Morphometric of fruits and Seeds of Brazil Nut Tree Populations (*Bertholletia excelsa* Humb. Bonpl.: Lecythidaceae) in Pará Southeastern as a Parameter of Phenotypic Variation

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ABSTRACT – The Brazil-nut (*Bertholletia excels* Humb. Bonpl., Lecythidaceae) is a law-protected Amazon native species in Brazil, classified as vulnerable in risk terms of extinction and quite explored by extractivists. The objective of this study consisted to evaluate the phenotypic diversity in different population of *Bertholletia excelsa* by fruits and seeds morphometry. A total of 60 fruits were evaluated, from three populations located in three Pará southeast areas: Tapirapé-Aquiri National Forest (FLONATA), Carajás National Forest (FLONACA) and Sousa Farm (FAZENDA). The measured variables were: number of seeds per fruit (NS), fruit weight (FW), fruit length (FL), fruit width (FWi), operculum diameter (OD), seed weight (SW), seed length (SL), seed width (Swi) and seed thickness (ST). These were tested about normality (Shapiro-Wilk) and homocedasticity (Bartlett) and posteriorly submitted to a variance test (ANOVA). A means comparison test was made (Tuckey) and multivariate analysis (PCA) to evaluate relations between the morphometric variable with different collection areas. The analysis evidenced the formation of three correspondent groups (FLONATA, FLONACA and FAZENDA), being the first that stands out for showing average measurements superior to mostly of the tested variables and significantly differs to the other two who does not differ among themselves. These answers evidenced greater phenotypic variation in populations that occur in environments with different edaphoclimatic conditions evidencing the importance of consider the exogenous factors besides the endogenous factors.

Keywords: Chestnut trees; fruits biometry; seeds biometrics.

Morfometria de Frutos e Sementes de Populações de Castanha-do-Pará (*Bertholletia excelsa* Humb. Bonpl.: Lecythidaceae) no Sudeste do Pará como Parâmetro de Variação Fenotípica

RESUMO – A castanha-do-Brasil (*Bertholletia excelsa* Humb. Bonpl., Lecythidaceae) é uma espécie nativa amazônica protegida por lei no Brasil, classificada como vulnerável em termos de risco de extinção, e bastante explorada por extrativistas. O objetivo deste trabalho consistiu em avaliar a diversidade fenotípica de diferentes populações de *Bertholletia excelsa* por meio da morfometria dos frutos e sementes. Foram avaliados um total de 60 frutos provenientes de três populações localizadas em três áreas do sudeste do Pará: Floresta Nacional do Tapirapé-Aquiri (FLONATA), Floresta Nacional de Carajás (FLONACA) e Fazenda Sousa (FAZENDA). As variáveis mensuradas foram: número de sementes por fruto (NS), peso do fruto (PF), comprimento do fruto (CP), largura do fruto (LF), diâmetro do opérculo (DO), peso da semente (PS), comprimento da semente (CS), largura da semente (LS) e espessura da semente (ES). Elas foram testadas quanto à normalidade (Shapiro-Wilk) e homocedasticidade (Bartlett) e, posteriormente, submetidas a um teste de variância (ANOVA). Foi realizado teste de comparação de média (Tuckey) e análise multivariada (PCA) para avaliar as relações entre as variáveis morfométricas com as diferentes áreas de coleta. As análises evidenciaram a formação de três grupos correspondentes (FLONATA, FLONACA e FAZENDA), sendo que a primeira se destaca por apresentar mensurações médias superiores para a maioria das variáveis testadas e diferir significativamente das outras duas, e que estas não diferem entre si. Tais respostas evidenciam maiores variações fenotípicas em populações que ocorrem em ambientes com condições edafoclimáticas distintas evidenciando a importância de se considerarem os fatores exógenos além dos fatores endógenos.

Palavras-chave: Castanhais; biometria de frutos; biometria de sementes.

Morfometría de Frutos y Semillas de Poblaciones de Castañas (*Bertholletia excelsa* Humb. Bonpl.: Lecythidaceae) en el Sureste de Pará como Parámetro de Variación Fenotípica

RESUMEN – La nuez de Brasil (*Bertholletia excelsa* Humb. Bonpl., Lecythidaceae) es una especie amazónica nativa protegida por la ley en Brasil, clasificada como vulnerable en términos de riesgo de extinción y ampliamente explotada por los extractivistas. El objetivo de este trabajo fue evaluar la diversidad fenotípica de diferentes poblaciones de *Bertholletia excelsa* a través de la morfometría de frutos y semillas. Se evaluaron un total de 60 frutos de 3 poblaciones ubicadas en tres áreas del sureste de Pará: Bosque Nacional Tapirapé-Aquiri (FLONATA), Bosque Nacional Carajás (FLONACA) y Finca Sousa (FAZENDA). Las variables medidas fueron: número de semillas por fruto (NF), peso del fruto (PF), largo del fruto (LP), ancho del fruto (AF), diámetro del opérculo (DO), peso de la semilla (PS), longitud semilla (LS), ancho de semilla (AS) y espesor de semilla (ES). Fueron probados para normalidad (Shapiro-Wilk) y homocedasticidad (Bartlett) y posteriormente sometidos a una prueba de varianza (ANOVA). Se realizó una prueba de comparación de medias (Tuckey) y análisis multivariado (PCA) para evaluar las relaciones entre las variables morfométricas con las diferentes áreas de recolección. Los análisis mostraron la formación de tres grupos correspondientes (FLONATA, FLONACA y FAZENDA), el primero de los cuales se destaca por presentar mediciones promedio más altas para la mayoría de las variables evaluadas y diferir significativamente de los otros dos y que no se diferencian entre sí. Estas respuestas muestran mayores variaciones fenotípicas en poblaciones que se dan en ambientes con diferentes condiciones edafoclimáticas, destacando la importancia de considerar factores exógenos además de factores endógenos.

Palabras clave: Castaños; biometría de frutas; biometría de semillas.

Introduction

In 1807, Humbolt and Bonpland first described a *Bertholletia excelsa* species in which it is the only species of *Bertholletia* genus (Ferreira & Carniello, 2018), Amazon native (Chalita *et al.*, 2019) that has nonflooded lands (dry land) as *habitat (Costa et al., 2009)*. It belongs to Lecythidaceae botanical family (Cardoso *et al.*, 2017), and is popularly known as Brazil-nut (Silva, 2019).

The *Bertholletia excelsa* is a social tree for making clusters known as chestnut trees, associated with others large forest species (Salomão, 2009). This association allows the formation of clusters of trees approximately 50 meters in heigh and 2 of diameter at breast height with the ability to survive for more than 500 years (Braga *et al.,* 2009). Generally, the Brazil-nut groves are made in clayey or sandy soils with good drainage, being in clayey soils their greatest occurrence (Silva, 2019).

Brazil-nut tree can be founded, naturally, in Brazil, Venezuela, Peru, Colombia, French Guyana, Suriname and Bolivia (Batista *et al.*, 2019); being distributed over 320 hectares (ha) between Brazil, Bolivia and Peru (Cardoso *et al.*, 2017). In Brazil, this species is present in the states of Pará, Acre, Roraima, Rondônia, Amazonas, Amapá, and in the north of the states of Mato Grosso and Goiás (Nogueira *et al.*, 2014).

The reason of this concentration in tropical area in given by the species adaptability to annual average temperatures of 24°C to 27°C with a 1400 to 2800 pluviometric index variation (Braga *et al.*, 2009). Brazil-nut tree produces globose shape fruits with woody characteristics, popularly known in Brazil as "ouriço" (Maués *et al.*, 2015), containing approximately 12 to 5 seeds named as Brazil-nut (Nogueira *et al.,* 2014), which experience variations in ouriço production every year, on the same tree (Maués *et al.*, 2015).

The Brazil-nut fruit is the most known non-timber forest product (NTFP) and solidly establish in domestic markets and exportation for over a century (Peters, 1994; Clay, 1997; Peres *et al.*, 2003; Scoles *et al.*, 2011; Albuquerque, 2015; Da Silva & Paraense, 2019). Obtaining the ouriços is carried out in the months of December to February after the fruit fall, with low environmental impact (Braga *et al.*, 2009; Haugaasen *et al.,* 2010), and its deriving almost exclusively from the native Brazil-nut trees extractivism (Shepard & Ramirez, 2011; Duchelle *et al.,* 2011; Neves *et al*., 2016).

The collection and processing of the nuts its often associated to an exemplar model of NTFP sustainable industry, as its contributes to many communities livehood and their regional economy, in the same time that contributes to the livehood of many communities and their regional economies while it contributes to the biodiversity preservation, avoiding deforestation and forest degradation (Allegretti, 1994; Clay, 1997; Peres *et al.*, 2003; Salomão *et al.*, 2006; Salomão, 2009; Camargo et al., 2010; Tonini, 2013; Salomão *et al.*, 2014; Da Silva & Paraense, 2019).

Brazil-nut seed has a historical value to regional populations (Salomão, 2014) and shows great value in nutritional matters (De Brito *et al.*, 2019). Due to its recognition as a functional food, there is a strong international appeal for its consumption with Bolivia, the United States of America, China, Peru and Tunisia as its main importing countries (Oliveira *et al.,* 2020). In relation to exports, in 2015, the Brazil exported the equivalent ou US$41.56 million. In relation to exports, in 2015, Brazil exported the equivalent of US $ 41.56 million in Brazil nuts. However, in 2017, the export revenue was only US $ 11.96 million, the lowest value since 2009 (Formigoni, 2018; Da Silva *et al.,* 2020). It also shows high levels of proteins, amino acids, flavonoids, phenolic compounds (De Brito *et al.*, 2019) and high selenium levels (Kluczkovski *et al.,* 2015). In addition, the intake of Brazil-nut contributes to cancer prevention (Balbi *et al.,* 2014) and neurodegenerative diseases (Martens *et al.*, 2015), mainly for its antioxidant action (Huguenin *et al.,* 2015).

The fruit, seed and seedling biometrics and morphometric analysis provide greater knowledge of the species as: germination, quality test, standardization and storage of fruits and seeds (Dos Santos, 2011). This identification allows to identify the populations intra and interspecific phenotypic variety, and provides information of physiological and ecological aspects, contributing to the species proper management (Aguiar *et al.*, 2018).

This study has as objective to evaluate the phenotypic diversity of different populations of *Bertholletia excelsa* by fruits and seeds variables evaluation. This study can subsidize actions of use and conservation of Brazil-nut tree population in different environments and the Brazil-nut valuation as a NTFP, contributing to characterize its behavior, allowing future projections for population and products from these population.

Material and Methods

Study areas

Fruits (ouriços) from 3 Brazil-nut tree populations, located in three areas of Pará southeast were used on evaluation: Tapirapé-Aquiri National Forest (FLONATA), Carajás National Forest (FLONACA) and Sousa Farm (FAZENDA) (Fig. 1-A e B). FLONATA and FLONACA compose a mosaic of conservation units known as "Mosaico de Carajás", being the first created from the decree n° 97.720 of 05 of May of 1989 (Brasil, 1989) and the second from the decree n° 2.486 of 02 of February of 1998 (Brasil, 1998).

The third Brazil-nut population is inserted in FAZENDA (Fig. 1-C), which characterize as a strong anthropogenic influence area and presence of Open Ombrophile Forest and Dense Ombrophile Forest remnants. The Brazil-nut trees which fruits were used in this study belong to the Open Ombrophile Forest biome.

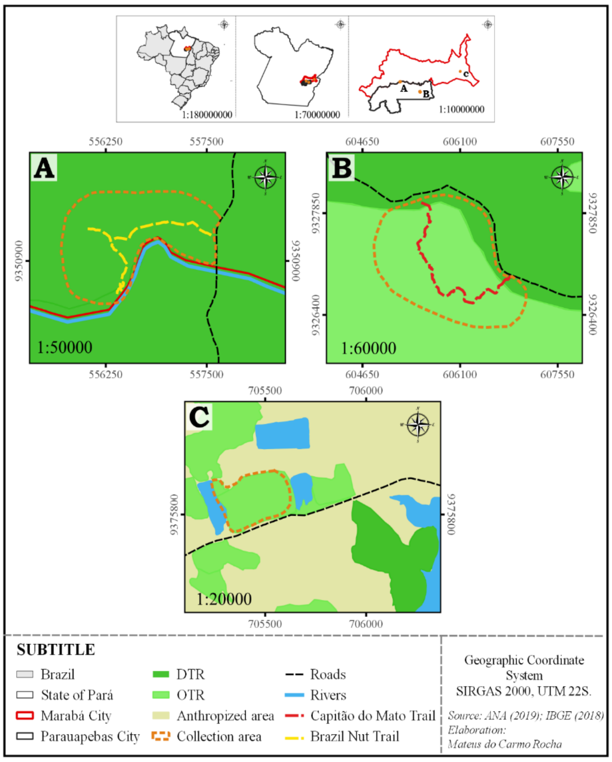

Figure 1 – Location of Bertholletia excela fruits collection areas: A) Tapirapé-Aquiri National Forest (FLONATA); B) Carajás National Forest (FLONACA); C) Sousa Farm (FAZENDA).

Subtitle: DTR: Dense Tropical Rainforest; OTR: Open Tropical Rainforest.

Serra dos Carajás stands out in the predominantly lowland landscape in southeast of Pará. The Serra is almost entirely in Carajás National Forest, that along with the other protected areas compound the "Mosaico Carajás", with around 1.207.000 hectares (Silva, 2006; Viana *et al*., 2016). They are: Igarapé Gelado Environmental Protection Area, Tapirapé Biological Reservation, National Forest of Itacaiúnas, National Forest of Tapirapé-Aquiri and National Forest of Carajás and the Indigenous Land of Xikrin do Cateté (STCP, 2016) *e* o Ferruginous Fields National Park (Brasil, 2017). The mosaic has great importance to the biodiversity conservation, ecological process and ecosystems services, considering the intense environmental degradation of the region which its insert (ICMBio, 2017).

According to the FLONATA Multiple Use Management Plan (ICMBio, 2006), it is located in the southeast portion of Pará state, covering a 190.000 ha area, between the geographic coordinates of 5°35' and 6°00' of south latitude and 50°24' and 51°06' of west longitude. The weather of Tapirapé-Aquiri National Forest region, according to Köppen classification, can by fitted in the "Awi" type – rainy tropical with dry in winter season (Rolim *et al.,* 2006). The pedological typologies that predominates are the following classes of soils and its associations: Red-Yellow Argisol with clayey texture; Dystrophic Red-Yellow Latosol with medium texture, associated with Lateritics Concretions and Dystrophic Neosoils with Rocky Outcrops (ICMBio, 2006).

The FLONATA is located in amazon biome and shows Open Ombrophile Forest and Dense Ombrophile Forest and in the flattened tops of the mountain range there is a presence of glades with a savanna vegetation, in herbaceous-shrubby form, known as ferruginous *rupestrian* field, canga or ferruginous outcrop (Ab'Saber, 1986; Nunes, 2009; Campos & Castilho, 2012; Mota *et al.,* 2015; Schaefer *et al.,* 2016).

Biometric analysis of fruits

In total, 60 fruits and 899 seeds were measured, representing as 3 groups studied (FLONATA, FLONACA and FAZENDA Sousa). It was collected in the months of December 2019 and January 2020 after the natural fall. These fruits are reminiscent of traditional extractivism and the indigenous population.

The fruits and seeds biometrics were made with assistance of an analytical balance (Marte AD3300) with a precision of 0,0001g and a digital pachymeter (Eda 7VT 8") with a 0,01mm precision. The measured variables were: number of seeds per fruit (NS); fruit weight (FW), obtained from the fruit with seed; fruit length (FL) from the distance of the base to the apex; fruit width (FWi) by the transverse diameter; operculum diameter (OD), measured by the size of that opening; seed weight (SW); seed length (SL) established from the base to apex; seed width (Swi) and seed thickness (ST). The Swi and ST were measured in the seed midline, being width of distal side and thickness of proximal side.

Statistics

Biometric variables were evaluated by variance analysis (ANOVA). For the biometrics statistical analysis, the areas were considered as treatments and each fruit was considered as a sampling unit. To verify the assumptions of variance analysis (ANOVA), the data were firstly tested for: a) normality with Shapiro-Wilk test ($p >$ 0.05); and b) and homoscedasticity by the Bartlett test ($p >$ 0.05). Once attended these assumptions the data were submitted to variance analysis by R program 4.0.4 version and, having significant differences between the data, the averages were compared by Tukey test ($p <$0.05).

Relations between the morphometrics variables with the different collection area were analyzed by principal component analysis (PCA). To perform this analysis, were identified and removed the variables that showed high correlation, to avoid multicollinearity problems in the matrix of the correlation used to execute the analysis. Through the main components scores was possible to cluster the treatments (areas) with biometrics variables that most contributed in each treatment.

Results

The Fig. 2 (A-I) shows up that the parameter number of seed per fruit (Fig. 2-A), fruits weight (Fig. 2-B), fruit length (Fig. 2-C), fruit width (Fig. 2-D), fruit weight (Fig. 2-F), length seed (Fig. 2-G) and seed thickness (2-I) of the FLONACA and FAZENDA areas (highlighted by letter a) are statistically similar and differ from FLONATA area (highlighted by letter b). The fruit length parameter (Fig. 2-A), operculum diameter (Fig. 2-E) and seed width (Fig. 2-H) were statistically similar for the three areas.

FLONATA showed higher average values for every analyzed phenotypic variable, except the number of seeds per fruits variable (Fig. 2-A) and operculum diameter.

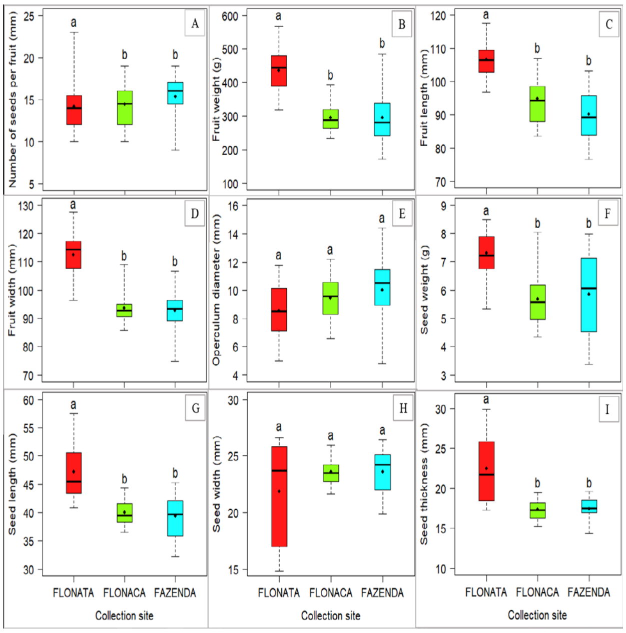

Figure 2 – Boxplot showing the averages to different morphometric variables of fruits and seeds of *Bertholletia excelsa* in different collection areas: Tapirapé-Aquiri National Forest (FLONATA), Carajás National Forest (FLONACA) and Sousa Farm (FAZENDA).

Main components analysis (Fig. 3) revealed that two of first main component explain 100% (93.8% = PC1 and 6.2% = PC2) of variability of morphometric data to *Bertholletia excelsa* fruits and seeds. It highlights the formation of three groups corresponding FAZENDA, FLONACA and FLONATA. In the first main component (PC1), the morphometric variables seed weight (SW), fruit weight (FW), seed thickness (ST), fruit width (FWi) e seed length (SL) of fruits and seeds of *Bertholletia excelsa* are positively associates with FLONATA and with the fruit length (FL) parameter in the second main component (CP2). The variables number of seeds (NS) and operculum diameter (OD) are associated to FAZENDA while seed width (SWi) is associated to FLONACA in the second main component.

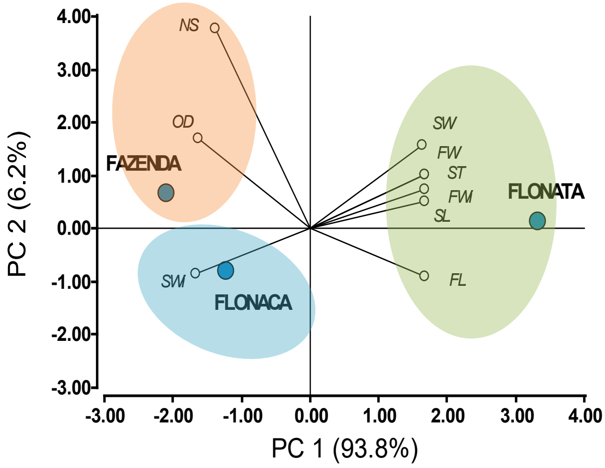

Figure 3 – Main component analysis (PCA) of morphometric variables of fruits and seeds *Bertholletia excelsa* in different collection areas.

Subtitle: NS:number of seeds; FW: fruit weight; FL: fruit length; FWi: fruit width; OD: operculum diameter; SW: seed weight; SL: seed length; SWi: seed width; ST: seed thickness.

The Fig. 4 (A-H) represent the frequency of seeds for biometric parameter representing each population by class. SW variable (Fig. 4-A) highlight that in FLONATA, from total of 282 measured seeds, 84.04% concentrated in the classes of 5-6 to 7.5 and to 7.6 to 9.5 mm; to FLONACA, from the total of 289 seeds, 85.12% concentrated in the classes of 3.6 to 5.5 and 5.6 to 7.5 mm; and to FAZENDA, from the total of 306 seeds, 76.14% are concentrated in the classes of 3.6 to 5.5 and 5.6 to 7.5 mm. For the ST parameter (Fig. 4-B), 76.60% are concentrated in the class of 34 to 53.9 mm in FLONATA; 88.24% are concentrated in the class of 34 to 43.9 mm in FLONACA; and 65.36% are concentrated in the class of 34 to 43.9 mm in FAZENDA.

The Fig. 4-C highlights the frequency of seeds by class related to SWi parameter. To FLONATA, was 86.88% representative of the 15 to 29.9 mm classes; to FLONACA, was 72.32% of the 20 to 24.9 mm classes; and to FAZENDA, was 92.81% of the 20 to 29,9 mm classes. And Fig. 4-D represents the ST variable by class and to the three areas, there were concentrations of the class comprised of 15 to 19.9 mm, with 36.89% to FLONATA, 88.24% to FLONACA and 72.88% to FAZENDA.

The Fig. 4-E relates the SW variable to biometric frequency (Fig 4-A), by class, to the three areas. To FLONATA, 55% of fruits showed mass comprised between the 370 to 469.9 g; to FLONACA and FAZENDA, the higher frequency is concentrated in the 270 to 469.9 g class, with 60 to 45 %, respectively. To the ST parameter (Fig. 4-E), FLONATA showed higher frequency in the 105 to 114.9 mm class, with 55% and the FLONACA and FAZENDA areas the higher frequency concentrated in the 85 to 94.9 mm class, both with 45%. To the FL parameter (Fig. 4-F), the higher frequency was 35% to the 105 to 114.9 mm class and of 35% to the 115 a 124.9% class (both classes corresponded to 70% of the total) to FLONATA; and of 50% to 75% for FLONACA and FAZENDA, both concentrated in the 85 to 94.9 mm class.

As for the FWi parameter (Fig. 4-G), the higher frequency classes were of 105 to 114.9 and 125 to 134.9 mm, with a concentration of 35% each (totalizing 70%) to FLONATA; in the classes of 7.5 to 84.9 mm, with representativeness of 75% to FLONACA; and in the 85 to 94.9 mm class (50%) to FAZENDA. And to the OD variable (Fig. 4-H), the frequency is concentrated in the 6.5 to 8,4 mm and 8.5 to 10.4 mm, both with 35% each, to FLONATA; 40% of the representative frequency of the 8.5 to 10.4 mm class to FLONACA and 45% in the class of 10.5 to 112.4 mm to FAZENDA.

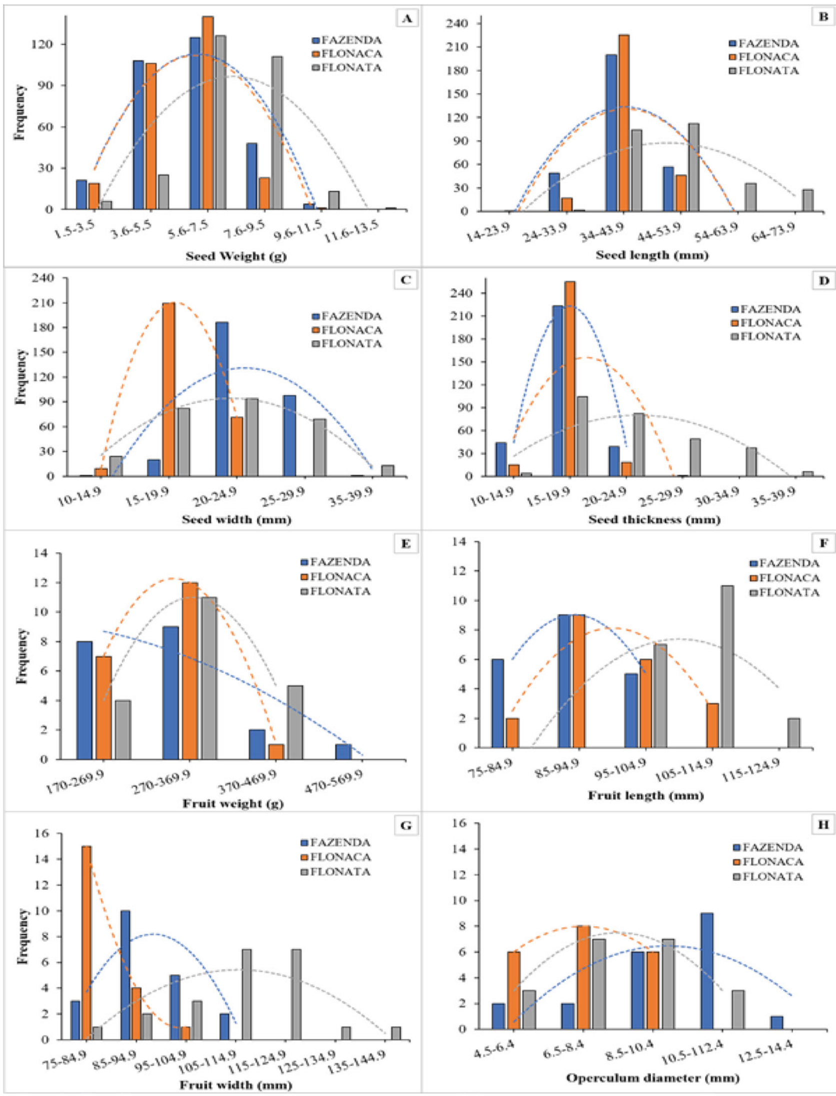

Figure 4 – Figure 4 – Frequency related to (A) seed weight (SW), (B) seed thickness (ST), (C) seed width (SWi), (D) seed thickness (ST), (E) fruit weight (FW), (F) fruit lenght (FL), (G) fruit weight (FWi), (H) operculum diameter (OD) of *Bertholletia excelsa* fruits and seed from Tapirapé-Aquiri National Forest (FLONATA), Carajás National Forest (FLONACA) and Sousa Farm (FAZENDA)

Discussion

The *Bertholletia excelsa* seed dispersion, according to Haugaasen *et al.* (2010), is relatively restricted to a few tens of meters, from the fruits that falls near to the mother-plant and also to the spreading promoted by the animals. Some researches, in face of strategy observations of inefficient discontinuous distribution of *B. excelsa* in Amazon, proposed the hypothesis that its origins are anthropogenic. Scoles & Gribel (2011) and Shepard Jr. & Ramirez (2011) defend this hypothesis based on the fact that the natural remaining Brazil-nut trees of Amazon forest showed the occurrence of mature individuals (large and great diameter) and almost no young individuals (Guedes *et al*., 2014).

Archeological evidences suggest that the species has been used by humans at least 11.000 years ago (Clement *et al.*, 2015) and that its modern distribution is closely connected to the standard of pre-colombian human settlement and reflected demography by Amazonian Darck Earth (or archeological black earth) and geoglyphs (Roosevelt *et al.*, 1996; Thomas *et al.*, 2015 & Andrade *et al.* 2019).

Brazil-nut tree is considered a long-term pioneer species (Mori & Prance, 1990; Scoles & Gribel Rogerio, 2014; Caetano Andrade *et al.,* 2019), which life cycle can be attached to events of natural disturbance as glades, dry and/ or extreme flooding and fires (Baker *et al.,* 2006; Vlam *et al.*, 2017; Caetano Andrade *et al.*, 2019). Its canopy survival and rise depend on favorable light conditions, according to Scoles & Gribel Rogerio (2014), Schöngart *et al.* (2015) & Caetano Andrade *et al.,* (2019).

Founded in clusters more or less extensive, known as castanhais, with fifty to 100 individuals, distanced around 1 Km (Prance & Mori, 1979), its always associated to others larges forest species (Salomão, 2009). The native Brazil-nut tree has been wiped out as consequence of deforestation and its economic production has decreased due to the forest fragments do not supports their ecological conditions to pollination and dispersion (Costa *et al.*, 2009). Besides being a law-protected species in Brazil (Federal Decree n° 5.975 of 30 of November of 2006) (Brasil, 2006), still classified as vulnerable, according to the red list of endangered species (IUCN, 2020).

The genetic distribution study inside and between populations and the comprehension of how this variability is structured in the space are important to define genetic conservation strategies, sustainable management and species improvement (Kageyama *et al.*, 2003; Rossi *et al.*, 2009; Rivas *et al.*, 2013; Vieira *et al.*, 2019; Baldoni *et al.,* 2020). Buckley *et al*. (1988) estimated the genetic variation inside and between two populations of Pará-nut located in the states of Acre and Amazonas, through enzymatic markers. Based on their study, evidenced that much of the genetic diversity of this species can be preserved inside one or a few populations. With these assumptions, the extinction endanger of Brazil-nut is even more evident, despite its law prohibition of cutting.

The distribution pattern clustered or scattered of Brazil-nut trees can be resultant of the forest typology of the natural occurrence areas of Brazil-nut trees (Wadt & Kainer, 2009). According to what can be observed in the Fig. 2 (A-I), the fruits from FLONACA and FAZENDA has a phenotypical resemblance for every analyzed morphometric variable. Both areas show the same predominant forest typology, the Open Ombrophile Forest (FOA) and, therefore the Brazil-nut tree is subject to similar edaphoclimatic conditions (as an example, less light competition) and, therefore the development patterns are also similar.

The Brazil-nut population of FLONATA is under influence of Dense Ombrophile Forest (FOD) biome and showed the greater average values to most of phenotypic variation. The morphometric parameters founded in FLONATA differed statistically of FLONACA and FAZENDA to mostly of the analyzed parameters, except the OP (Fig. 2-E) and SWi (Fig. 2-H). These results corroborate with the fact that environmental conditions directly influence in the genetic interactions of a species with the environment, where the biometric variations in the same population are related to endogenous and exogenous factors (Rodrigues et al., 2006; Smith & Kruglyak, 2008; Souza *et al.,* 2013; Bezerra *et al.,* 2014; Li & Zhang, 2018; Ahmed I *et al.*, 2020; Lundgren & Marais, 2020; Vaidya & Stinchcombe, 2020; Véron *et al.,* 2020; Zan & Carlborg, 2020).

FLONATA fruits showed the greater weigh average of seeds per fruit, followed by FLONACA and FAZENDA. According to Müller *et al.* (1995), the seeds bigger and heavier showed more important for commercialization, as well as to seedlings production. Similar result founded in the fruit related variables were presented by Rocha *et al.* (2016) in his study in natural occurrence area of edges within forest fragments in the state of Mato Grosso and by Kaminsk *et al.* (2008) when analyzing permanent plots through Kamukaia project in Roraima, Brazil, in native forest area of São João da Baliza city.

About the number of seeds per fruit parameter, FLONATA showed 10 to 23 seeds; FLONACA, of 10 to 19; and FAZENDA, of 9 to 19. The founded results agrees with Moritz (1984), who stated that the Brazil-nut tree fruits shows, on average, 10 to 25 seeds per fruit and Cornejo (2004), which registered an average of 18,5 seeds per fruit, with maximum of 36 and minimum of 6 seeds por fruit, in his biometry studies of Brazil-nut fruits and seeds, fruits with 10 to 25 seeds were founded.

For the seeds measured phenotypic variables, the study results of Aguiar (2018) were similar to the FLONATA matrix, obtained 47,2 mm of length, 28,7 mm of width, 21,2 of thickness. Mori & Prace (1990) and Wadt & Kainer (2009) founded 80 to 150 mm of width values. This population stands out for having the greater averages biometrics and its distinguished of FLONACA and FAZENDA, that showed similar characteristics of results. This fact is related to the habitat and edaphoclimatic conditions where this species is inserted.

Conclusion

The phenotypic variations evaluated by the Tukey test demonstrated that FLONATA differs significantly from the other two areas, FLONACA AND FAZENDA, and that these do not differ significantly from each other. This fact is corroborated by the fact that the populations of FLONACA and FAZENDA, despite being spatially distant, are under the influence of the same forest phytophysiognomy, and, therefore, are subject to similar edaphoclimatic conditions. While the representative population of FLONATA, which stood out for presenting higher average measurements for most phenotypic variables, is inserted in a distinct environment.

These answers show that exogenous factors involving the edaphoclimatic parameters had a greater influence on the phenotypic variations present in this study, because the determining factor was the fact that FLONACA and FAZENDA present themselves in an environment with the Open Ombrophilous Forest as opposed to FLONATA which is found in the Dense Ombrophilous Forest. Thus, it demonstrates the importance of exogenous factors (external factors) as a complement to endogenous (internal) factors.

References

Ab'Saber NA. Geomorfologia da região, p. 88-124. In: J. M.G. ALMEIDA JR. (org.): Carajás: desafio político, ecologia e desenvolvimento. CNPq/Brasiliense, São Paulo/Brasília, 1986.

Aguiar ALS, Da Silva KE, Alves TCV. 2018. Biometria de sementes de Bertholletia excelsa Bonpl. em duas agroindústrias localizadas no estado do Amazonas, p. 65-66. In: BELTRAN-Pedreros S, Godinho Jones (org.). Anais do III Congresso Amazônico de Iniciação Científica. Rios da Amazônia, Caminhos de Saber e de Cultura: Faculdade La Salle MANAUS. 68p.

Ahmed I, Reshi QM, Fazio F. The influence of the endogenous and exogenous factors on hematological parameters in different fish species: a review. Aquacult Int, 28: 869-899. 2020.

Albuquerque TCS, Evangelista TC, De Albuquerque Neto AAR. Níveis de sombreamento no crescimento de mudas de castanheira do Brasil. Revista Agro@mbiente On-line, 9(4): 440-445, 2015.

Allegretti MH. 1994. Reservas Extrativistas: Parâmetros para uma Política de Desenvolvimento Sustentavel na Amazônia. O Destino da Floresta: Reservas Extrativistas e o Desenvolvimento Sustentável na Amazônia. R. Arnt. Rio de Janeiro, Relume Dumará, p. 17-47.

Baker PJ, Bunyavejchewin S, Oliver CD, Ashton PS. História de perturbação e dinâmica de povoamento histórico de uma floresta tropical sazonal no oeste da Tailândia. Ecol Monogr. 75(3): 317-43, 2005.

Balbi ME, Penteado PTPS, Cardoso G, Sobral MG, Souza CR. Brazil nut (Bertholletia excelsa Bonpl.): chemical composition and its health benefits. Visão Acadêmica, 15(2): 51-63, 2014.

Baldoni AB et al. Genetic diversity of Brazil nut tree (Bertholletia excelsa Bonpl.) in southern Brazilian Amazon. Forest Ecology and Management, 458: 117795, 2020.

Batista APB et al. Spatial association of fruit yield of Bertholletia excelsa Bonpl. trees in eastern Amazon. Forest Ecology and Management, 441: 99-105, 2019.

Bezerra FTC, De Andrade LA, Bezerra MAF, Da Silva MLM, Nunes RCR, Da Costa EG. Biometria de frutos e sementes e tratamentos pré-germinativos em Cassia fistula L. (Fabaceae-Caesalpinioideae). Ciências agrarias, 35(4): 2273-2286, 2014.

Braga ETM, Wadt LHO, Martins K. 2009. Morfologia de frutos e análise de produção de castanha-do-brasil Bertholletia excelsa HBK na Reserva Extrativista Chico Mendes-Acre, p. 109-113. In: Duchelle AE, Passos VTR, Melchior LA, Silva, GM (eds). Anais do VII Seminário Anual de Cooperação UFAC/UF. 250p.

Brasil, 1989. Decreto nº 97.720 de 5 de maio de 1989. Diário Oficial da União. Disponível em:https://legislacao.presidencia.gov.br/atos/?tipo=DEC&numero=97720&ano=1989&ato=c17oXTE9EeFpWT8ea. Acesso em: 13/11/2020.

Brasil, 1998. Decreto nº 2.486 de 2 de fevereiro de 1998. Diário Oficial da União. Disponível em: http://www.planalto.gov.br/ccivil_03/decreto/D2486.htm. Acesso em: 13/11/2020.

Brasil, 2006. Decreto nº 5.975 de 30 de novembro de 2006. Diário Oficial da União. Disponível em: http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/decreto/d5975.htm. Acesso em: 12/11/2020.

Brasil, 2017. Decreto s/nº de 5 de junho de 2017. Diário Oficial da União. Disponível em: <http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/dsn/Dsn14470.htm#:~:text=DECRETO%20DE%205%20DE%20JUNHO,e%20Parauapebas%2C%20Estado%20do%20Par%C3%A1>. Acesso em: 13/11/2020.

Baker PJ, Bunyavejchewin S, Oliver CD, Ashton PS. Disturbance history and historical stand dynamics of a seasonal tropical forest in western Thailand. Ecol Monogr.75(3):317-343, 2005.

Buckley DP, O'malley DM, Apsit V, Prance GT, Bawa KS. Genetics of Brazil nut (Bertholletia excelsa Humb. & Bonpl.: Lecythidaceae). Theoret. Appl. Genet. 76(6): 923-928, 1988.

Caetano Andrade VL, Flores BM, Levis C, Clement CR, Roberts P, Schöngart J. Growth rings of Brazil nut trees (*Bertholletia excelsa*) as a living record of historical human disturbance in Central Amazonia. Plos One, 14(4): 1-23, 2019.

Camargo, FF et al. Variabilidade genética para caracteres morfométricos de matrizes de castanha-do-brasil da Amazônia Mato-grossense. Acta Amazônica, 40(4):705-710, 2010.

Campos JC, Castilho AF. 2012. Uma visão geográfica da região da Flona de Carajás, p. 30-61. In: Martins FD, Castilho AF, Campos J, Hatano FM, Rolim SG (org.). Fauna da Floresta Nacional de Carajás. São Paulo: Nitro Editorial. 233p.

Cardoso BR et al. Brazil nuts: Nutritional composition, health benefits and safety aspects. Food ResearchIinternational, 100(2): 9-18, 2017.

Chalita PB et al. Characterization of bacterial endophytes from the roots of native and cultivated Brazil nut trees (Bertholletia excelsa). Acta Amazonica, 49(4): 257-267, 2019.

Clement CR et al. The domestication of Amazonia before European conquest. Proceedings of the Royal Society B: Biological Sciences, 282(20151813): 1-9, 2015.

Clay JW. 1997. Implications for Biodiversity and Conservation. In: C. H. FREESE (ed.): Harvesting Wild Species: Ed. John Hopkins University Press, Baltimore and London. p. 246-282.

Cornejo E. 2004. Historia natural de Ia castaüa (Bertholletia excelsa Humb & Bonpl.) y propuetas para su manejo. Asociación para Ia Conservación de Ia Cuenca Amazônica (ACCA). Madre de Dios, Peru. 52p.

Costa AKF, Freire FCO, Vieira IGP, Alves JÁ, Mendes FNP. Fungos associados à castanha-do-Brasil (Bertholletia excelsa Humb, & Bompl) e ao amendoim (Arachis hypogaea L.) comercializados em Fortaleza (Ceará). Revista Ciência Agronômica, 40(3): 455-460, 2009.

Da Silva ASO, Paraense VC. Production chain for brazil-nuts (Bertholletia excelsa Bonpl.) at Ipaú-Anilzinho extractive reserve, municipality of Baião, Pará, Amazonian Brazil. Revista Agro@ mbiente On-line, 13: 68-80, 2019.

Da Silva TP et al. Cadeias de produção sustentáveis no extrativismo de castanha do Brasil na Amazônia brasileira. Brazilian Journal of Development, 6(8): 63460-63478, 2020.

De Brito RCM, Pereira Junior JB; Dantas, KGF. Quantification of inorganic constituents in Brazil nuts and their products by inductively coupled plasma optical emission spectrometry. LWT - Food Science and Technology, 116: 108383, 2019.

Dos Santos M G. 2011. Morfometria de frutos e sementes, desenvolvimento pós seminal e germinação de Theobroma subincanum Martius in Buchner (Malvaceae). Dissertação (Mestrado em Ciências Ambientais). Universidade do Estado de Mato Grosso. 57p.

Duchelle AE, Cronkleton P, Kainer KA, Guanacoma G, Gezan ES. Resource theft in tropical forest communities: implications for non-timber management, livelihoods, and conservation. Ecology and Society, 16(1): 1708-3087, 2011.

Ferreira SAL, Carniello MA. Saberes e práticas dos castanheiros envolvidos com a coleta de castanha (Bertholletia excelsa Bonpl.) no município de Itaúba, Mato Grosso, Brasil. Gaia Scientia, 12(3): 129-144, 2018.

Formigoni I. A exportação de castanha do Pará. Disponível em <http://www.farmnews.com.br/dados/exportacao-de-castanha-do-para/>: Acesso em: 02/04/2021.

Guedes MC et al. 'Castanha na roça': expansão da produção e renovação dos castanhais em áreas de agricultura itinerante no Amapá, Brasil. Boletim do Museu Paraense Emílio Goeldi: Ciências Naturais, 9(2): 381-398, 2014.

Hagaausen JTH, Hagaausen T, Peres CA, Gribel R, Wegge P. Seed dispersal of the Brazil nut tree (Bertholletia excelsa) by scatter-hoarding rodents in a central Amazonian forest. Journal of Tropical Ecology, 26: 251–262, 2010.

Huguenin GVB, Oliveira GMM, Moreira ASB, Saint'Pierre TD, Gonçalves RA, Pinheiro-Mulder AR et al. Improvement of antioxidante status after Brazil nut intake in hypertensive and dylidemic subjects. Nutrition Journal 2015; 14(54): 1-10.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE - ICMBIO. Plano de Manejo para Uso Múltiplo da Floresta Nacional do Tapirapé-Aquiri: Capítulo 1 – Aspectos Gerais. 2006. Disponível em: https://www.icmbio.gov.br/portal/images/stories/imgs-unidades-coservacao/flona_tapirape-aquiri.pdf. Acesso em: 11 de dez. 2020.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE – ICMBIO. Plano de Manejo: Floresta Nacional de Carajás – Diagnóstico. 2006. Disponível em: <https://www.icmbio.gov.br/portal/images/stories/biodiversidade/UC-RPPN/DCOM_ICMBio_plano_de_manejo_Flona_Carajas_volume_I.pdf>. Acesso em: 11 de dez. 2020.

INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE – ICMBIO. Plano de Pesquisa Geossistemas Ferruginosos da Floresta Nacional de Carajás. 2017. Disponível em: <https://www.icmbio.gov.br/portal/images/stories/plano_de_pesquisa_flona_carajas_-_06-09-2017_-_final_2.pdf>. Acesso em: 12/11/2020.

IUCN (2020). The IUCN Red List of Threatened Species. Version 2017-3. Available at <https://www.iucnredlist.org/species/32986/9741363>. Acesso em 12/11/2020.

Kageyama PY, Sebbenn AM, Ribas LA, Gandara FB, et al. (2003). Diversidade genética em espécies tropicais de diferentes estágios sucessionais por marcadores genéticos. Sci. For. 64: 93-107, 2003.

Kaminsk PE, Tonini H, Mourão Júnior M, Schwengber. 2008. Biometria de frutos de castanha-do-brasil (Bertholletia excelsa Bonpl.) em Roraima, p. 45-51. In: Anais do I Seminário do projeto Kamukaia: Manejo Sustentável de produtos florestais não madeireiros na Amazônia, 2008. 182p.

Kluczkovski AM, Martins M, Mundim SM, Simões RH, Nascimento KS, Marinho HA et al. Properties of Brazil nuts: a review. African Journal of Biotechnology, 2015; 14(8): 642-648.

Li C, Zhang J. Multi-environment fitness landscapes of a tRNA gene. Nature Ecology & Evolution, 2: 1025-1032. 2018.

Lundgren MR, Des Marais DL. Life History Variation as a Model for Understanding Trade-Offs in Plant–Environment Interactions. Current Biology, 30(4): 180-189, 2020.

Maués MM, Krug C, Wadt TH, Drumond PM, Cavalcante MP, Santos ACS. 2015. A castanheira-do-brasil: avanços no conhecimento das práticas amigáveis à polinização. Embrapa Amazônia Oriental-Livro científico (ALICE). 84p.

Martens IBG et al. Selenium status in preschool children receiving a Brazil nut–enriched diet. Nutrition, 31(11-12): 1339-1343, 2015.

Moritz, A. 1984. Estudos Biológicos da Floração da castanha-do-brasil (Bertholletia excelsa Humb. And Bonpl.; Lecythidaceae). EMBRAPACPATU. 82p.

Mori AS, Prance GT. Taxonomy, ecology and economic botany of the Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.: Lecythidaceae). *Advances in Economic Botany,* 8: 130-150, 1990.

Mota NFO, Silva LVC, Martins FD, Viana, PL. Vegetação sobre Sistemas Ferruginosos da Serra dos Carajás. Geossistemas Ferruginosos no Brasil. Instituto Prístino, Belo Horizonte. P. 289-315, 2015.

Müller CH, Figueiredo FJC, Carvalho JEU. Características comparativas entre frutos e sementes de castanha-do-brasil. Belém: Embrapa CPATU, 1995, 21p.

Neves ES, Wadt LHO, Guedes MC. Estrutura populacional e potencial para o manejo de Bertholletia excelsa (Bonpl.) em castanhais nativos do Acre e Amapá. Scientia Forestalis, 44(109): 19-31, 2016

Nogueira RM, Álvares VS, Ruffato S, Lopes RP, Silva JSE. Physical properties of Brazil nuts. Engenharia Agrícola, 34(5): 963-971, 2014.

Nunes JA. 2009. Florística estrutura e relações Solo-Vegetação em gradiente fitofisionômico sobre canga, na Serra Sul, FLONA de Carajás-Pará. Dissertação (Mestrado em Botânica) – Universidade federal de Viçosa, Belo Horizonte. 112p.

Oliveira GS et al. Exportações brasileiras de castanha-do-Pará (Bertholletia excelsa, H.B.K), sob a ótica de concentração de mercado. BIOFIX Scientific Journal, 5(1): 07-12, 2020.

Peres CA et al. Demographic threats to the sustainability of Brazil-nut exploitation. Science. 302: 12-14, 2003.

Peters CM. 1994. Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer: Biodiversity Support Program, Washington. P. 1-45.

Prance GT, Mori SA. Lecythidaceae. Flora Neotropica 21(1): 1-270, 1979.

Rivas LH, Giustina LD, Luz LN, Karsburg IV, Pereira TNS, Rossi AAB. Genetic diversity in natural populations of Theobroma subincanum Mart. in the Brazilian Amazon. Genet. Mol. Res, 12: 4998-5006, 2013.

Rocha VD, Lima JS, Bispo, RB, Cochev JS, Rossi AAB. Caracterização biométrica de frutos e sementes de castanha-do-Brasil na Amazônia Mato-Grossense. Enciclopédia biosfera, 13(24):196-195, 2016.

Rodrigues, ACC, Osuna JTA, Queiroz, SROD, Rios APS. Biometria de frutos e sementes e grau de umidade de sementes de angico (Anadenanthera colubrina (vell.) Brenan var. cebil (Griseb.) Altschul) procedentes de duas áreas distintas. Revista Científica Eletrônica de Engenharia Ambiental, 4(8): 2-8, 2006.

Roosevelt AC, Lima da Costa M, Lopes Machado C, Michab M, Mercier N, Valladas H, et al. Paleoindian cave dwellers in the Amazon: the peopling of the Americas. Science, 272(5260): 373-84, 1996.

Rossi AAB, Oliveira LO, Venturini BA, Silva RS. Genetic diversity and geographic differentiation of disjunct Atlantic and Amazonian populations of Psychotria ipecacuanha (Rubiaceae). Genetics. 136: 57-67, 2009.

Rolim SG, Couto HTZ, Jesus RM, França JT. Modelos volumétricos para a Floresta Nacional do Tapirapé-Aquirí, Serra dos Carajás (PA). Acta Amazônica, 36(1): 107-114, 2006.

Salomão RP. Densidade, estrutura e distribuição espacial de castanheira-do-brasil (Bertholletia excelsa H. & B.) em dois platôs de floresta ombrófila densa na Amazônia setentrional brasileira. Bol. Mus. Para. Emilio Goeldi Cienc. Nat., 4(1): 11-25, 2009.

Salomão RP. Castanheira: história natural e importância socioeconômica. Boletim do Museu Paraense Emílio Goeldi, 9(2): 259-266, 2014.

Salomão RP, Rosa NA, Castilho AF, Morais KAC. Castanheira-do-brasil recuperando áreas degradadas e provendo alimento e renda para as comunidades da Amazônia setentrional. Boletim do Museu Paraense Emílio Goeldi. Ciências Naturais 2(1): 65-78, 2006.

Salomão, RP, Brienza Júnior S, Rosa NA. Dinâmica de reflorestamento em áreas de restauração após mineração em unidade de conservação na Amazônia. Revista Árvore, 38(1): 1-24, 2014.

Schaefer CEGR et al. The Physical Environment of Rupestrian Grasslands (Campos Rupestres) in Brazil: Geological, Geomorphological and Pedological Characteristics, and Interplays, p. 15-33. In: FERNANDES, G.W. (Ed.). Ecology and Conservation of Mountaintop Grasslands in Brazil. Switzerland: Springer International Publishing. 2016.

Schöngart J, Gribel R, Fonseca SF Jr., Haugaasen T. Age and growth patterns of Brazil Nut trees (*Bertholletia excelsa* Bonpl.) in Amazonia, Brazil. Biotropica, 47 (5): 550-8, 2015.

Scoles, R, Gribel, R, Klein GN. Crescimento e sobrevivência de castanheira (Bertholletia excelsa Bonpl.) em diferentes condições ambientais na região do rio Trombetas, Oriximiná, Pará. Boletim do Museu Paraense Emílio Goeldi: Ciências Naturais, 6(3): 273-293, 2011.Shepard Júnior GH, Ramirez H. HYPERLINK “about:blank” \t “_blank” “Made in Brazil”: human dispersal of the Brazil Nut (*Bertholletia excels*, Lecythidaceae) in Ancient Amazonia. Economic Botany, 65(1): 44-65. 2011.

Silva BIA. 2019. Predação de mudas de castanheira em área sob restauração florestal na Amazônia. Dissertação (Mestrado em Ciências Biológicas/Botânica Tropical), Universidade Federal Rural da Amazônia/Museu Paraense Emílio Goeldi, Belém, 2019. 48p.

Silva, M.A. 2006. Arranjos político-institucionais: a criação de novos municípios, novas estruturas de poder e as lideranças locais - a divisão territorial de Marabá na década de 1980. Tese (Doutorado em Desenvolvimento Socioambiental). Universidade Federal do Pará. 188p.

Smith EN, Kruglyak L (2008) Gene-Environment Interaction in Yeast Gene Expression. PLOS Biology, 6 (4): e83. 2008.

Souza DCL et al. Produção de frutos e características morfofisiológicas de Schinus terebinthifolius Raddi., na região do baixo São Francisco, Brasil. Revista Árvore, 37(5): 923-932, 2013.

STCP. 2016. Plano de manejo da Floresta Nacional de Carajás. Vol. 1. Diagnóstico. Engenharia de Projetos Ltda., Curitiba. 190p.

Thomas E, Caicedo CA, McMichael CH, Corvera R, Loo J. Uncovering spatial patterns in the natural and human history of Brazil nut (*Bertholletia excelsa*) across the Amazon Basin. Journal of Biogeography, 42(8): 1367-1382, 2015.

Tonini H. Amostragem para a estimativa de produção de sementes de castanheiradobrasil em floresta nativa. Pesquisa Agropecuária Brasileira, 48(5): 519-527, 2013.

Vaidya P, Stinchcombe JR. The Potential for Genotype-by-EnvironmentInteractions to Maintain Genetic Variation in a Model Legume–Rhizobia Mutualism. Plant Communications 1(6): 100114. 2020.

Véron M et al. Major changes in sardine growth and body condition in the Bay of Biscay between 2003 and 2016: Temporal trends and drivers. Progress in Oceanography, 182: 102274. 2020.

Viana PL et al. Flora of the cangas of the Serra dos Carajás, Pará, Brazil: history, study area and methodology. Rodriguésia, 67(5 Especial): 1107-1124. 2016.

Vieira FS et al. Genetic diversity of Brazil-nut populations naturally occurring in the municipality of Alta Floresta, MT, Brazil. Genetics and Molecular Research, 18 (2): gmr18174. 2019.

Vlam M, Van der Sleen P, Groenendijk P, Zuidema PA. Tree Age Distributions Reveal Large-Scale Disturbance-Recovery Cycles in Three Tropical Forests. Frontiers in Plant Science. 2017; 7.

Wadt LHO, Kainer, KA. 2009. Domesticação e melhoramento da castanheira, 297-317p. In: Borém A, Lopes MTG, Clement CR (ed.). Domesticação e melhoramento: espécies amazônicas. Viçosa, MG: Universidade Federal de Viçosa, 2009. 317p.

Zan Y, Carlborg O. Dynamic genetic architecture of yeast response to environmental perturbation shed light on origin of cryptic genetic variation. PLOS Genetics, 16(5): e1008801. 2020.

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