

Original Article

Linking genetic variability to fruit and pyrene traits in *Endopleura uchi* genotypes from the Eastern Brazilian Amazon

Relacionando a variabilidade genética às características dos frutos e pirênios em genótipos de *Endopleura uchi* da Amazônia Oriental Brasileira

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Abstract

Endopleura uchi is a valuable tree species with significant nutraceutical potential and extensive applications. However, there is a lack of information regarding genetic parameters and the characterization of phenotypic variability that could be applied to the conservation and genetic improvement of this species. In this study, we estimated genetic parameters and quantified genetic variability based on the physical characteristics of fruits and pyrenes of *E. uchi* genotypes from a native population in the Eastern Brazilian Amazon. We collected 1,636 mature fruits from 13 genotypes and characterized them in terms of biometric measurements, volume, and fresh mass of both fruits and pyrenes. Additionally, we quantified the pulp yield from the fruit. Genetic analyses were conducted using the SELEGEN REML/BLUP software, model 81, and clustering analysis was performed using the unweighted pair group method with arithmetic mean (UPGMA). We also utilized a genotype selection index. We observed significant phenotypic variability within the population. Heritability coefficients ranged from 0.16 to 0.44 for the analyzed traits, with environmental variance exceeding genotypic variance. A strong negative correlation (-0.80) was found between pulp yield and fruit diameter. The results suggest the need for conservation and genetic improvement of the species. Additionally, we suggest the selection of key genotypes to boost the Amazonian bioeconomy, such as higher pulp yield, resulting in positive impacts on a regional or local scale, with greater income and social well-being.

Keywords: Amazonian fruits, genetic conservation, plant breeding, biometry, rank-sum index.

Resumo

Endopleura uchi é uma árvore com frutos de elevado valor nutracêutico, com amplo potencial de uso. No entanto, não há informações sobre parâmetros genéticos e caracterização da variabilidade fenotípica que possam ser aplicadas a conservação e ao melhoramento genético desta espécie. Aqui, estimamos os parâmetros genéticos e quantificamos a variabilidade genética baseado em características físicas dos frutos e pirênios de genótipos de *E. uchi* em uma população nativa da Amazônia Oriental brasileira. Coletamos 1636 frutos maduros de 13 genótipos, os quais foram caracterizados quanto a biometria, volume e massa fresca dos frutos e pirênios. Por último, quantificamos o rendimento de polpa dos frutos. O software Selegen REML/BLUP, modelo 81, foi utilizado para análises genéticas, e a análise de agrupamento foi realizada pelo método de grupos de pares não ponderados com média aritmética. Também foi utilizado um índice de seleção de genótipos. Observou-se que a espécie apresenta ampla variabilidade fenotípica dentro da população. Os coeficientes de herdabilidade variaram de 0,16 a 0,44 para as características analisadas, com a variância ambiental superior à genotípica. Constatou-se forte correlação negativa ($-0,80$) entre o rendimento de polpa e o diâmetro dos frutos. Os resultados sugerem a necessidade de conservação e melhoramento genético da espécie. Além disso, sugerimos a seleção de genótipos-chave para impulsionar a bioeconomia amazônica, como maior rendimento de polpa, resultando em impactos positivos em escala regional ou local, com maior obtenção de renda e bem-estar social.

Palavras-chave: frutas amazônicas, conservação genética, melhoramento de plantas, biometria, índice de soma de postos.

1. Introduction

Endopleura uchi (Huber) Cuatrec. (family Humiriaceae) is an endemic tree of the tropical forest biome, found in Bolivia, Venezuela, and Brazil (POWO, 2024). In Brazil, it is

confirmed to occur in the northern states (Acre, Amazonas, Amapá, Pará, Rondônia, and Tocantins), where it primarily inhabits Terra Firme Forest, characterized by dense, tall

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vegetation located on interfluvies, areas not subject to seasonal river flooding (Silva et al., 2024).

Wood of this species is generally used for civil and naval construction and is also a viable option for laminate manufacturing (Carvalho and Nascimento, 2022). The stem bark is utilized in the pharmaceutical industry because it contains bergenin, a glycosidic derivative of trihydroxybenzoic acid, along with phenolic acids and bioactive compounds that exhibit antimicrobial, anti-inflammatory, anticholesterol, antibacterial, antidiabetic, and antioxidant activities (Freitas et al., 2018; Oliveira et al., 2021; Lima et al., 2024).

E. uchi trees produce fruits with a distinctive flavor, adding economic value to traditional communities that use the fruits for both fresh consumption and pulp extraction. This pulp is employed in the production of cream, ice cream, and juice (Carvalho and Nascimento, 2022; Oliveira et al., 2021). The fruits hold nutraceutical importance, primarily due to their high fat content, which includes oils rich in unsaturated fatty acids, a substantial number of dietary fibers and phytosterols, tocopherols, carotenoids, aromas, and volatiles, in addition to being rich in vitamin C, vitamin E, and minerals (Pinto et al., 2023).

Despite its widespread use, the production chain of the species is not consolidated, as it relies on plant extraction by traditional communities (Shanley et al., 2012; Mabetana et al., 2024). This presents a serious issue, as the plant withdrawal of *E. uchi* genotypes from natural populations can lead to genetic erosion, resulting in the loss of plant material that could be used in plant breeding programs. In Brazil, there are few studies providing information for the pre-breeding of native species with timber or non-timber potential, despite the high biodiversity (Pereira et al., 2023).

Information that supports the pre-breeding stages is crucial for understanding the genetics of the species of interest and contributes to establishing a known genetic base for potential genetic gains in plant breeding programs and for conserving these species in their natural habitats (Leão et al., 2023; Santos et al., 2024). The scientific literature reveals a gap in studies on estimating parameters and genetic variability in *E. uchi*, hindering the selection of superior genotypes and the overall plant breeding process, as well as affecting the establishment of orchards of the species for fruit production purposes.

Estimating genetic parameters in conjunction with genetic variability based on fruit and seed size and mass in non-domesticated tree genotypes is a fundamental step in developing conservation and plant breeding strategies (Cola et al., 2024; Leão et al., 2023; Santos et al., 2024). These preliminary characterizations facilitate the selection of the most promising trees. Here, we tested the hypothesis that the genetic variability of *E. uchi* influences the physical traits of fruits and pyrenes, enabling the selection of genotypes for conservation and genetic improvement, with an emphasis on increasing pulp yield. Therefore, this study aimed to estimate genetic parameters and assess the genetic variability of *E. uchi* genotypes based on fruit and pyrene biometrics and fresh mass, contributing to the conservation and genetic improvement of the species in the Brazilian Amazon.

2. Material and Methods

2.1. Study area

The fruit collection was carried out in the Castanhil municipality, state of Pará, Brazil (1°19'11.6"S and 47°58'07.6"W), on a private property covering 14.35 hectares (Figure 1). The region's topography is slightly undulating, and the soils are classified as Yellow Latosols with low natural fertility (IUSS, 2015; Tenório et al., 1999). According to Köppen's climate classification, the region has an Af3 climate type, with an average annual rainfall ranging from 2,000 to 2,500 mm (Alvares et al., 2013). The wettest period extends from December to May, while the drier period spans from June to November (INMET, 2024). The original vegetation type is classified as Dense Ombrophilous Forest (IBGE, 2012), predominantly consisting of secondary forests that have been altered primarily by shifting agricultural cultivation.

2.2. Fruit collects

The fruits were collected from February to April 2023 from 13 genotypes (e.g., G01 to G013) from a natural population (Figure 1). This period coincided with the peak for fruit maturation and dispersal. The number of fruits collected varied between 13 and 211 among the genotypes due to the species' irregular and asynchronous production (Table 1). The fruits from each genotype were temporarily stored in boxes for transport to the Seed Laboratory (LASEM) at the Federal Rural University of Amazonia, Capitão Poço, PA, Brazil. Previously evaluation, all fruits were cleaned with 70% alcohol and paper towels to remove impurities that could affect the measurement of the variables.

2.3. Fruit and Pyrene biometrics

The length of the fruits and pyrenes (mm) was measured from the apex to the base, while the diameter (mm) was measured at the midline in two opposite directions relative to their longitudinal axis, respectively, using a digital caliper (Figure 2).

2.4. Fresh mass fruits and pyrenes

The fresh mass of fruits, pyrenes, and pulp was measured using an analytical balance with a precision of 0.001 g. During this stage, de-pulping was carried out manually with the aid of a knife. Subsequently, the pyrenes were washed with 1% sodium hypochlorite and air-dried for approximately 3 hours.

2.5. Volume of fruits pyrenes and pulp yield

The volume of fruits and pyrenes was measured by immersing each one individually in distilled water at room temperature. A 1000 mL graduated cylinder was used to determine the volume of water displaced, which was calculated by the difference in the water level before and after immersion. The pulp yield was subsequently calculated for each genotype (Equation 1).

$$PY(\%) = \frac{FMF - FMP}{FMF} * 100 \quad (1)$$

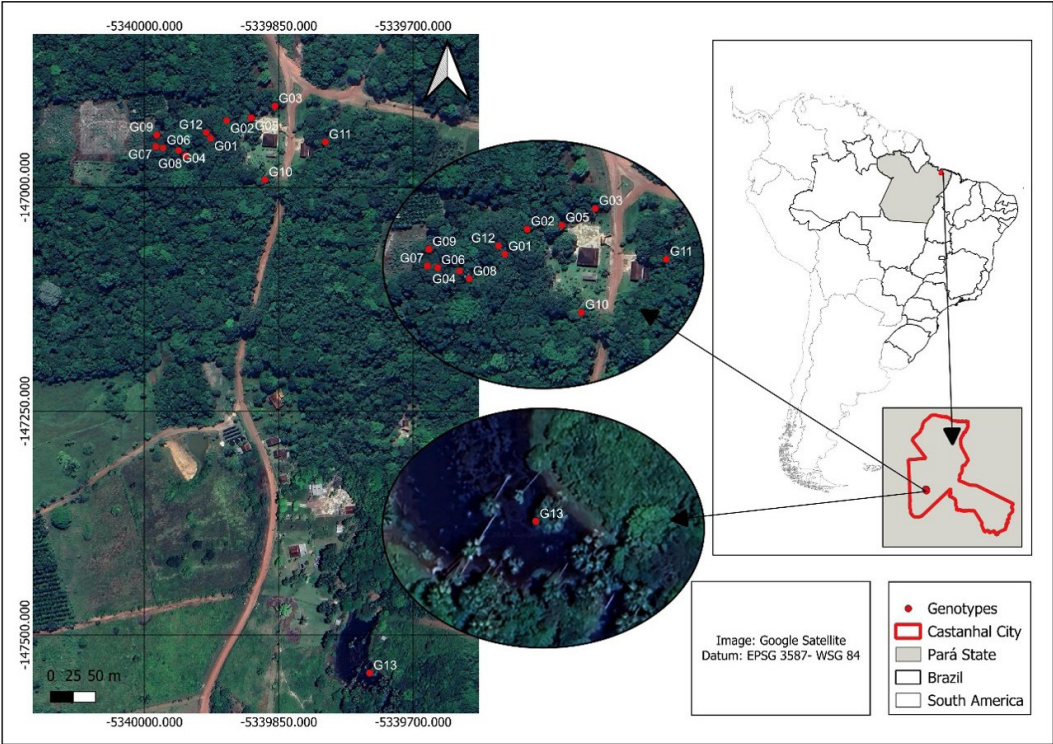


Figure 1. Location of *Endopleura uchi* (Huber) Cuatrec. genotypes from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Table 1. Dendrometric characteristics of 13 *Endopleura uchi* (Huber) Cuatrec. genotypes from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Genotypes	Height (m)	DBH (cm)	<i>n</i>
G01	25.3	11.59	64
G02	19.3	12.70	64
G03	13.9	7.99	208
G04	20.5	7.48	19
G05	17.3	11.94	210
G06	26.1	18.49	203
G07	29.5	24.80	161
G08	22.1	18.02	211
G09	15.1	7.48	210
G10	18.7	12.54	66
G11	22.2	14.26	79
G12	42.8	68.82	128
G13	17.0	65.25	13

Note: *n* = indicates the number of fruits collected from each genotype; DBH = Diameter at breast height.

where: PY = pulp yield (%); FMF = fresh mass of fruit (g); and MFP = fresh mass of pyrene (g).

2.6. Determination of genetic parameters

The estimates of genetic parameters were obtained using the restricted maximum likelihood (REML) method,

and genotypic values were predicted using the best linear unbiased predictor (BLUP) for the improvement of perennial plants (Resende, 2016; Equation 2). The significance of the model's random effects was assessed through deviance analysis (ANADEV) using the likelihood ratio test (LRT) (Resende, 2007).

$$y = Xr + Zg + e \quad (2)$$

where: y = vector of data; r = vector of replication effects (assumed to be fixed) plus the overall mean; g = vector of genotypic effects (assumed to be random), and e = vector of errors or residuals (random). Uppercase letters represent the incidence matrices for the aforementioned effects.

2.7. Estimates of genotypic correlations and genetic variability

Genotypic correlations were calculated according to Falconer e Mackay (1996). The genetic variability was assessed using the genotypic values ($\mu + g$) of the traits for 13 genotypes through cluster analysis using the unweighted pair group method with arithmetic mean (UPGMA) and the standardized average Euclidean genetic distance. The cutoff point on the horizontal axis of the dendrogram was based on the results from the Tocher clustering method using the standardized average Euclidean genetic distance (Cruz et al., 2014).

2.8. Selection index

The identification of superior genotypes based on the physical traits of fruits and pyrenes was conducted using the mean rank index (Mulamba and Mock, 1978). The values for each trait of the genotypes were summed to obtain an overall value, which was considered as the selection index (Cruz et al., 2014). Lower values in the mean rank sum indicate greater potential for genetic gains in the traits of interest.

2.9. Statistical analysis

The data were tested for normality using the Shapiro-Wilk test and for homogeneity of variance using Bartlett's test, both at a 5% significance level. After these assumptions were met, an analysis of variance (ANOVA) was performed. In the case of significant differences, means were compared

using the Scott-Knott clustering and ranking test ($p < 0,05$). For the analysis of genetic parameters, the SELEGEN-REML/BLUP software (Statistical System and Computerized Genetic Selection with Mixed Linear Models), version 2016, model no. 02, was used (Resende, 2016).

3. Results

3.1. Phenotypic diversity of fruits and pyrenes

The physical traits assessed (biometrics, volume, fresh mass, and pulp yield) for fruits and pyrenes differed significantly among the genotypes (Figure 3 and 4). The fruits of genotype G09 had the highest mean values for length (61.45 mm), diameter (41.19 mm), and volume (60.00 cm³). Genotypes G09 (64.61 g) and G08 (63.55 g) had the highest values for fresh mass. The lowest fresh mass was observed in G02 (47.11 g) and G11 (45.46 g), with G02 also having the shortest fruits (51.86 mm), and the fruits of G11 showing the smallest diameters (35.25 mm) and volume (39.00 mm).

Regarding the pyrene, the average length ranged from 44.34 mm to 54.85 mm for G13 and G09, respectively, with statistical differences between the genotypes. For diameter, G03 (31.74 mm) and G09 (31.81 mm) had the highest averages, while G11 had the lowest (25.63 mm). G09 was the genotype with the highest fresh mass and volume of the pyrene, whereas G11 had the lowest values for both variables. The highest fresh masses of pulp were observed for G08 (31.16 g) and G05 (33.13 g), while the lowest were for G02, G03, G04, and G07. The pulp yield ranged from 43.79% to 57.28% for G04 and G11, respectively (Figure 4).

3.2. Estimates of genetic parameters and coefficient of variation

Estimates of genetic parameters for the physical traits of fruits and pyrenes of *E. uchi* revealed that

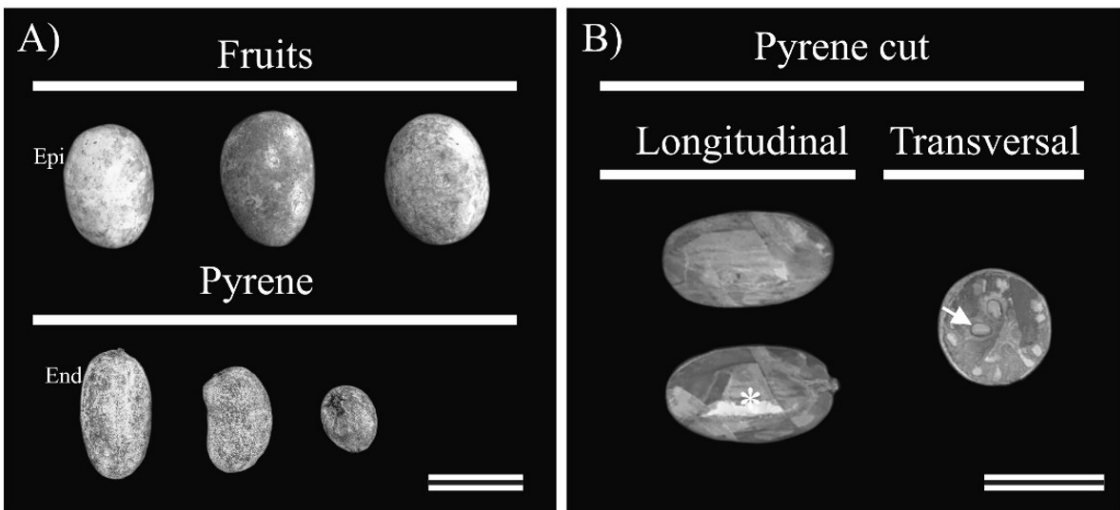


Figure 2. Fruits and pyrenes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon. (A) Fruits are shown in the upper image, and pyrenes are shown in the lower image; (B) The pyrene is showed both longitudinally and transversely. The asterisk indicates the embryo, while the arrow points to the seed. Epi = epicarp; End = endocarp.

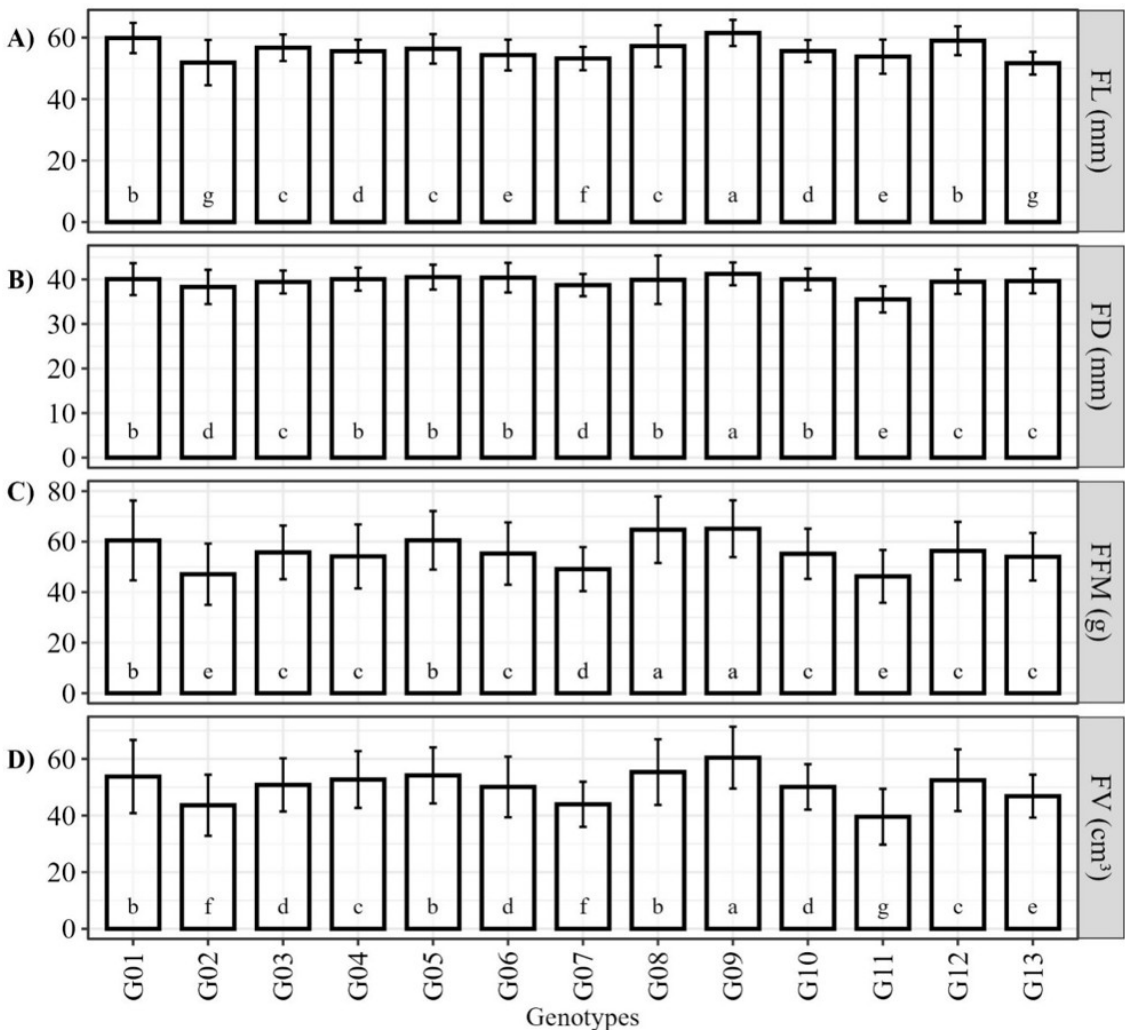


Figure 3. Mean $\pm$ standard deviation of physical traits in fruits from 13 genotypes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon. Identical letters among genotypes for each variable indicate significant differences according to the Scott-Knott test at a 5% significance level. FL = fruit length; FD = fruit diameter; FFM = fruit fresh mass; FV = fruit volume.

environmental variance was higher than the genotypic variance of the genotypes (Table 2). The broad-sense heritability coefficients ranged from 0.16 to 0.44 for the traits analyzed. The accuracy was equal to or greater than 99% for all traits (Table 1).

The broad-sense heritability on the individual plant (h^2_g) were considered “moderate,” and the accuracies were “high” for all evaluated traits (Table 2), indicating considerable genetic control over these traits and therefore a high potential for their transmission to future generations within the context of genetic improvement programs.

Selective accuracy is an important parameter to estimate, as it represents a correlation between true and predicted genetic values, with higher values indicating greater confidence in the evaluation of individuals. According to the classification of heritability and accuracy in terms of magnitude and their associations proposed by Resende et al. (1998), the values found in this study were considered of

‘high’ magnitude (above 70%), indicating an advantage in performing selection using these traits.

3.3. Genotypic correlations among physical traits of fruits and pyrenes

Genotypic correlations among the physical traits of fruits and pyrenes of uxizeiro revealed significant associations among various characteristics analyzed (Table 3). Very strong positive correlations (0.90 to 1.00) were observed between fruit length and pyrene length, as well as between fruit fresh mass and fruit volume. Fruit volume, in turn, showed very strong correlations with both pyrene fresh mass and pyrene volume. Pyrene diameter revealed a very strong correlation with pyrene fresh mass, while pyrene fresh mass demonstrated a very strong positive correlation with pyrene volume. Pulp yield was negatively correlated with all physical traits (Table 3).

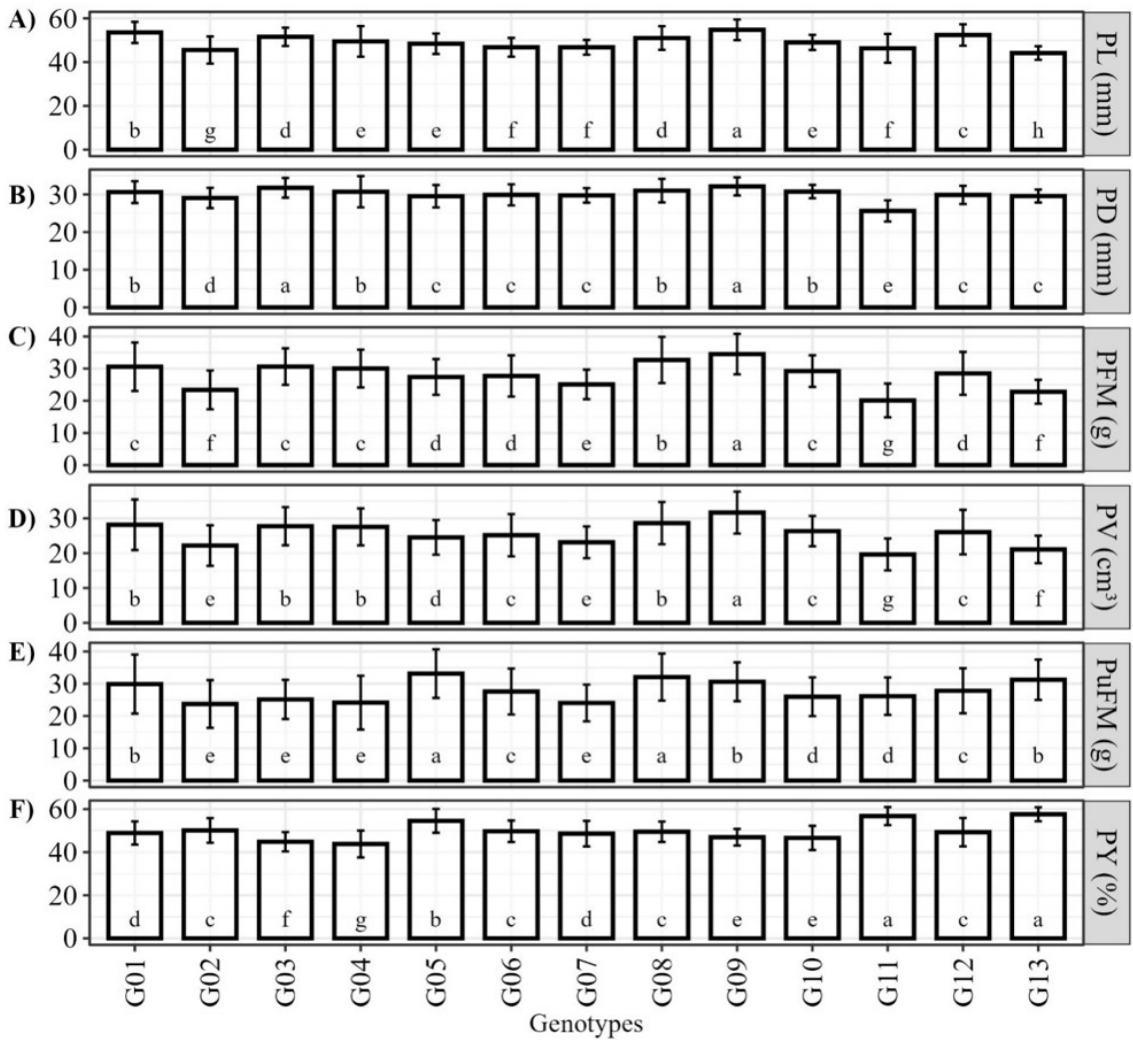


Figure 4. Mean ($\pm$ standard deviation) of physical traits in pyrene and pulp from 13 genotypes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon. Identical letters among genotypes for each variable indicate significant differences according to the Scott-Knott test at a 5% significance level. PL = pyrene length; PD = pyrene diameter; PFM = pyrene fresh mass; PV = pyrene volume; PuFM = pulp fresh mass; PY = pulp yield.

3.4. Multivariate analysis of physical traits of fruits and seeds

Cluster analysis using the Tocher and UPGMA methods revealed the formation of distinct groups (Figure 5), suggesting the presence of genetic diversity within the analyzed uxizeiro population. A total of six genotype groups were identified, with five of these groups consisting of single genotypes: G13, G11, G09, G04, and G01, respectively. Additionally, a sixth group was formed containing eight genotypes: G05, G08, G02, G03, G12, G06, G07, and G10 (Figure 5).

3.5. Selection index of uxizeiro genotypes based on physical traits of fruits and seeds

The results of the genotype selection index analysis for physical traits of fruits and pyrenes revealed a descending

order of genetic improvement potential, where a lower rank value indicates a more favorable combination of the established traits, and a higher value indicates an unfavorable combination. The genotypes G05, G13, G12, G08, and G11 stood out as the most promising (Table 4). These genotypes occupied the top five positions in the average ranks and are recommended for selection, as they exhibited desirable characteristics in relation to the traits evaluated, suggesting their applicability in genetic improvement programs for the species.

4. Discussion

Endopleura uchi plays a significant role in the bioeconomy of the Brazilian Amazon due to its potential for multiple uses. However, the production chain, which

Table 2. Estimates of genetic parameters for physical traits of fruits and pyrenes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Physical traits	Vg	Ve	Vf	h ² g	Acc	CVgi%	CVe%	CVr	M
FL	10.73	25.20	35.92	0.30	0.99	5.93	9.08	0.65	55.25
FD	2.53	10.68	13.21	0.19	0.99	4.07	8.37	0.49	39.06
FFM	40.79	132.53	173.32	0.24	0.99	11.64	20.98	0.55	54.86
FV	41.52	102.29	143.81	0.29	0.99	13.27	20.83	0.64	48.57
PL	13.12	22.18	35.30	0.37	1.00	7.48	9.72	0.77	48.43
PD	3.42	6.70	10.12	0.34	1.00	6.27	8.77	0.71	29.50
PFM	21.98	34.96	56.94	0.39	1.00	17.56	22.14	0.79	26.70
PV	14.24	30.54	44.78	0.32	0.99	15.33	22.45	0.68	24.62
PuFM	9.03	45.99	55.02	0.16	0.99	10.70	24.14	0.44	28.09
PY	19.22	24.74	43.96	0.44	1.00	8.59	9.75	0.88	51.02

Note: Vg = genotypic variance among genotypes; Ve = residual variance; Vf = individual phenotypic variance; h²g = broad-sense heritability; Acc = accuracy; CVgi% = genotypic coefficient of variation; CVe% = residual coefficient of variation; CVr = relative coefficient of variation; M = overall mean of the experiment; FL = fruit length; FD = fruit diameter; FFM = fruit fresh mass; FV = fruit volume; PL = pyrene length; PD = pyrene diameter; PFM = pyrene fresh mass; PV = pyrene volume; PuFM = pulp fresh mass; PY = pulp yield.

Table 3. Genotypic correlation of physical traits in fruits and pyrenes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Traits	FD	FFM	FV	FL	PD	PFM	PV	PuFM	PY
FL	0.6235*	0.8319*	0.8583*	0.978*	0.6299*	0.8454*	0.8657*	0.4832*	-0.5054*
FD		0.8243*	0.8955*	0.5995*	0.8941*	0.8365*	0.8089*	0.4607*	-0.5793*
FFM			0.9600*	0.7884*	0.7523*	0.8901*	0.8659*	0.7499*	-0.3990*
FV				0.8287*	0.8374*	0.9409*	0.9299*	0.5966*	-0.5634*
PL					0.6908*	0.8760*	0.8989*	0.3476*	-0.6288*
PD						0.9030*	0.8901*	0.2077*	-0.7973*
PFM							0.9929*	0.3673*	-0.7679*
PV								0.328*	-0.7831*
PuFM									0.2981*

Note: FL = fruit length; FD = fruit diameter; FFM = fruit fresh mass; FV = fruit volume; PL = pyrene length; PD = pyrene diameter; PFM = pyrene fresh mass; PV = pyrene volume; PuFM = pulp fresh mass; PY = pulp yield. *significant ($p \leq 0.05$).

relies on extractivism, may pose genetic risks to the conservation of the species. In this study, fruits and pyrenes from 13 genotypes were evaluated for their genetic and biometric diversity. The high phenotypic variability observed in *E. uchi* fruits within the same population is a characteristic of non-domesticated trees (Zsögön et al., 2018). The results also suggest that *E. uchi* is an allogamous species and, consequently, capable of reproducing through cross-pollination, like most Brazilian species (Tedesco et al., 2002). This is further supported by the fact that, in seed propagation, fruits identical to the mother plant are not obtained in terms of length, diameter, weight, pulp yield, and pyrene, as well as in the physicochemical characteristics of the edible part (Carvalho and Nascimento, 2022).

The present study highlights the urgent need to monitor the species' gene flow, as this factor contributes to the homogenization of genetic frequencies between populations and enhances genetic diversity within the

population (Ellstrand, 1992). Greater genetic diversity increases adaptability to different environments and facilitates the identification of desirable traits for selecting superior genotypes in genetic improvement programs (Li et al., 2017). Estimating genetic parameters is essential for studying genetic diversity (Leite et al., 2015; Francisconi et al., 2021) and can be inferred from phenotypic variations in observable traits (Cruz et al., 2020).

The heritability values obtained suggest that commercially relevant traits, such as pulp yield, have a high likelihood of being passed on to future generations (Lebedev et al., 2020). However, moderate heritability values (0.16 to 0.44) indicate that environmental factors significantly influence phenotypic expression. This is further supported by the higher environmental variance compared to genetic variance and the residual variation coefficients exceeding the genotypic variation coefficients, reinforcing the species' sensitivity to environmental fluctuations.

Table 4. Classification based on the sum of rankings of the five main genotypes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Genotype	FL	FD	FFM	FV	PL	PD	PFM	PV	PuFM	PY	AR	SO
G05	6	2	3	3	8	4	7	5	1	3	4,2	1 st
G13	13	11	10	11	1	3	2	2	5	1	5,9	2 nd
G12	2	6	5	4	11	6	8	8	6	6	6,2	3 rd
G08	4	4	2	2	9	11	12	12	2	8	6,6	4 th
G11	11	13	13	13	3	1	1	1	8	2	6,6	5 th
G01	3	7	4	6	12	7	10	10	4	5	6,8	6 th
G06	8	3	7	7	5	10	9	7	7	7	7,0	7 th
G09	1	1	1	1	13	13	13	13	3	11	7,0	8 th
G02	12	12	12	12	2	2	3	3	12	4	7,4	9 th
G10	7	8	8	9	7	9	6	6	9	10	7,9	10 th
G07	10	10	11	10	4	5	4	4	13	9	8,0	11 th
G04	9	9	9	8	6	8	5	9	11	12	8,6	12 th
G03	5	5	6	5	10	12	11	11	10	13	8,8	13 th

Note: FL = fruit length; FD = fruit diameter; FFM = fruit fresh mass; FV = fruit volume; PL = pyrene length; PD = pyrene diameter; PFM = pyrene fresh mass; PV = pyrene volume; PuFM = pulp fresh mass; PY = pulp yield; AR = average ranking; SO = selection order.

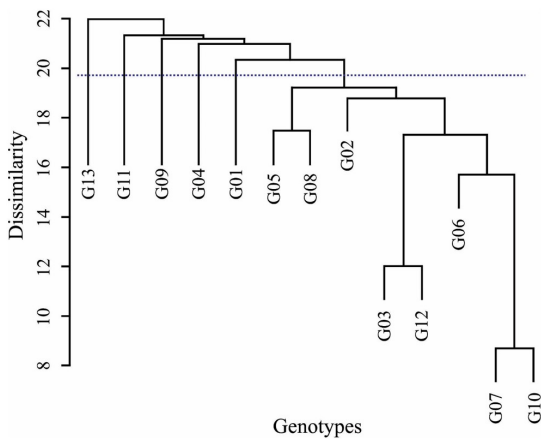


Figure 5. Dendrogram of genetic dissimilarity based on Mahalanobis distance of standardized genotypic values using the unweighted pair group method with arithmetic mean (UPGMA) among 13 genotypes of *Endopleura uchi* (Huber) Cuatrec. from the municipality of Castanhal, Pará state, Eastern Brazilian Amazon.

Future studies integrating environmental variables, such as soil properties, climate conditions, and management practices, could refine selection strategies and improve genetic gains in breeding programs.

This study provides key insights into genetic selection in *E. uchi*, reinforcing the potential for identifying superior genotypes. The strong negative correlation between pyrene diameter and pulp yield suggests that selecting genotypes with smaller pyrene diameters may enhance pulp production. The selection index (see Table 4) identified G05, G13, G12, G08, and G11 as the most promising for breeding programs. These genotypes not only exhibit

higher pulp yield but also maintain a favorable balance of other biometric traits, ensuring genetic diversity while optimizing productivity. These results have direct applications in genetic conservation and breeding programs. The selected genotypes can serve as the foundation for orchard establishment, contributing to sustainable fruit production and commercial exploitation. Additionally, their conservation in germplasm banks ensures the availability of superior genetic material for future breeding efforts and ecological restoration.

The strong negative correlation between pyrene diameter and pulp yield demonstrated in this study is also a relevant result for genetic improvement programs. It suggests that an increase in pulp yield is associated with selecting genotypes that have smaller pyrene diameters. The proportion of pulp relative to fruit size is crucial for fruit species with agroindustrial potential, and selecting genotypes with more advantageous traits can enhance pulp yield (Chavarría-Perez et al., 2020; Chaves et al., 2021). Among the genotypes evaluated in this study, G09 was superior in terms of biometric characteristics of fruits and pyrenes. However, it had the lowest pulp yield, which excluded it from the top five genotypes with the highest potential for genetic improvement for agroindustrial purposes.

The strong positive correlations between fruit length and pyrene length, as well as between fruit fresh mass and fruit volume, suggest that selecting larger fruits may simultaneously favor an increase in pyrene size. This is particularly important when considering the selection of genotypes aimed at improving pulp yield, as the strong negative correlation between pulp yield and fruit diameter (-0.80) indicates that larger fruits do not necessarily have higher pulp content. These findings highlight the complexity of genetic selection in *E. uchi*, where an increase

in certain fruit traits may not always result in higher pulp yield, requiring a balanced selection approach. Future studies incorporating multi-trait selection indices could enhance the identification of superior genotypes that optimize pulp yield while maintaining favorable fruit characteristics.

The observed heritability values and genotypic correlations indicate that traits such as pulp yield and fruit size can be optimized through targeted selection. These findings highlight the applicability of genetic selection in guiding conservation efforts and breeding strategies aimed at improving fruit production and ensuring the long-term sustainability of the species in the Amazonian bioeconomy.

Environmental factors such as soil fertility, water availability, temperature, and light exposure play a crucial role in determining pulp yield, as they influence fruit development, metabolic activity, and nutrient allocation, leading to variations in pulp production even among genetically similar genotypes (Ali et al., 2021). Studies have shown that environmental variation can significantly influence genetic structure in fruit species, as observed in *Cucurbita ficifolia*, where genetic differentiation was more strongly associated with environmental factors than with geographic distance (He et al., 2023). These findings highlight the need to integrate environmental data into breeding programs to enhance selection strategies for genotypes with stable pulp yield across different conditions.

The results of this research highlight that genotype selection should consider a combination of traits rather than focusing on isolated characteristics. The selection of G05, G13, G12, G08, and G11 represents a promising approach for genetic improvement, as these genotypes not only offer higher pulp yield but also contribute to genetic conservation. Their integration into breeding programs can enhance pulp production while preserving genetic diversity, supporting the sustainable development of the Amazonian bioeconomy. Furthermore, their conservation in germplasm banks ensures long-term availability for breeding programs and restoration initiatives.

5. Conclusion

Our findings demonstrated significant phenotypic variability among *Endopleura uchi* genotypes, mainly influenced by environmental. Genetic parameters suggested a strong likelihood of desirable traits, like pulp yield, being passed on to future generations. Additionally, genotypes G05, G13, G12, G08, and G11 are particularly promising for enhancing pulp yield in plant breeding programs. These results provide a valuable foundation for guiding management, conservation, and genetic improvement strategies, supporting the sustainable use of *E. uchi* in agroindustry and enhancing fruit production in the Amazon biome.

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