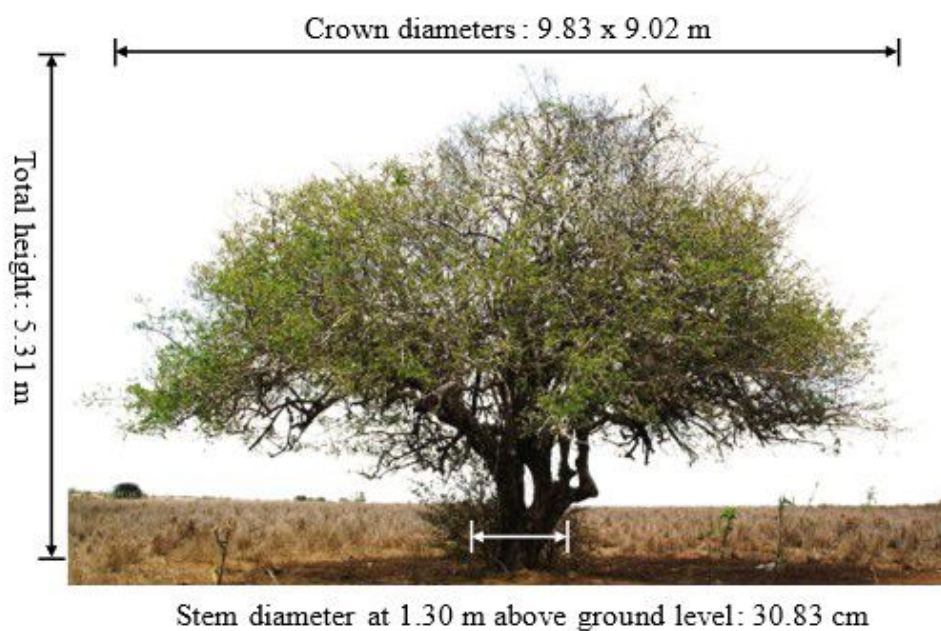


Figure 3

Representation in a matrix of the mean height (m), larger and smaller crown diameter (m²), and stem diameter at 1.30 m above ground (cm²) of the natural population of umbu trees (*Spondias tuberosa* Arr. Câmara) in Sergipe.

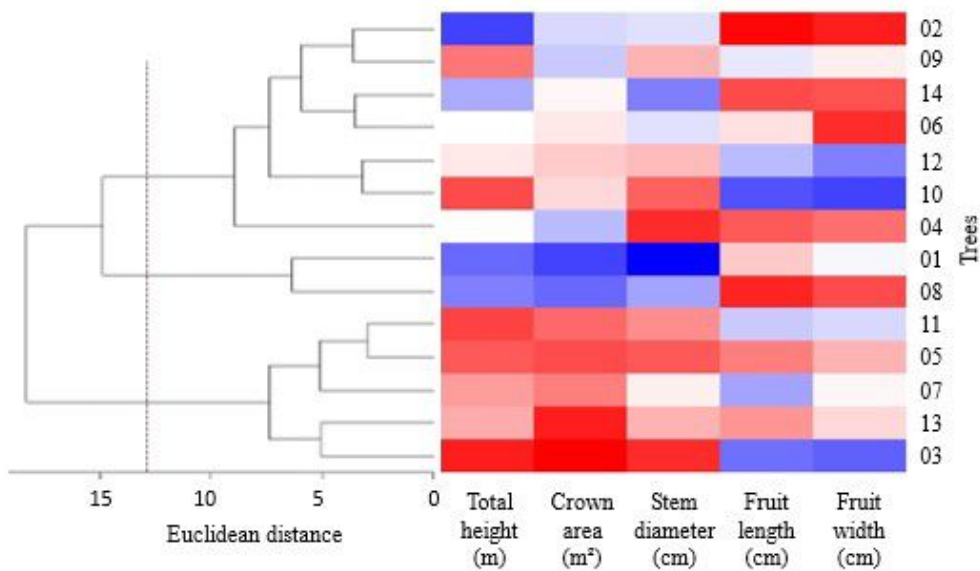


Figure 4

Dendrogram generated by the UPGMA method, using dissimilarity, and graphical representation of phenotypic values for 14 matrices of umbu trees (*Spondias tuberosa* Arr. Câm) in a natural population in Sergipe, covering five quantitative characteristics. The color scale ranges from red, indicating the smallest variable values, to blue, representing the largest values.

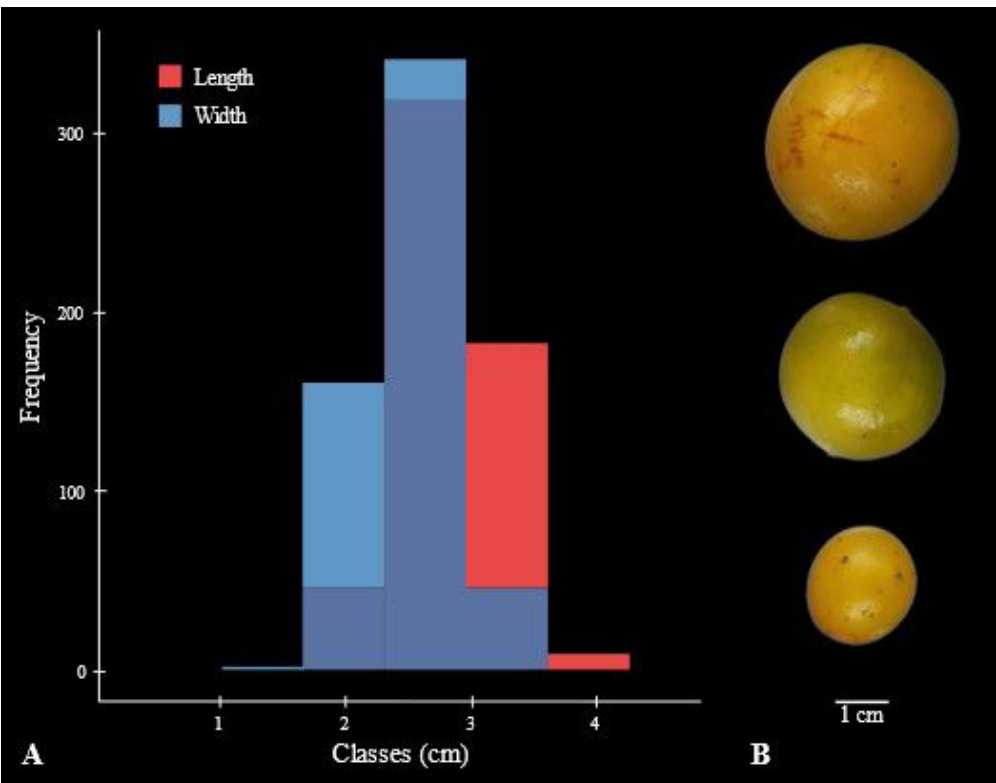


Figure 5

Frequency distribution of the length and width of 551 fruits from 14 matrices of a natural population of umbu trees (*Spondias tuberosa* Arr. Câm.) in Sergipe (A) and variation in the size of fruits in the studied population

(B).

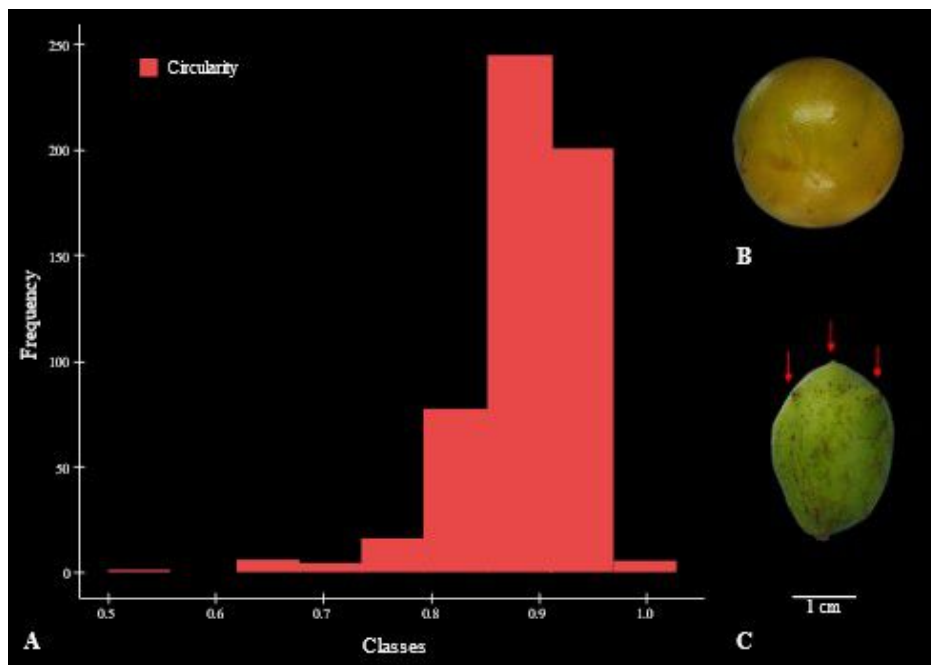


Figure 6

Circularity of umbu fruits (*Spondias tuberosa* Arr. Câm.) from a natural population in Sergipe (A): umbu with a very circular shape (0.98) (B); elongated umbu (0.64) with protrusions indicated by red arrows (C).



Figure 7

Distribution of colors in umbu fruits (*Spondias tuberosa* Arr. Câm.) from a natural population in Sergipe (A): Fruit with 57.22% olive and small black spots (B); 99.48% yellow (C); and 100.00% orange (D).

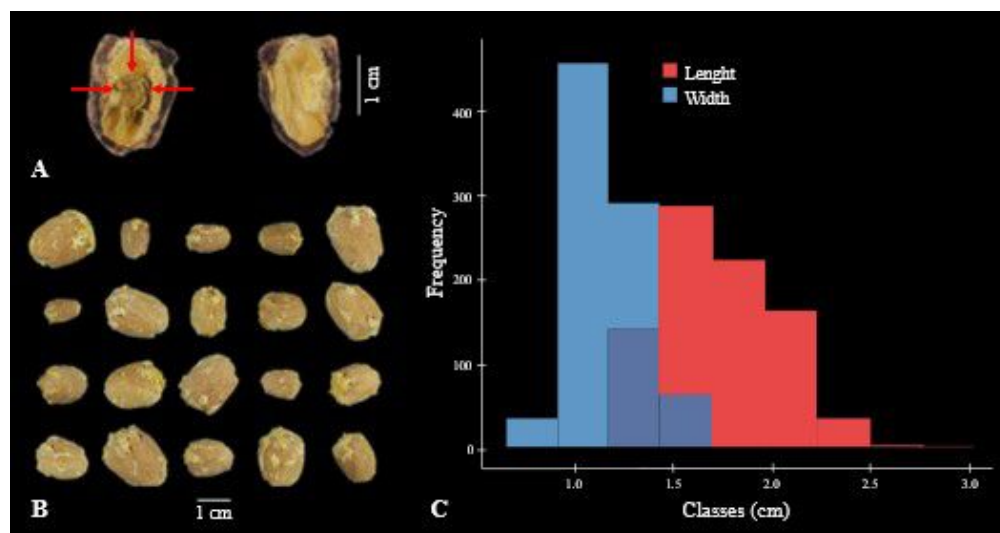


Figure 8

Endocarps of umbuzeiros (*Spondias tuberosa* Arr. Câm) from a natural population in Sergipe: open structure of the endocarp with the seed indicated by red arrows (A); biometrics of the endocarps from the population (B), and variation in the size of endocarps from the same matrix (C).

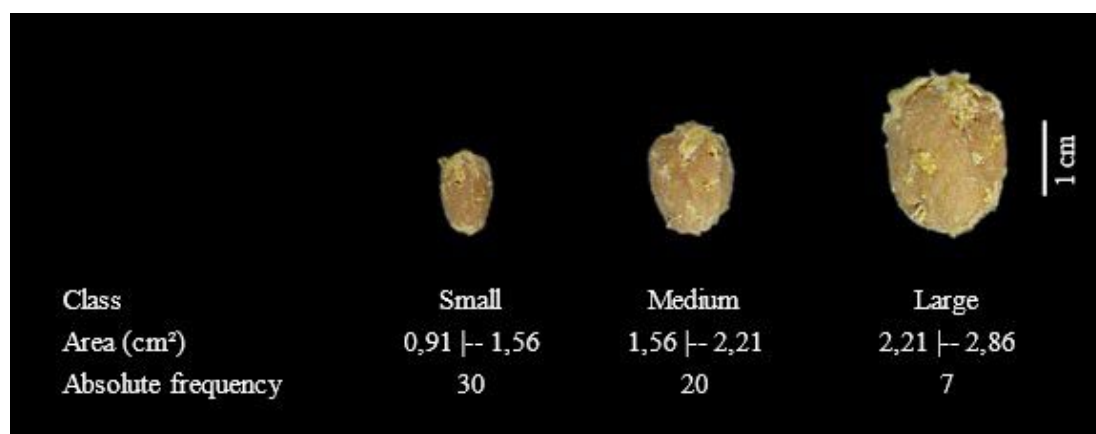


Figure 9

Distribution of umbuzeiro (*Spondias tuberosa* Arr. Câm.) endocarps from a natural population in Sergipe, used in germination tests, and resulting in normal seedlings. They are grouped into three classes based on area (cm²).

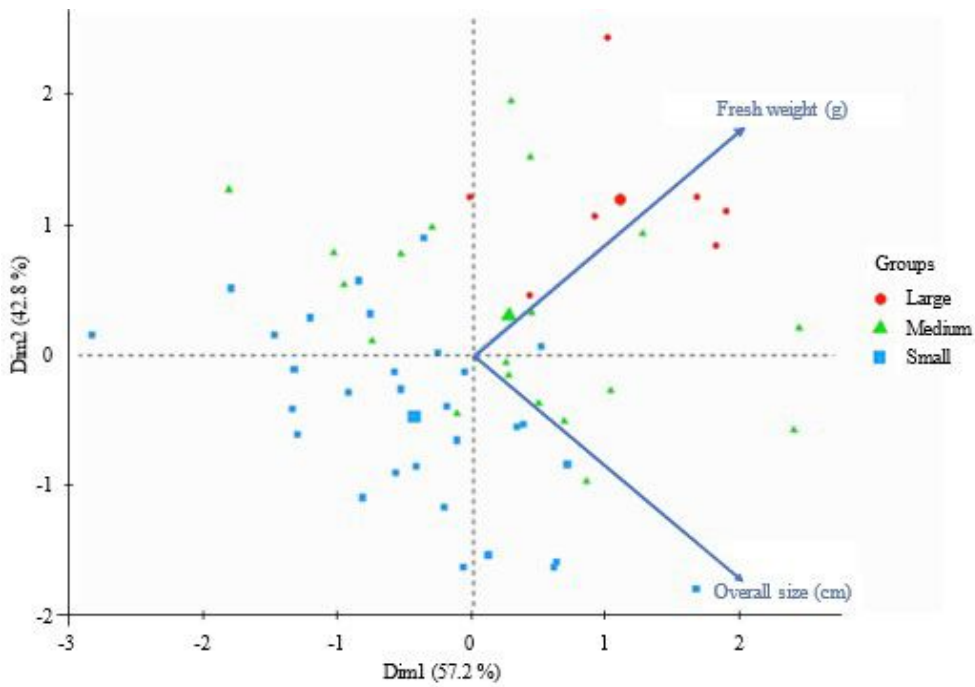


Figure 10

Graphical scatterplot through Principal Component Analysis (PCA) for the vigor of endocarps in size classes (small, medium, and large) in relation to the fresh mass (g) and total size (cm) of seedlings of umbuzeiros (*Spondias tuberosa* Arr. Câm) from endocarps of a natural population in Sergipe.

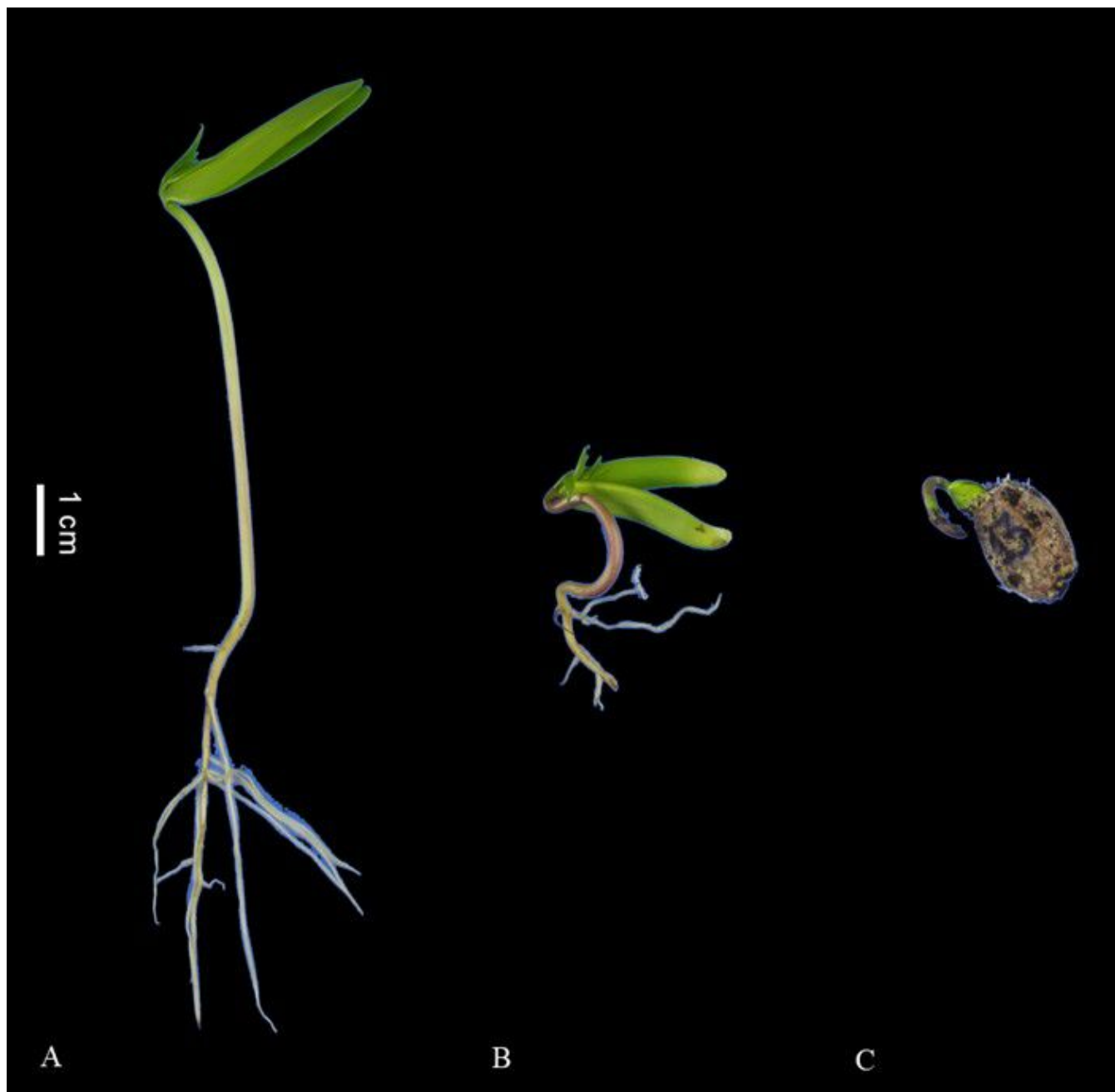


Figure 11

Seedlings of umbuzeiro (*Spondias tuberosa* Arr. Câmara) from endocarps of a natural population in Sergipe: normal seedling (A); abnormal seedling (B); and deteriorated seedling (C).

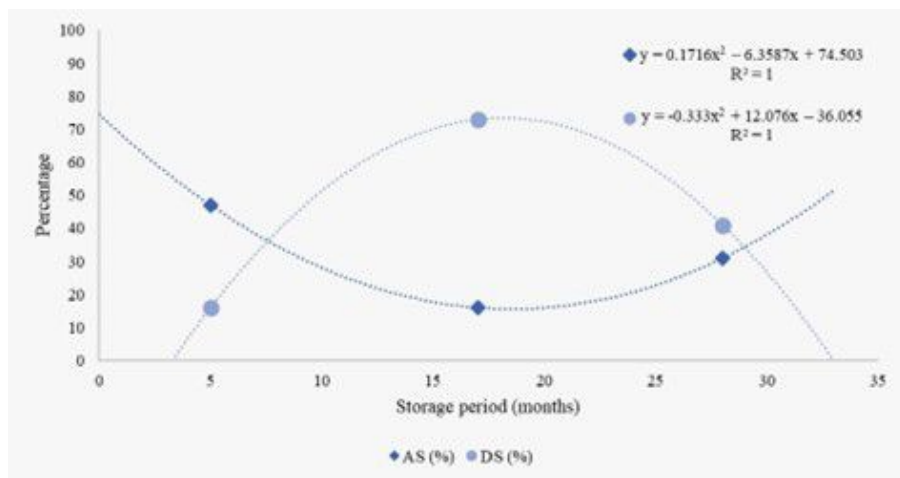


Figure 12

Percentage of abnormal seedlings (AS) and deteriorated seeds (DS) derived from endocarps of a natural population of umbu trees (*Spondias tuberosa* Arr. Câm) in Sergipe, stored for 05, 17, and 28 months.