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Characteristics of the physical properties of seeds and reproductive aspects of *Paullinia stellata* Radlk

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ABSTRACT

Paullinia stellata is found in anthropogenic places and lowland forests, yet little information about their reproductive characteristics is known. This study aimed to determine the physical properties of seeds and the characteristics of their reproductive aspects. Racemes, fruits, and seeds were measured and weighed. The physical properties of the seeds were determined using three-dimensional data. A descriptive statistic was applied for racemes and fruits, and a statistic of small samples was conducted for the physical properties. The results showed low magnitude variations for variables analyzed in both parameters. The physical properties of the seeds are relatively moderate variations from low oscillations. Fruit maturity is detected by the opening of the endocarp exposing the seed, but it presents early and late fruit with asynchronous maturation. This study was conducted only on a single plant and observed asynchronous fruits within the same raceme.

Keywords: Forest species, Morphometry, Sexual reproduction.

Características das propriedades físicas de sementes e dos aspectos reprodutivos de *Paullinia stellata* Radlk

RESUMO

A espécie *Paullinia stellata* é encontrada em locais antropizados e floresta de várzea, sendo limitadas as informações sobre suas características reprodutivas. O objetivo deste trabalho foi determinar as propriedades físicas de sementes e as características de seus aspectos reprodutivos. Foram mensurados e pesados racemos, frutos e sementes. Através dos dados tridimensionais foram determinadas as propriedades físicas das sementes. Foi aplicada uma ferramenta de estatística descritiva para racemos e frutos e para a propriedades físicas foi aplicada estatística de pequenas amostras. Os resultados demonstraram variações de baixa magnitude para as variáveis analisadas em ambos os parâmetros. As propriedades físicas das sementes apresentaram variações relativamente moderadas de baixas oscilações. A maturidade dos frutos foi detectada pela abertura do endocarpo expondo a semente, porém apresenta frutos precoces e tardios com maturação assíncrona. Este estudo foi conduzido apenas em uma única planta e observou frutos assíncronos no mesmo racemo.

Palavras-chave: Espécie florestal, Morfometria, Reprodução sexuada.

1. Introduction

Paullinia stellata, which belongs to the Sapindaceae family, is a species of lianescent habit whose fruit is fleshy and has a whitish aril layer between the seed and the endocarp. It is popularly called 'guaraná bravo', so knowing its characteristics and being similar to the cultivated guaraná (*Paullinia cupana*) can, for this reason, have the potential to be used in breeding programs of the cultivated species. It is native to the Amazon, being most frequent in the border region of Brazil (Acre) and Bolivia (Pando) (Chery et al., 2019).

This species under study still has little information about its reproductive aspects, especially about the seeds, which are essential for the propagation of the species. Seed properties such as germination, density, and quality depend on moisture content, an important factor influencing harvest, storage, processing, yield, and selling price (Besharati et al., 2021). In addition, the physical properties collaborate to generate information that will help optimize processes, develop projects, and regulate equipment used in post-harvest processes (Oliveira et al., 2021).

The propagation of species that produce fleshy fruits can present limiting factors in obtaining seeds with ideal physiological maturity for germination. This is because fruit coloration does not always indicate that the seeds are fully mature. However, it is necessary to investigate some factors that can collaborate in identifying this process. In this sense, there is a need for more detailed descriptive studies to assist in identifying species in the field and collaborate in the interpretation of germination tests and seed vigor (Luz et al., 2021).

Species descriptions are essentially based on the characteristics of roots, stems, leaves, flowers, and inflorescences of plants (Cruz et al., 2019) and habitat and rarely describe the seeds. Although many native species are not managed commercially, it is extremely important to know about floristic, reproductive, and especially seed quality control and seedling vigor (Guareschi et al., 2015). The literature describes that the position of the seed in the fruit can affect seed vigor and quality, but this issue, although discussed since the 1960s, is rarely a topic in scientific papers (Mendonça et al., 2016).

Several factors influence fruit quality and seed physiology, such as temperature, light, and humidity (abiotic factors) and biotic factors, such as seed size, maturity, and fruit size. Knowing and studying these aspects can assist in obtaining higher quality lots (Piña-Rodrigues et al., 2015). The descriptive characteristics of this species about its reproductive composition can help in the knowledge of floral biology, the influence of fruit size on seeds, and the classification of seed lots, increasing the performance and potential of plants in a field or nursery conditions, keeping them uniform. Therefore, this study aimed to determine the physical properties of seeds and the characteristics of reproductive aspects of *Paullinia stellata*.

2. Material and Methods

The data on *Paullinia stellata* used in this study were collected from a parent plant found in the secondary forest fragment of the Parque Zoobotânico - PZ of the Federal University of Acre - UFAC, located on the UFAC Campus of Rio Branco, Acre (10º02'11" S and 67º47'43" W).

To obtain the fresh mass of the seeds individually, a heterogeneous sample was used, one unit/seed weighed on a precision analytical balance, where 99 units were evaluated. Afterward, measurements of the three-dimensional dimensions of the seeds were performed as pre-established by Pinheiro et al. (2019). The measurements were determined according to the location of the hilum in the seeds; then, from the hilum to the opposite base, the length was measured, sides of the median region of the greater amplitude of the seeds were considered the width, the thinner apparent side was determined as the thickness (Figure 1).

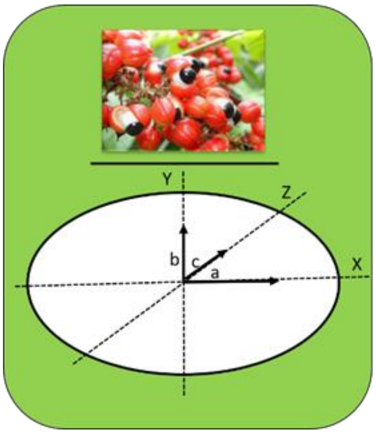

Figure 1. Characteristics of the three-dimensional geometric dimensions of *Paullinia stellata* seeds: (a) = length; (b) = width; (c) = thickness. Seed size: length mm x width mm x thickness mm.

Evaluations were made with a King Tools 150BL digital caliper (sensitivity of 0.01 mm) and a digital scale (sensitivity of 0.001g). After determining the measurements of dimensions, results of aspects of physical properties were obtained through mathematical calculations, where SVI - seed volume index (Vieira et al., 2008), GMD - geometric mean diameter, EMD - equivalent mean diameter, AMD - arithmetic mean diameter (Sahay and Singh, 1994), Sa - surface area (Mccabe et al., 2005), Ø - seed sphericity, V - seed volume (Mohsenin, 1986), and Ra - aspect ratio (Varnamkhasti et al., 2008) were estimated. The following properties were calculated according to the mathematical equations (Eq. 1; Eq. 2; Eq. 3; Eq. 4; Eq. 5; Eq. 6; Eq. 7; and Eq. 8).

SVI = lenght x width x thickness (Eq.1)

GMD=SVI^(1/3) (Eq.2)

$$\mathrm{EMD} = \left[\mathrm{lenght}\ \frac{(\mathrm{width\ x\ thickness})}{4}\right]^{1/3} \quad (\mathrm{Eq.}\,3)$$

$$\mathrm{AMD} = \frac{\mathrm{lenght} + \mathrm{width} + \mathrm{thickness}}{3} \quad (\mathrm{Eq.}\,4)$$

$$\mathrm{Sa} = \pi \mathrm{GMD}^2 \quad (\mathrm{Eq.}\,5)$$

$$\emptyset = \left[\frac{\mathrm{GMD}}{\mathrm{lenght}}\right] 100 \quad (\mathrm{Eq.}\,6)$$

$$\mathrm{Ra} = \left[\frac{\mathrm{width}}{\mathrm{thickness}}\right] 100 \quad (\mathrm{Eq.}\,7)$$

$$\mathrm{V} = \frac{\mathrm{IVS}}{6} \quad (\mathrm{Eq.}\,8)$$

The frequency distribution calculations were defined using pre-established classes. Knowing that the relative frequency is a way of performing data analysis through a comparison because the relative frequency determines the percentage of that data represented to all data collected, it was used only for the data of fruits and seeds, defined by the following equation (Eq. 9).

$$Fr = \frac{fi}{n}\ \mathrm{x}\ 100 \quad (\mathrm{Eq.}\,9)$$

Fr= relative frequency; fi= absolute frequency; n=total of elements

Small sample statistics (Sokal and Rohlf, 1995) were performed, maintaining the statistical principles and assumptions, using 99 seeds, divided into three sub-samples with 33 seeds. The classes were calculated in a statistical program. The data on biometric characteristics were explored by mean and range (maximum and minimum, coefficient of variation= CV, relative frequency, arithmetic mean, standard deviation, and confidence interval) to determine the possible association between phenotypic variation and the variables analyzed. A normality test was performed for a specific distribution function, with known mean and variance, normality being assessed by the Lilliefors test to determine whether a normal distribution well modeled the data set of random variables or not.

Twenty racemes were evaluated, in which some fruits were maturing on the parent plant. The racemes were measured for total length (cm) and fresh mass (g) with and without fruits. We counted the number of fruits in each raceme that presented visual aspects of ripe fruits, however, some were green, and in the development phase, we also checked the number of seeds in each fruit selected for the study. The measurements of the fruits were length and circumference due to their rounded shape. The fresh mass was obtained by weighing on digital scales, 100 fruits were individually evaluated, and from these 100 fruits, the seeds were extracted to evaluate their dimensions. At this stage, quantitative descriptive statistics were performed (similar procedure for the seeds).

3. Results and Discussion

The results of the physical characteristics of the reproductive aspects of *Paullinia stellata* according to the physical properties of the seeds can be seen in Table 1. The dimensions of the seeds showed relatively low variations (CV < 15%), with uniformity for the three-dimensional characteristics of the seeds evaluated. The length and thickness are similar, demonstrating a spherical character for these two variables. Therefore, the width was greater than the length and thickness.

Table 1. Characterization of physical (seed volume index = SVI, geometric mean diameter = GMD, equivalent mean diameter = EMD, arithmetic mean diameter = AMD, surface area = SA, seed sphericity = Ø, seed volume = V, and aspect ratio = AR) and three-dimensional (length = L, width = W, and thickness = T) properties, and mass (M) of seeds *of Paullinia stellata*.

Parameters	Minimum	Media ± SD	Maximum	CV(%)	± 95% CI	Valor *p*
L (mm)	4.14	6.54 ± 0.56	8.21	8.60	6.42 – 6.64	*
W (mm)	6.17	8.0 ± 1.04	10.22	13.03	7.79 – 8.20	*
T (mm)	5.34	6.70 ± 0.79	8.40	11.83	6.54 – 6.85	**
M (g)	0.10	0.26 ± 0.08	0.47	31.29	0.24 – 0.27	*
SVI	169.35	361.01± 118.01	679.18	32.69	337.76 –384.25	**
GMD (mm)	5.53	7.04 ± 0.75	8.79	10.63	6.89 – 7.18	**
EMD (mm)	2.45	2.88 ± 0.19	3.35	6.62	2.84 – 2.91	ns
AMD (mm)	5.55	7.08 ± 0.76	8.82	10.76	6.92 – 7.22	**
SA (mm²)	96.16	157.51 ± 33.90	242.74	21.52	150.82 – 164.18	**
V (mm³)	88.67	189.02 ± 61.79	355.62	32.69	176.85–201.19	**
Ø (%)	97.30	107.66 ± 5.25	120.38	4.88	106.62 – 107.65	ns
AR	105.09	122.16 ± 10.13	145.12	8.29	120.16 – 124.15	*

^{ns}: did not differ significantly from each other, *: indicates statistical difference between variables ($p < 0.05$), **: indicates statistical difference between variables ($p < 0.001$). In columns: CV = coefficient of variation; CI = confidence interval; SD = standard deviation.

The fresh seed mass determined by weighing presented a high coefficient of variation according to the seed size (31.29%) because the fresh seed mass varies according to morphological and physiological aspects, in which its water content suffers oscillations of moisture loss or gain in the environment, being the main factor to determine the seed deterioration process. Mathematical equations obtain the physical properties of the seeds through linear three-dimensional measurements (Table 1).

This Table allows us to observe the geometric variations of the seeds and thus relate the morphological aspects of the seeds for sizing and regulation of machines in the post-harvest processes; it is essential to understand the variations that can guarantee a good operation of equipment during processing, drying, and mechanized harvesting. The mean values of seed volume index (SVI) and seed volume (V - mm³) are different, but the coefficient of variation values was equal (32.69%).

The geometric mean diameter (GMD), equivalent mean diameter (EMD), and arithmetic mean diameter (AMD) show similar results of mean, minimum, maximum, and coefficient of variation values, only the EMD shows more variation. The seed surface area (SA - mm²) evidenced a high coefficient of variation. Seed sphericity (Ø) was the variable with the least variation, along with EMD. The seed aspect ratio (AR) was also less than 10% variation, demonstrating that the seeds have a greater tendency toward a spherical shape.

To better understand the size variation and variations among them, it is possible to observe in Table 2 the frequency of distribution in the fruit and seed ranges found in the seed lot studied. This is related to the genetic characteristics of the plant, the environment, and nutritional factors (soil), which will ensure better conditions of energy expenditure for the reproduction of the species at the time of flowering and the sequence of the reproductive system of the plant.

Concerning the distribution frequency of the fruits in the classes determined among the variables studied, it was possible to observe that the parent plant produced the greatest number of fruits, with their fresh mass varying from 0.60 to 1.39 g, comprising 84% of the actual sample collected. The largest fruits found in class IV represented 6% of the sample (1.40 to 1.80 g).

Table 2. Values for frequency distribution and amplitudes of the variables in the analyzed classes of *Paullinia stellata* fruits and seeds, '|—, this symbol shows the range in which the first number is included in the class, but the limit number does not count.

Fruits	Classes	Xi	Fi	Percentage
Mass (g)	I – 0.20 |— 0.60	0.4	10	10%
	II – 0.60 |— 1.00	0.8	46	46%
	III – 1.00 |— 1.40	1.2	38	38%
	IV – 1.40 |— 1.80	1.6	6	6%
Lenght (cm)	I – 13.01 |— 14.87	13.94	16	16%
	II – 14.87 |— 16.72	15.79	60	60%
	III – 16.72 |— 18.58	17.65	16	16%
	IV – 18.58 |— 20.43	19.50	8	8%
Circumference (cm)	I – 32.32 |— 36.77	34.54	20	20%
	II – 36.77 |— 41.22	38.99	24	24%
	III - 41.22 |— 45.66	43.44	46	46%
	IV – 45.66 |— 50.11	47.89	10	10%
Seeds				
Fresh Mass (g)	I – 0.01 |— 0.19	0.10	25	25%
	II – 0.19 |— 0.38	0.29	63	63%
	III – 0.38 |— 0.57	0.47	12	12%
Lenght (cm)	I – 5.14 |— 5.91	5.52	9	9%
	II – 5.91 |— 6.68	6.29	64	64%
	III – 6.68 |— 7.44	7.06	17	17%
	IV – 7.44 |— 8.21	7.83	10	10%
Width (cm)	I – 6.07 |— 7.13	6.60	31	31%
	II – 7.13 |— 8.20	7.66	20	20%
	III – 8.20 |— 9.26	8.73	36	36%
	IV – 9.26 |— 10.32	9.79	13	13%
Thickness (cm)	I – 5.34 |— 6.10	5.72	30	30%
	II – 6.10 |— 6.87	6.49	30	30%
	III – 6.87 |— 7.64	7.25	27	27%
	IV – 7.64 |— 8.40	8.02	13	13%

Xi= midpoint; Fi = absolute frequency.

As for the measurements of length and circumference of the fruits, it was observed that the largest fruits are in class II (60%) and class III (46%), which demonstrates the irregularity of the seeds, when it presents similar average values of length and thickness, but the width with greater amplitude. The fruits have a rounded shape with a septate capsule, but their characteristics, obtained by the frequency of amplitudes, differ among the classes evaluated for length and circumference. Regarding the frequency of distribution of seed sizes in the classes determined, it was possible to observe that for length, the intervals of greatest amplitude ranged from 7.44 to 8.21 mm, of the 10.0% represented in class IV were predominant in these, as the largest, for the other classes were 17% (III); with a larger quantity of seeds predominated with 64% in class II and I (9.0%).

For width, the greatest amplitude was in class III (36.0%), followed by I (31%), II with 20.0%, and class IV (13.0%). The thickness presented percentages of classes with equal behavior for I and II; 5.36 to 6.09 mm; 65.33%; 7.13 to 6.86 mm; 30%, the greatest amplitudes represented for class III (27%) and class IV with 13% of the value higher than the other classes (Table 2). To understand the dynamics of *Paullinia stellata* inflorescence composition in fruit quantification, it is essential to discriminate the racemes for fruit production, which can directly influence the physiological quality of the seeds. The maturation of the seeds is accompanied by visible changes in the external appearance of the fruit and its dispersal type. And also, the phenotypic characteristics of the racemes can be used as an indicator for the identification of the harvest point of physiological maturity of the fruits and, consequently, the seeds.

In the evaluation of the racemes found with aspects of color changes in the fruits (physiological maturity), it was observed that there is a variation between the sizes of each raceme, which was verified through the length measurement. Size fluctuations directly influence the mass of the racemes, but for the fruits, it is not a rule to find the largest ones on longer racemes (Figures 2 and 3). The fresh mass of the racemes with fruits is higher than 9.91% of the racemes without fruits, characterizing that these inflorescences mainly transport solutes to develop their fruits and seeds better.

The racemes presented several fruits in a single inflorescence with the most varied sizes, and these fruits vary in quantity according to the capacity of fecundation and predation of the flowers or even of the fruits in the maturation phase. The inflorescences presented many immature fruits, so there were few suitable for harvesting (Figure 3), but it was observed that some fruits harbored more than one seed and others only one, which is classified as monospermic and polyspermic. However, its predominance was to present only one seed, so when 20 racemes/unit were evaluated, the number of fruits was 100 (fruits/unit), and the number of seeds (108 seeds/unit) was higher, due to some fruits harboring more than one seed (Figure 3A).

The *Paullinia stellata* has a white aril covering almost the entire seed, with only the part opposite the hilum uncovered. It is the basal part of the seeds that demonstrates the shiny black coloration, the arylode presents thick thickness in the hilum region and is thinned in the basal part of the seed, it is a fleshy structure and areiusc consistency (Figure 3B). The fresh mass of the seed and fruit show the oscillations found in the quantifications of each individual evaluated, the dotted lines represent the standard deviation in the sampling and thus observe the degree of dispersion of the set of data analyzed, indicating that there is disuniformity in the seed lot studied. It can also be seen that the coefficient of variation was high (Figure 4).

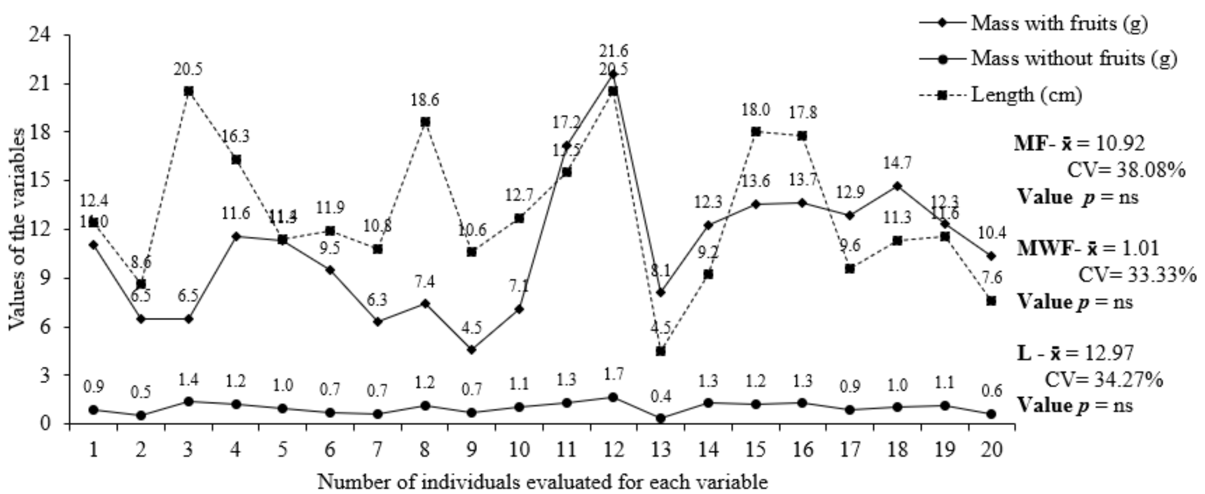

Figure 2. Number of individuals found with their respective mass and size of racemes. MF - Mass with fruits, MWF - Mass without fruit, L – length, and CV - coefficient of variation. Ns: did not differ significantly from each other. CV = coefficient of variation.

The mass content of seed and fruit generally varies according to the moisture content and phytomass. Still, seed harvesting in fleshy fruits must attend to aspects of fruit maturation for the seeds to reach physiological maturity. Another important feature that can help in choosing the harvest time for mature *Paullinia stellata* fruits is to monitor the changes in epicarp color and capsule opening during their development. Each species that produces seed differs from one another in its morphology and, therefore, can present individual engineering for manufacturing equipment according to its physical properties with specific shapes.

The size of seeds from dry fruits facilitates the identification process at physiological maturity, unlike seeds from species with fleshy fruits. Seed dimensions are crucial for establishing equipment standards, manufacturing designs, and sizing systems for most forest species. As *Paullinia stellata* is not commercially exploited, information on its reproductive biology, germination aspects, processing, drying, physiological quality of seeds, etc., is still almost non-existent. In this study, we evaluated the physical properties of seeds after physiological maturity, and at this stage, the morphological and structural components can be altered by water loss or the natural drying process. Jesus et al. (2013) state that the drying process alters the physical characteristics of products, and it is essential to study the physical properties of seeds during this process because such changes can influence the sizing of equipment and systems for harvesting, handling, transport, drying, processing, and storage.

Seeds can show significant changes in their physical characteristics, such as size and shape when subjected to conditions capable of modifying their water content (Oba et al., 2019). Therefore, it is important to know the biometric variables and the physical properties of the seeds to improve the projections of machines for the beginning of projects or adaptations of structures and equipment used in post-harvest, such as transport systems, drying, cleaning, grading, and aeration, it is essential to obtain data regarding the main physical properties of the product studied (Goneli et al., 2016; Silva and Carvalho, 2015; Araújo et al., 2022).

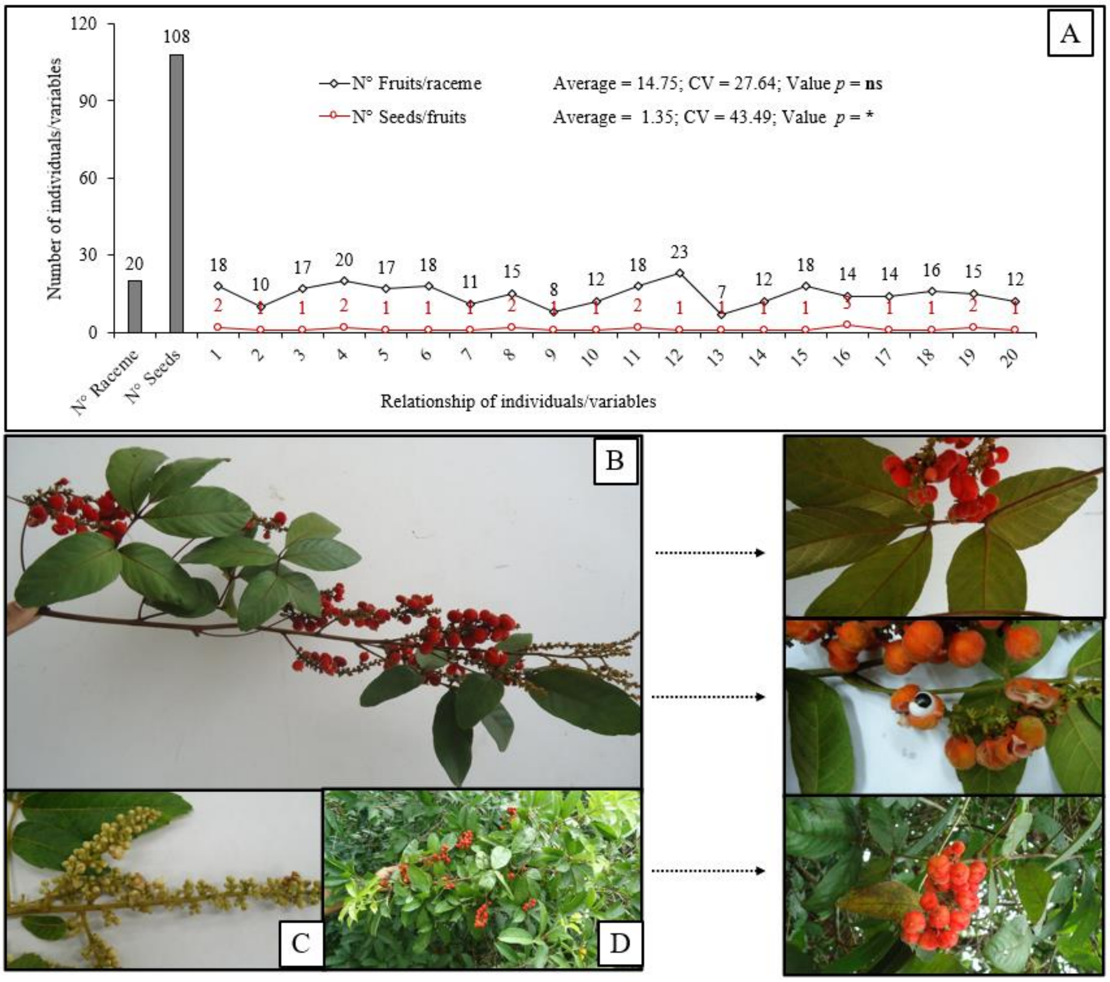

Figure 3. Relationships found under the physical aspects of the racemes producing fruits and the quantification of seeds inside. A - Number of fruits per raceme and number of seeds per fruit; B - leaves and racemes with mature fruits and seeds; C - inflorescence, D - parent plant with mature fruits (liana). ns: did not differ significantly from each other, * indicates statistical difference among the variables (p<0.001).

The values obtained for the three-dimensional dimensions (length, width, thickness) of the seeds reinforce a low coefficient of variation, demonstrating homogeneity as to their shape. For it is common for forest species to present a high variation among a batch of seeds from the same plant. This can occur because genetic variability is predominant in unexploited species. However, from a post-harvest point of view, these data are important to observe the variations in the dimensions and three-dimensional and geometric aspects of the seeds and thus to note a possible environmental interference on phenotypic characteristics and seed mass and dimensions with more details.

The mean values of SVI and V are different, but the coefficient of variation values was equal. This reflects different magnitudes but with equal dispersion. This way, the variables can be interpreted only once instead of two. Knowing that volume is the ratio of water detachment in the seeds inside, which can change their dimensions and shape, the seeds can increase or lose apparent specific mass. For the GMD, EMD, and AMD, there were similar results of mean, minimum, maximum values, and coefficient of variation; only the EMD shows less variation, being more homogeneous. These actual variations of the mean diameters demonstrate the intensity of the disuniformity of the morphological shape and in, which is related to the volume aspect. Pontes et al. (2018a) state that these diameters provide information on the intensities of three-dimensional oscillations of the seeds.

The seed drying process involves surface area (As mm2), consequently, storage because it directly interacts with the surrounding object. Larger surface areas are found in larger seeds. Zareiforoush et al. (2011) state that the process for conditioning the seeds is related to volume effects and the surface itself, which consequently influence gas exchange and even the hygroscopic process. A study conducted by Pontes et al. (2018b) points out that the relationship between surface area and seed volume involves the drying time, soaking, and energy expenditure of the seeds during the germination stages. The effects of surface area on seed water absorption and loss rates can also be characterized by surface area utilization relative to its volume (Mir et al., 2013).

The Ø is a variable that demonstrates the real spherical aspect of a seed, in this case, the seeds presented 95.12% for a spherical trend, configuring that the width and thickness of the seed are greater than the length. The Ø values are close to 1.0 (100%), which indicates a sphere (Pontes et al., 2018a). In this study, this approximation configures a seed that is not fully spherical but has an oval shape. The Ra of the seeds was also less than 10% variation, demonstrating that the seeds tend to be spherical, with a greater area of contact being the median region of the seeds.

The relative frequency relationship of seeds and fruits details how the characters of both dimensions are grouped. In this way, the distribution of seeds can be observed in classes according to their size and thus determine homogeneous lots. Frequency distribution is a means of synthesizing and organizing the data collected, thus arranging them clearly and meaningfully, facilitating their understanding, and highlighting significant trends in these data (Feijoo, 2010), as can be observed in fruits and seeds of *Paullinia stellata*. Flowering is an important stage in the growth and development of plants that produce flowers. Flowering time directly affects whether a plant can produce offspring capable of performing well in nursery seedling establishment or even in fields, becoming economically important (Peng et al., 2022).

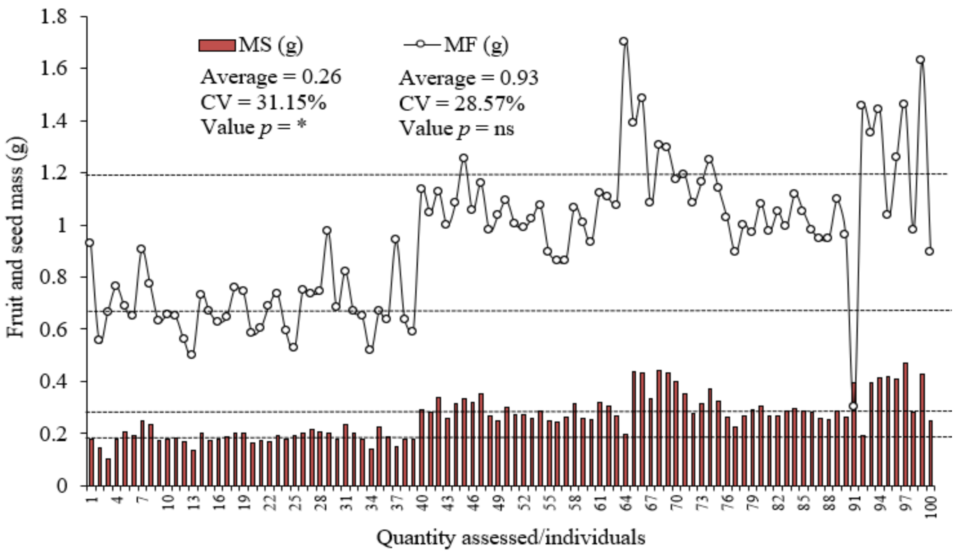

Figure 4. Fresh mass of seeds and fruit of *Paulínia stellata*, SM = seed mass; FM = fruit mass. CV = coefficient of variation, ns: did not differ significantly from each other. * indicates a statistical difference between variables (p<0.001). The dotted lines represent the standard deviation in the sample analyzed.

In general, the characterization of fruits and racemes to indicate the physiological maturity of the seeds needs to be observed *in loco* because the coloration and maturity are not synchronous, thus requiring a detailed evaluation. This species presents late maturing fruits in the same racemes. When working with a commercial species, this situation generates losses for producers since this species has the potential to be incorporated into a guarana (*Paullinia cupana*) breeding program. Fruit with asynchronous ripening may compete for shoot nutrients with each other, and the trait is inconvenient at harvest for growers; the impact and commercial value of this trait need further evaluation (Lee and Chang, 2019).

They know that racemes are a type of inflorescence in which the flower pedicels insert at various levels into the main axis of the plant. This study verified that there is asynchronous flowering, where the youngest flowers are located at the ends of the branches of *Paullinia stellata*, causing heterogeneity in fruit formation. And in this way, understanding the physiological maturity point of seeds is essential in fleshy fruit species; however, flowering and harvesting of asynchronously maturing *Paullinia stellata* fruit are five and two weeks apart, respectively. Fruit growth can be affected by air temperature and the pollination of new flowers because there is an expenditure of energy and transport of metabolites in the fertilization of new flowers and, consequently, a delay in replacement that the photosynthetic rate can influence.

The fruits present a superiority concerning the seed mass of 67%, characterizing that the energy expenditure in forming fruits is high. What remains to be seen is how much this interferes with the physiological quality of the seeds. Chang et al. (2015) report late ripening fruits may have smaller seeds and a higher proportion of wrinkled seeds. Other reports highlight wrinkling caused by embryo abortion resulting from stenospermocarpy (Huang and Qiu, 1987) and in addition to liquid endosperm collapse and competition for nutrients between the pulp and embryo (Lee and Chang, 2014).

The seeds obtained from early fruits can present better physiological quality, whereas, for late fruits, the seeds can present lower physiological quality caused by environmental conditions and nutritional competition. The mass of the collected seeds indicated a high variation, demonstrating that their germination capacity requires attention to the shape of the seeds since larger seeds need more water, more space in the tubes, depth proportional to their size, etc. (Pinheiro et al., 2021). Therefore, it is important to standardize the size and provide equal conditions for all seeds.

4. Conclusions

The physical properties of the seeds showed relatively moderate low-sway variations with a spherical trend. Fruit maturity was detected by the opening of the endocarp, exposing the seed but presenting early and late fruits with asynchronous maturation. This study was conducted on a single plant only and observed asynchronous fruit within the same cluster; the interactions and differences in maturity between early and late maturing cluster fruit can be explored in future studies.

Authors' Contribution

Romário de Mesquita Pinheiro: Conceptualization, project administration, formal analysis, writing (Original Draft), Resources. Evandro José Linhares Ferreira: Conceptualization, project administration, formal analysis, writing (Original Draft), Resources. Gizele Ingrid Gadotti: Project administration, funding acquisition, writing (Review and Editing), Resources, Supervision, Funding acquisition. Ruan Bernardy, Rafael Rico Timm and Ednéia Araújo dos Santos: writing (Review and Editing).

Bibliographic References

Araújo, Á.S., Pinheiro, R.M., Silva, E.J.S., Gadotti, G.I., Monteiro, R.C.M. Bernardy, R. 2022. Determination of physical properties and viability in different colors of Pueraria seeds. Revista Agrogeoambiental, 14(1), e20221659. DOI: https://doi.org/10.18406/2316-1817v14n 120221659.

Besharati, B., Lak, A., Ghaffari, H., Karimi, H., Fattahzadeh, M. 2021. Development of a model to estimate moisture contents based on physical properties and capacitance of seeds, Sensors and Actuators A: Physical, 318, 112513, DOI: https://doi.org/10.1016/j.sna.2020.112513.

Chang, J.Y., Chang, Y.A., Tang, L., Chang, J.W. 2015. Characterization of generative development in early maturing litchi 'Early Big', a novel cultivar in Taiwan. Fruits, 70, 289-296. DOI: http://dx.doi.org/10.1051/fruits/2015026.

Chery, J.G., Acevedo-Rodríguez, P., Rothfels, C.J., Specht, C.D. 2019. Phylogeny of *Paullinia* L. (Paullinieae: Sapindaceae), a diverse genus of lianas with dynamic fruit Evolution. Molecular Phylogenetics and Evolution, 140, 106577. DOI: https://doi.org/10.1016/j.ympev .2019.106577.

Cruz, O.M., Souza, R.L.F., Freitas, R.R., Souza, L.M., Mafra, E.R.M.L.S., Silva, B.M., Bufalino, L. 2019. The properties of the mesocarp fibers of patauá, a multiple-use palm from the Amazonia forest. SN Applied Sciences, 1, 1317-1317. DOI: https://doi.org/10.10 07/s42452-019-1366-7.

Feijoo, A.M.L. C. 2010 Distribuição de frequência. In: A pesquisa e a estatística na psicologia e na educação [online]. 1 ed. Centro Edelstein de Pesquisas Sociais, Rio de Janeiro. DOI: https://doi.org/10.7476/9788579820489.

Goneli, A.L.D., Martins, E.A.S., Jordan, R.A., Geisenhoff, L.O., Garcia, R.T. 2016. Experimental dryer design for agricultural products. Engenharia Agrícola, 36(5), 938-950. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v36n5p938-950/2016.

Guareschi, D.G., Lanzarini, A.C., Lazarotto, M., Maciel, C.G., Barbieri, G. 2015. Envelhecimento acelerado de sementes e qualidade de plântulas de *Bauhinia forficata* em diferentes substratos e tamanho de tubetes. Revista Agro@mbiente On-line. 9(1), 65-71. DOI: https://doi.org/10.18227/1982-8470ragro.v9i1.2175.

Huang, H., Qiu Y. 1987. Growth correlations and assimilate partitioning in the arillate fruit of *Litchi chinensis* Sonn, Australian Journal of Plant Physiology, 14, 181-188.

Jesus, F.F., Souza, R.T.G., Teixeira, G.C.S., Teixeira, I.R., Devilla, I.A. 2013. Propriedades físicas de sementes de feijão em função de teores de água. Engenharia na Agricultura. 21(1), 9-18. DOI: https://doi.org/10.13083/reveng.v21i1.390.

Lee, Y. C.; Chang, J. C. 2019. Altered development, quality and sink strength in asynchronous maturing fruits produced from the two-sequence female flowers inflorescence/cluster of 'Yu Her Pau' litchi, Scientia Horticulturae, 249, 131-142. DOI: https://doi.org/10.1016/j.scienta.2019.01.028.

Luz, A.O., Ferreira; A.M., Matta, J.R.T., Ferreira, J.C.C., Nascimento, O.S., Bufalino, L., Silva, S.B.M. 2021. Aspectos morfológicos do fruto, da semente e do desenvolvimento pós-seminal de areca bambu (*Dypsislutescens* (H. Wendl.) Beentje & J. Dranssf.). Almanaque Multidisciplinar de Pesquisa, 8(1), 24-36.

Mccabe, W.L., Smith, J.C., Harriot, P. 2005. Unit operation of chemical engineering. New York, McGraw-Hill, 1140 p.

Mendonça, A.V.R., Freitas, T.A.S., Souza, L.S., Fonseca, M.D.S., Souza, J.S. 2016. Morfologia de frutos e sementes e germinação de *Poincianella pyramidalis*. Ciência Florestal, 26(2), 375-387. DOI: https://doi.org/10.5902/1980509822738.

Mir, S.A., Bosco, S.J.D., Sunooj, K. 2013. Evaluation of physical properties of rice cultivars grown in the temperate regions of India. International Food Research Journal, 20(4), 1521-1527.

Mohsenin, N.N. 1986. Physical properties of plant and animal materials. 2th ed. New York: Gordon ad Breach, 891 p.

Oba, G.C., Goneli, A.L.D., Martins, E.A.S., Hartmann Filho, C.P., Gonçalves, A.A. 2019. Caracterização física das sementes de feijão-caupi, cultivar brs guariba, durante o processo de secagem. Energia na Agricultura, 34(2), 283–296. DOI: http://dx.doi.org/10.17224/energagric.2019v34n2p283-296.

Oliveira, J.A.V., Coradi, P.C., Alves, C.Z., Teodoro, P.E., Alvarez, R.C.F. 2021. Correlation of physical properties for establishments of standardized groups of soybean seed technologies in post-harvest. Journal of Stored Products Research, 93, 101854. DOI: https://doi.org/10.1 016/j.jspr.2021.101854.

Peng, J., Li, W., Yuan, Y., Han, Z., Cao, Y., Shahid, M.Q., Zhang, Z., Gao, Y., Lin, S., Jiang, Y. 2022. Removal of the main inflorescence to induce reflowering of loquat, Horticultural Plant Journal. 8(1), 35-43. DOI: https://doi.org/10.1016/j.hpj.2021.03.009.

Piña-Rodrigues, F.C.M., Figliosa, M.B., Silva, A.A. 2015. Sementes florestais tropicais: da ecologia a produção. Abrates, Londrina.

Pinheiro, R.M., Macedo, V.G.K., Soares, V.N., Tunes, L.V.M., Almeida, A.S. 2019. Viabilidade e métodos para superação de dormência e análise biométrica das sementes de puerária. Revista Brasileira de Engenharia e Sustentabilidade, 6(1), 16-21. DOI: https://doi.org/10.15210/rbes.v6i1.13751.

Pinheiro, R.D.M., Soares, V.N., Gadotti, G.I., Silva, E.J.S.D., Almeida, A.D.S. 2021. Germinative performance of mulungú seeds (*Ormosia grossa* Rudd) after dormancy overcoming. Revista Árvore, 45, e4532. DOI: https://doi.org/10.1590/1806-908820210000032.

Pontes, M.S., Carlos, M.P., Misra, V.B., Ribeiro-Junior, H.L., Graciano, D.E., Santos, J.S., Nobrega, M.A.S., Fernandes, S.S.L., Caires, A.R.L., Santiago, E.F. 2018a. High-throughput phenotyping by applying digital morphometrics and fluorescence induction curves in seeds to identifying variations: a case study of *Annona* (Annonaceae) species. Information Processing in Agriculture, 5, 443-455. DOI: https://doi.org/10.1016/j.inpa.2018.07.001.

Pontes, M.S., Santiago, E.F., Nobrega, M.A.S., Freitas, V.M.B. 2018b. Caracterização morfológica usando dimensões lineares sobre os atributos biométricos em sementes de *Annona reticulata* (L.) Vell. (Annonaceae). Ciência Florestal, 28, 696-707. DOI: https://doi.org/10.5902/1980509832070.

Sahay, K.M., Singh, K.K. 1994. Unit operations of agricultural processing. Vikas Publishing House, New Delhi.

Silva, M.C.A.T., Carvalho, L.S. 2015. Ferramenta computacional para dimensionamento de silo unicelular de concreto armado -parte I: silo de seção circular. Engenharia Agrícola, 35(2), 378-389. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v35n2p378-389/2015 .

Sokal, R.R., Rohlf, F.J. 1995. Biometry: The Principles and Practice of Statistics in Biological Research. 3rd Edition, W.H. Freeman and Co., New York.

Varnamkhasti, M.G., Mobli, H., Jafari, A., Keyhani A.R., Soltanabadi, M.H., Rafiee, S. 2008. Some physical properties of rough rice (*Oryza Sativa* L.) grain, Journal of Cereal Science, 47(3), 496501. DOI: http://dx.doi.org/10.1016/J.JCS. 2007.05.014.

Vieira, L.M., Pereira, W.V.S., Oliveira, T,G.S., Aquino, F.F., Ribeiro, L.M.; Mercadante-Simões, M.O. 2008. Análise biométrica de frutos e sementes de *Passiflora setacea*. In: IX Simpósio Nacional Cerrado e II Simpósio Internacional de Savanas Tropicais. Brasília. Anais... Brasília: [s. n.], 1-6. http://simposio.cpac.embrapa.br/simposio/trabalhos_pdf/00135_trab1_ap.pdf. (acessado 05 de maio de 2022).

Zhang, J., Wu, Z., Hu, F., Liu, L., Huang, X., Zhao, J., Wang, H. 2018. Aberrant seed development in Litchi chinensis is associated with the impaired expression of cell wall invertase genes. Horticulture Research, 5, 39. DOI: https://doi.org/10.1038/s41438-018-0042-1.

Zareiforoush, H., Hosseinzadeh, B., Adabi, A. 2011. Moisture dependent physical properties of paddy grains. Journal of American Science, United States, 7(7), 175-182.