Annals of Agri-bio Research
https://agribiop.com/

Article

Comparative Characteristics of Fruits and Seeds of Guaba de Machete (*Inga spectabilis*) across Four Reproductive Ages in Arraijan, Panama Oeste

Francisco Corella Justavino [1,2,*], Juan Corella Justavino [3], Félix Camarena [4], José Sánchez Ávila [2], Iris Arauz Moreno [2,5], Sugely Serrano [2,6] and Gladys Robles Nieto [1,7]

1 Unidad Socioagroalimentaria Aplicada, Centro I+D+i en Biotecnología, Energías Verdes y Cambio Climático, Facultad de Biociencias y Salud Pública, Universidad Especializada de las Américas (UDELAS), Panama City 0849-0141, Panama
2 Centro de Investigación Científica de UDELAS, Extensión Universitaria de Chiriquí, Chiriqui 0849-0141, Panama
3 Facultad de Ciencias Agropecuarias, Universidad de Panamá, Campus Octavio Méndez Pereira, Avenida José D. Fábrega, Panama City 0824, Panama
4 Facultad de Ciencias Naturales, Exactas y Tecnología, Universidad de Panamá, Panama City 0824, Panama
5 UDELAS, Extensión Universitaria de Chiriquí, Chiriquí 0824, Panama
6 UDELAS, Chiriquí University Extension, Panama City 0849-0141, Panama
7 Facultad de Biociencias y Salud Pública, Universidad Especializada de las Américas, Panama City 0849-0141, Panama
* Correspondence: francisco.corella@udelas.ac.pa

How To Cite: Corella Justavino, F., Corella Justavino, J., Camarena, F., Sánchez Ávila, J., Arauz Moreno, I., Serrano, S., & Robles Nieto, G. (2026). Comparative Characteristics of Fruits and Seeds of Guaba de Machete (Inga spectabilis) across Four Reproductive Ages in Arraijan, Panama Oeste. *Annals of Agri-bio Research*, *31*(2), 39–48. https://doi.org/10.53941/agrbio.2026.100009

Received: 20 May 2026
Revised: 29 July 2026
Accepted: 6 August 2026
Published: 25 August 2026

Abstract: *Inga spectabilis* is a Neotropical Fabaceae tree with ecological, agroforestry, and local food relevance in Panama. However, quantitative information on the morphometric characteristics of its fruits and seeds across reproductive ages remains limited. This study compared fruit and seed traits of guaba de machete (Inga spectabilis) in Burunga, Arraijan, Panama Oeste, across four reproductive age groups: 8, 15, 22, and 27 years. Six trees were evaluated per age group, and two fruits were selected from each tree, resulting in 48 fruit observations. Fruit weight, length, width, thickness, number of seeds, seed length, seed width, seed thickness, individual seed weight, and total seed weight were measured. Data were analyzed using analysis of variance and Duncan's multiple range test, complemented by correlation and multiple regression analyses. Significant differences among reproductive-age groups were observed for all evaluated traits. Trees aged 22 years showed the highest fruit weight, number of seeds, and total seed weight, whereas trees aged 15 years showed the greatest fruit and seed dimensions. Individual seed weight was highest in 8-year-old trees. Correlation analysis showed strong positive associations among fruit dimensions, seed dimensions, seed number, and total seed weight, while individual seed weight was negatively associated with seed number. Regression models showed strong multivariate associations among morphometric variables, although these relationships should be interpreted as exploratory rather than causal. These findings provide a local morphometric baseline for I. spectabilis in Panama and suggest that intermediate reproductive ages may be relevant for tree selection, propagation planning, and future studies integrating morphometry with productivity, germination, nutritional, and ecological analyses.

Keywords: *Inga spectabilis*; guaba de machete; fruit morphometry; seed traits; reproductive age; agroforestry; Panama

1. Introduction

Inga spectabilis (Vahl) Willd. is an accepted Neotropical tree species in Fabaceae, with a native range extending from southern Mexico to Venezuela and western Bolivia, and with confirmed occurrence in Panama. Within the broader genus *Inga*, which includes roughly 300 species of tropical trees, edible arillate fruits, rapid growth, and ecological usefulness have made several species important in both natural and managed landscapes. In Panama, *I. spectabilis* is not merely a taxonomic entry; it is part of the documented native flora and persists in productive agroecological settings, making it relevant to both botanical and applied research. The common name "guaba de machete" refers to the elongated shape of its pods (as shown in Figure 1), which resemble the machete traditionally used in rural agricultural work. Its white, sweet, and soft aril surrounds the seeds. It is consumed by local people and wildlife, linking the species to both local food practices and animal-mediated seed dispersal processes. (Royal Botanic Gardens Kew, 2026; Smithsonian Tropical Research Institute, 2026; Collantes-González et al., 2024).

(**A**) (**B**)

Figure 1. Morphological appearance of guaba de machete (*Inga spectabilis*). (**A**) Mature pod showing the elongated machete-like shape. (**B**) Opened fruit showing the white aril surrounding the seeds.

The importance of *Inga* in tropical America goes beyond species occurrence. Across the region, congeners such as *I. edulis*, *I. densiflora*, and *I. vera* have been widely associated with agroforestry systems because they provide shade, contribute organic matter, enhance nutrient cycling, and can improve the performance of associated crops or trees. Experimental and field studies have shown nitrogen-related benefits of *Inga* interplanting, nutrient release from *Inga* mulch, and hydrological complementarity when *Inga* functions as a shade component in coffee systems. FAO also frames agroforestry more broadly as a nature-based strategy that can diversify production, strengthen resilience, and improve food security for rural producers, with nitrogen-fixing trees and leguminous shade species playing a central role in that logic. Beyond human use, fruits and seeds of edible *Inga* species can support wildlife feeding and contribute to natural regeneration dynamics in tropical landscapes. In this context, the study of a local edible *Inga* species is justified not only for taxonomic interest but also for its potential contribution to diversified tropical production landscapes. (Doland Nichols & Lynn Carpenter, 2006; Leblanc et al., 2006; Cannavo et al., 2011; Food and Agriculture Organization of the United Nations, 2026).

Fruit and seed morphometry provides an especially useful entry point for studying reproductive expression in tropical trees. Comparative research across large tropical floras has shown that fruit size, seed size, biomass allocation, and pericarp investment are not arbitrary descriptors, but components of coordinated reproductive syndromes. Likewise, community-level analyses of tropical rainforest species have shown that reproductive and dispersal contexts better explain fruit and seed dimensions than by general vegetative traits such as leaf size. For species of direct human interest, these traits are also relevant because they help describe the phenotypic variation that underlies management, selection, dispersal, and regeneration potential. In a congeneric example, cultivated populations of *I. edulis* in the Peruvian Amazon presented significantly longer pods than wild populations, indicating that reproductive morphology in *Inga* can vary meaningfully across biological or management contexts. (Ramírez & Briceño, 2024; Stevenson et al., 2023; Rollo et al., 2020).

Within *Inga*, reproductive biology and seed behavior further strengthen the value of morphometric work. Classical studies established that flowering phenology and floral biology are central to understanding variation within the genus. At the same time, more recent work on *I. edulis* has refined phenophase description in productive settings. Seed-focused studies also show that several *Inga* species have prompt germination and short-lived or recalcitrant seeds, which means that fruit and seed traits at harvest have practical implications for propagation and handling. In other words, measurements such as fruit mass, pod dimensions, seed number, and seed size are not merely descriptive agricultural data; they are biologically linked to reproduction, regeneration, and the species' functional role in managed landscapes. (Koptur, 1983; Quijia-Quijia et al., 2020; Rodrigues et al., 2021; Pereira et al., 2020).

The applied dimension of edible *Inga* species also deserves careful mention. Although the present study does not measure chemical composition, work on edible congeners indicates that Inga seeds are increasingly being recognized as biologically and nutritionally relevant tissues rather than incidental by-products. Verified studies on *Inga paterno* and *Inga laurina* have shown that seeds can contain meaningful protein, lipid, carbohydrate, or mineral fractions. At the same time, recent work on *I. edulis* reflects renewed interest in seed valorization and broader use. In the present manuscript, this evidence should not be used to claim nutritional properties for *I. spectabilis* directly. Instead, it supports a more modest and more defensible argument: local knowledge on fruit and seed traits of edible *Inga* trees matters because these organs have both biological significance and potential applied relevance in food, propagation, and agroforestry contexts. (Sánchez Mendoza et al., 2016; Martins et al., 2024; de Oliveira et al., 2024).

From a regional perspective, the main justification for the study lies in the type of evidence still missing. Panamanian and regional literature already provides partial foundations: broad seed-biology information on native trees in Panama, provincial work on Inga morphology and distribution in Chiriquí, and regional agronomic studies demonstrating the establishment and growth-relevance of *I. spectabilis* in neighboring tropical systems. However, based on the accessible verified literature reviewed here, a focused comparison of fruit and seed morphological characteristics in *I. spectabilis* across clearly defined reproductive ages under Panamanian field conditions appears to be absent. That gap is not trivial. It limits both biological interpretation of reproductive variation and practical guidance for selecting productive trees in local agroforestry or diversified farming systems. (Sautu et al., 2006; Vargas Jiménez, 2010; Abril-Saltos et al., 2018; Collantes-González et al., 2024).

The present study evaluates the comparative characteristics of fruits and seeds of Guaba de machete (*Inga spectabilis*) in Arraijan, Panama Oeste, across four reproductive ages. By comparing fruit weight, fruit length, width and thickness, as well as seed number, seed length, width, thickness, weight per seed, and total seed weight, this study provides a localized morphometric baseline for a native edible tree with ecological and productive relevance. In doing so, it contributes new evidence on how reproductive-age classes may differ in the expression of fruit and seed traits, while also generating information that can support future work on tree selection, propagation, and agroforestry use under Panamanian conditions.

2. Materials and Methods

2.1. Study Area

The study was conducted in the district of Arraijan, Panama Oeste, located between 9°02′42″ and 8°51′45″ N latitude and between 79°37′00″ and 79°37′05″ W longitude. The area has a humid tropical climate and is located on a lowland plain with an average elevation of approximately 100 m above sea level. The district includes relevant elevations such as Cerro Cabra, the highest point in the area at 512 m, and Cerro Galera at 341 m, both located toward the southwest. The study area is shown in Figure 2.

To describe the edaphic conditions associated with the study site, six soil samples were collected from the upper 20 cm of soil along a 200 m linear transect within a 41 m × 240 m plot, using a lattice arrangement with 10 m spacing, following Holste, as cited by Molino et al. (2021). Soils were loamy in texture, slightly acidic to neutral (pH 6.9–7.2), with organic matter content of 1.9–2.4%, and moderate levels of extractable phosphorus, potassium, calcium, and micronutrients (full values in Supplementary Table S2). Since soil variables were not directly analyzed in relation to fruit and seed morphometric traits, they are reported here as descriptive site characterization only."

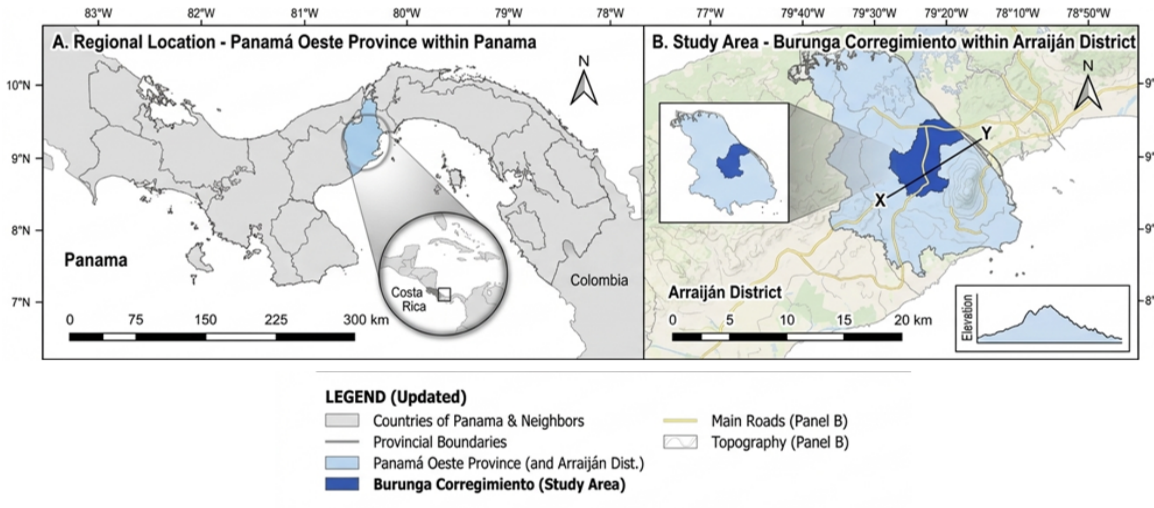

Figure 2. Geographic location and physical setting of the study area. (**A**) Regional location of Panama Oeste Province within Panama. (**B**) Detailed view of Burunga corregimiento within Arraijan District, including the road network, topography, and elevation profile (X–Y). Administrative boundaries were obtained from the 2025 Political Administrative Division dataset of Panama, with road and topographic data from OpenStreetMap and SRTM.

2.2. Tree, Fruit, and Seed Sampling

Fruit and seed measurements were carried out during the harvest season. Four reproductive-age groups of *Inga spectabilis* trees were evaluated: 8, 15, 22, and 27 years old. Each age group included six trees. Two fruits were selected from each tree, resulting in twelve fruits per age group and forty eight fruits in total.

The fruits were selected as representative samples from each tree, preferably close to the average fruit size observed for that individual. This criterion was used to reduce within-tree variability and to allow a more consistent comparison among reproductive age groups. Tree age was estimated using wood core samples obtained with a Pressler increment borer. Although growth-ring periodicity in tropical tree species may vary depending on species-specific characteristics and environmental conditions, increment coring is a widely used dendrochronological approach for estimating tree age and evaluating growth patterns when wood samples are properly prepared, interpreted, and assessed following standardized procedures and quality-control criteria. This approach has been successfully applied in tropical forest species, although the validation of ring formation should be considered at the species and site level (Worbes, 1995; Brienen & Zuidema, 2006; Quesada-Roman et al., 2022). Fruits and seeds were then classified according to the age group of the tree from which they were collected.

For each fruit, the following variables were measured: fruit weight in grams, fruit length in centimeters, fruit width in centimeters, fruit thickness in centimeters, and number of seeds per fruit. For the seeds, the following variables were recorded: average seed length in centimeters, average seed width in centimeters, average seed thickness in centimeters, weight per seed in grams, and total seed weight per fruit in grams.

2.3. Statistical Analysis

Data were organized in Microsoft Excel and analyzed using SAS. Descriptive statistics were first calculated for each fruit and seed variable according to tree age group. The experimental arrangement was treated as a completely randomized design, with reproductive age group as the main factor.

Analysis of variance was applied to evaluate whether fruit and seed characteristics differed significantly among the four reproductive age groups. When significant differences were detected, Duncan's multiple range test was used to compare group means. Statistical significance was evaluated at the 5% level. The analysis focused on differences in means across age groups, consistent with the study's quantitative and comparative objectives.

Normality of ANOVA residuals was evaluated using the Shapiro-Wilk test, and homogeneity of variances among reproductive-age groups was evaluated using Levene's test, for each fruit and seed variable. Because some variables showed deviations from normality and/or variance homogeneity, results were cross-validated using the non-parametric Kruskal-Wallis test, which confirmed statistically significant differences among reproductive-age groups for all evaluated traits ($p \leq 0.002$ in all cases), supporting the robustness of the ANOVA-based conclusions. Multicollinearity among predictor variables in the regression models was evaluated using the Variance Inflation Factor (VIF).

3. Results

3.1. General Fruit and Seed Characteristics according to Reproductive Age

A total of 48 fruits of Inga spectabilis were evaluated across four reproductive age groups. The sampled trees were classified into four age groups: 8, 15, 22, and 27 years old. Each treatment included six trees, and two fruits were selected from each tree, yielding 12 fruit observations per reproductive age group. The evaluated fruit variables included fruit weight, length, width, thickness, and number of seeds per fruit. Seed traits included average seed length, average seed width, average seed thickness, individual seed weight, and total seed weight per fruit. The complete dataset of fruit and seed measurements is presented in Supplementary Table S1.

The descriptive and inferential summary of fruit and seed characteristics showed significant differences among reproductive age groups for all evaluated variables. For fruit traits, the highest mean fruit weight was observed in trees aged 22 years, with an average of 539.69 g. In contrast, the highest mean values for fruit length, width, and thickness were observed in trees aged 15 years, with means of 52.00 cm, 4.85 cm, and 3.22 cm, respectively. These results indicate that expression of fruit size traits was not uniform across age groups, with different fruit attributes reaching their highest values in trees aged 15 and 22 years, as summarized in Table 1.

Table 1. Results of the characteristics of fruits and seeds from machete guaba trees at reproductive ages in Burunga, Arraijan, Panama.

Fruits						Seeds					
Indicator	**Treatment (Years)**	**Avg.**	**F-Value**	**Pr > F**	**R-Squared**	**Indicator**	**Treatment (Years)**	**Avg.**	**F-Value**	**Pr > F**	**R-Squared**
Weight (g)	22 years	539.69	62.46	<0.0001	0.81	Number of seeds (n)	22 years	24.25	9.62	<0.0001	0.40
Length (cm)	15 years	52.00	12.23	<0.0001	0.45	Length (cm)	15 years	3.19	11.27	<0.0001	0.43
Width (cm)	15 years	4.85	22.01	<0.0001	0.60	Width (cm)	15 years	1.80	11.35	<0.0001	0.44
Thickness (cm)	15 years	3.22	17.24	<0.0001	0.54	Thickness (cm)	15 years	0.50	20.67	<0.0001	0.47
						Weight (g)	8 years	4.87	3.93	0.0144	0.21
						Total weight per sample (g)	22 years	80.89	48.31	<0.0001	0.77

Note: F value, Pr > F, and R^2 correspond to the one-way ANOVA comparing the four reproductive age groups (8, 15, 22, and 27 years). Treatment (years) indicates the age group with the highest mean (Avg) for each trait.

For seed traits, trees aged 22 years showed the highest mean number of seeds per fruit (24.25) and the highest total seed weight (80.89 g). However, the largest seed dimensions were observed in trees aged 15 years, with mean seed length, width, and thickness values of 3.19 cm, 1.80 cm, and 0.50 cm, respectively. Individual seed weight showed a different pattern, with the highest mean value observed in trees aged 8 years (4.87 g). This suggests that younger trees produced fewer but heavier individual seeds, while trees aged 22 years produced a greater number of seeds and higher total seed mass per fruit. These trends are also summarized in Table 1.

3.2. Morphometric Patterns of Fruits and Seeds

Fruit traits showed a differentiated pattern across reproductive age groups. The highest mean fruit weight was recorded in 22-year-old trees, whereas the highest mean values for fruit length, width, and thickness were recorded in 15-year-old trees. According to the summary presented in Table 1, fruit weight reached 539.69 g in the 22-year-group, while fruit length, width, and thickness reached 52.00 cm, 4.85 cm, and 3.22 cm, respectively, in the 15-year-group. These results indicate that fruit mass and fruit dimensions did not peak in the same reproductive age group.

Seed traits followed a similar pattern of differentiation among age groups. The 22-year-old trees showed the highest mean number of seeds per fruit and the highest total seed weight, with values of 24.25 seeds and 80.89 g, respectively. In contrast, the 15-year-old trees showed the largest average seed dimensions, with mean seed length, width, and thickness of 3.19 cm, 1.80 cm, and 0.50 cm, respectively.

Individual seed weight differed from these patterns, with the highest mean value observed in the 8-year-old trees at 4.87 g. This indicates that the age group with the largest individual seeds by weight was not the same age group with the highest seed number or total seed mass.

The lower values observed in the 27-year-old group across several fruit and seed variables suggest that the relationship between reproductive age and morphometric expression was not linear. Instead, the strongest fruit and seed responses were concentrated in the 15- and 22-year-old groups, depending on the trait considered. This pattern is consistent with the Duncan group comparisons summarized in Table 1, in which the variables were separated into distinct mean groups based on reproductive age.

The complete dataset of fruit and seed measurements is presented in Supplementary Table S1.

3.3. Statistical Association among Fruit and Seed Traits

The correlation analysis showed that most fruit and seed variables were positively associated when all reproductive age groups were analyzed together. Fruit length was strongly correlated with fruit width, fruit thickness, and number of seeds, with correlation coefficients of 0.91, 0.96, and 0.96, respectively. Fruit thickness also showed strong positive correlations with fruit width and number of seeds. These results indicate that larger fruits tended to show coordinated increases in linear dimensions and seed number, as presented in Table 2.

Table 2. Correlation matrix (Pearson r) for fruit and seed morphometric traits of *Inga spectabilis* across reproductive age groups (n = 48).

Variable	1	2	3	4	5	6	7	8	9	10
1. Fruit weight (g)	1.00	0.37 **	0.44 **	0.50 ***	0.39 **	0.20	0.22	0.32 *	−0.04	0.83 ***
2. Fruit length (cm)		1.00	0.91 ***	0.96 ***	0.96 ***	0.80 ***	0.94 ***	0.92 ***	−0.80 ***	0.50 ***
3. Fruit width (cm)			1.00	0.93 ***	0.84 ***	0.90 ***	0.90 ***	0.96 ***	−0.60 ***	0.47 ***
4. Fruit thickness (cm)				1.00	0.94 ***	0.77 ***	0.88 ***	0.91 ***	−0.70 ***	0.59 ***
5. No. of seeds (n)					1.00	0.70 ***	0.87 ***	0.86 ***	−0.83 ***	0.55 ***
6. Mean seed length (cm)						1.00	0.88 ***	0.92 ***	−0.51 ***	0.30 *
7. Mean seed width (cm)							1.00	0.95 ***	−0.72 ***	0.40 **
8. Mean seed thickness (cm)								1.00	−0.65 ***	0.42 **
9. Seed weight (g)									1.00	−0.12
10. Total seed weight (g)										1.00

Note: Correlation coefficients were calculated using all 48 observations from trees aged 8, 15, 22, and 27 years combined (Pearson product-moment correlation). Positive values indicate direct associations; negative values indicate inverse associations. * p <0.05; ** p <0.01; *** p <0.001. Correlations without an asterisk were not statistically significant ($p \geq 0.05$).

Seed dimensional traits were also strongly correlated with one another. Average seed length, width, and thickness showed positive correlations, suggesting that increases in the other dimensions generally accompanied increases in one seed dimension. In contrast, individual seed weight showed negative correlations with several fruit and seed traits, particularly with number of seeds, where the correlation was strongly negative. This pattern indicates that fruits with more seeds tended to have lower individual seed weight, while total seed weight was positively correlated with fruit weight. These relationships are summarized in Table 2.

Multiple regression analysis was then used to explore the multivariate associations between selected response variables and the remaining fruit and seed morphometric traits. The model for fruit weight showed a multiple correlation coefficient of 0.94, a coefficient of determination of 0.89, and an adjusted R^2 of 0.86, based on 48 observations. The regression model was statistically significant (F = 33.89, p < 0.001). A second model, using total seed weight as the response variable, showed a multiple correlation coefficient of 0.96, a coefficient of determination of 0.92, and an adjusted R^2 of 0.90. This model was also statistically significant (F = 48.87, p < 0.001). The comparative summary of both regression models is presented in Table 3.

The significant predictors differed between the two response variables. In the fruit weight model, fruit width, number of seeds, average seed width, individual seed weight, and total seed weight were significant predictors. In the total seed weight model, fruit weight, fruit width, number of seeds, average seed width, and individual seed weight were significant predictors. The significant coefficient estimates for both models are presented in Table 4.

Because several fruit and seed variables were highly correlated, the regression results should be interpreted as exploratory multivariate associations rather than as independent causal effects. The high R^2 values indicate strong joint explanatory capacity of the measured morphometric variables. Still, the correlation structure among predictors suggests that some coefficients may reflect shared variation among fruit and seed dimensions.

Table 3. Summary of multiple regression models for fruit weight and total seed weight in *Inga spectabilis*.

Response Variable	Multiple R	R^2	Adjusted R^2	Standard Error	Observations	Regression df	Residual df	F Value	*p* Value
Fruit weight (g)	0.94	0.89	0.86	14.58	48	9	38	33.89	$p < 0.001$
Total seed weight (g)	0.96	0.92	0.90	2.30	48	9	38	48.87	$p < 0.001$

Note: Multiple R, R^2, adjusted R^2, standard error, and number of observations were taken from the regression summaries. Regression and residual degrees of freedom, F values, and *p* values correspond to the global ANOVA test for each regression model. Both models included the remaining fruit and seed morphometric variables as predictors.

Table 4. Significant predictors in the multiple regression models for fruit weight and total seed weight in *Inga spectabilis*.

Response Variable	Significant Predictor	Coefficient	Standard Error	*t* Statistic	*p* Value
Fruit weight (g)	Fruit width (cm)	88.69	18.91	4.69	$p < 0.001$
Fruit weight (g)	Number of seeds (n)	−7.69	2.46	−3.12	0.0034
Fruit weight (g)	Mean seed width (cm)	−351.31	109.68	−3.20	0.0028
Fruit weight (g)	Seed weight (g)	−14.08	5.09	−2.77	0.0087
Fruit weight (g)	Total seed weight (g)	5.29	0.57	9.31	$p < 0.001$
Total seed weight (g)	Fruit weight (g)	0.13	0.01	9.31	$p < 0.001$
Total seed weight (g)	Fruit width (cm)	−12.33	3.16	−3.90	0.0004
Total seed weight (g)	Number of seeds (n)	1.69	0.34	4.99	$p < 0.001$
Total seed weight (g)	Mean seed width (cm)	50.92	17.64	2.89	0.0064
Total seed weight (g)	Seed weight (g)	3.81	0.63	6.09	$p < 0.001$

Note: Only predictors with $p < 0.05$ are shown. The full regression models included all fruit and seed morphometric variables described in the Methods section. Intercepts were retained in the models but are not shown because they do not have direct biological interpretation in this context.

To formally evaluate multicollinearity, Variance Inflation Factors (VIF) were calculated for each predictor in both regression models. Most predictors showed VIF values well above the conventional threshold of 10 (range: 3.8–44.7 in the fruit weight model; 2.8–45.0 in the total seed weight model; Table 5), confirming severe multicollinearity among the morphometric predictors, consistent with the strong pairwise correlations reported in Table 2. Given this level of collinearity, the regression coefficients in Table 4 should not be interpreted as independent effects of individual traits, but as descriptors of a tightly coordinated multivariate growth pattern. These results support interpreting the regression models strictly as exploratory rather than predictive tools, as already noted in Section 4.

Table 5. Variance Inflation Factors (VIF) for predictor variables in the multiple regression models of fruit weight and total seed weight in *Inga spectabilis*.

Predictor Variable	VIF (Fruit Weight Model)	VIF (Total Seed Weight Model)
Fruit weight (g)	—	2.75
Fruit length (cm)	44.71	44.98
Fruit width (cm)	24.61	27.76
Fruit thickness (cm)	28.42	28.28
Number of seeds (n)	29.51	22.42
Mean seed length (cm)	10.44	10.96
Mean seed width (cm)	17.95	18.70
Mean seed thickness (cm)	30.13	30.03
Seed weight (g)	9.97	6.06
Total seed weight (g)	3.83	—

Note: Variance Inflation Factors were calculated for each predictor variable included in the regression models presented in Tables 3 and 4. A dash (—) indicates that the variable was the response variable in that model and was therefore not included as a predictor. VIF values were interpreted following conventional thresholds: VIF < 5 indicates low collinearity, VIF between 5 and 10 indicates moderate collinearity, and VIF > 10 indicates severe collinearity. Most predictors in both models exceeded the threshold of 10, indicating severe multicollinearity among fruit and seed morphometric variables, consistent with the strong pairwise correlations reported in Table 2.

4. Discussion

The findings suggest that reproductive age affects fruit and seed morphometry in *Inga spectabilis*, although not in a simple age-dependent manner. The 22-year-old trees showed the highest fruit weight, seed number, and total seed weight, whereas the 15-year-old trees showed the greatest fruit and seed dimensions. This separation indicates that fruit size, fruit mass, and seed allocation may peak at different reproductive stages, suggesting differentiated developmental or allocation patterns rather than a uniform increase with age.

The morphometric characteristics observed in *Inga spectabilis* are generally consistent with the broad reproductive variability reported for other species of the genus *Inga*. Studies on *I. edulis*, *I. vera*, and *I. densiflora* have demonstrated considerable variation in fruit size, seed dimensions, and reproductive allocation under different environmental and management conditions. In the present study, fruits from 15-year-old trees frequently exceeded 50 cm in length, confirming that *I. spectabilis* ranks among the largest-fruited species within the genus. These findings reinforce previous observations that fruit and seed morphology in *Inga* reflects both species-specific characteristics and developmental or environmental influences.

The correlation structure reinforces this interpretation. Fruit length, width, thickness, and seed number were strongly and positively associated, indicating coordinated fruit development. Seed dimensions were also positively associated with one another. However, individual seed weight was negatively correlated with seed number, suggesting a possible trade off between producing more seeds and allocating greater mass to each seed. Therefore, larger fruits in this population appear to be more closely associated with seed number and total seed biomass than with heavier individual seeds.

The regression models showed high explanatory values, but they should be interpreted cautiously. Because several morphometric predictors were strongly correlated, the models are better understood as exploratory descriptions of joint trait behavior rather than evidence of independent causal effects. This is important because fruit and seed measurements are structurally and developmentally interdependent.

This interpretation is further supported by variance inflation factor diagnostics (Table 5), which indicated severe multicollinearity (VIF > 10) for most predictors in both regression models, confirming that the observed R^2 values reflect coordinated multivariate covariation rather than independent predictive relationships.

From an applied perspective, the results suggest that trees aged 15 and 22 years may be relevant for different selection goals: the former for larger fruit and seed dimensions, and the latter for greater fruit mass, seed number, and total seed biomass. However, the study did not evaluate total yield per tree, nutritional composition, germination performance, genetics, or repeated harvest seasons. Therefore, the results should be interpreted as a local morphometric baseline for *I. spectabilis* in Panama and as a foundation for future studies integrating morphometry with analyses of productivity, propagation, nutrition, and ecology.

This study has some limitations that should be considered when interpreting the results. First, the sample size was relatively small, comprising six trees per reproductive-age group and two fruits per tree. Second, fruits were intentionally selected to represent the average size observed within each tree rather than by random sampling. Although this approach reduced within-tree variability and facilitated comparisons among reproductive-age groups, it may have introduced selection bias and limited the representation of the complete range of fruit variability. Therefore, the findings should be interpreted as a localized morphometric baseline rather than as a comprehensive characterization of the species. Future studies should incorporate larger sample sizes, random fruit selection, multiple harvest seasons, and additional populations to improve the generalizability of the results.

5. Conclusions

This study provides a morphometric baseline for fruits and seeds of *Inga spectabilis* across four reproductive age groups in Burunga, Arraijan, Panama Oeste. The results showed significant differences among age groups for all evaluated fruit and seed traits, indicating that reproductive age is associated with measurable variation in these traits. Trees aged 22 years showed the highest fruit weight, number of seeds, and total seed weight, whereas trees aged 15 years showed the greatest fruit and seed dimensions. Individual seed weight was highest in trees aged 8 years, suggesting that seed number and seed mass may follow different allocation patterns.

Correlation and regression analyses indicated strong associations among fruit and seed traits, particularly among fruit dimensions, seed dimensions, seed number, fruit weight, and total seed weight.

However, these relationships should be interpreted as exploratory morphometric associations rather than causal effects. Overall, the findings suggest that intermediate reproductive ages, especially 15 and 22 years, may be relevant for selecting trees according to specific morphometric objectives. Future studies should expand sampling across sites and harvest seasons and integrate morphometry with yield, germination, nutritional composition, and genetic analyses to better understand the productive and ecological potential of *I. spectabilis* under Panamanian conditions.

Supplementary Materials

The additional data and information can be downloaded at: https://media.sciltp.com/articles/others/2608251052409329/AGRBIO-26050148-SM.pdf. Table S1. Characteristics of fruits and seeds from six machete guaba trees, with two observations per tree, across four reproductive age groups. Table S2. Edaphological composition of soil samples collected in the study area.

Author Contributions

F.C.J.: Conceptualization, methodology, investigation, data management, formal analysis, resources, project administration, writing, original draft, review, and editing. J.C.J.: Validation, data management, formal analysis, data curation, and review. F.C.: Validation, formal analysis, review, and editing. J.S.Á.: Formal analysis, review and editing. I.A.M.: Formal analysis and review. S.S.: Review, validation and formal analysis. G.R.N.: Fieldwork and formal analysis. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding. The APC was funded by the authors.

Institutional Review Board Statement

Not applicable. This study did not involve humans or animals; it consisted exclusively of morphometric measurements of fruits and seeds collected from Inga spectabilis trees.

Informed Consent Statement

Not applicable. This study did not involve human subjects.

Data Availability Statement

The data presented in this study, including the complete descriptive values for the edaphic characterization referenced in Section 2.1, are available in this article and its Supplementary Materials (Supplementary Table S2). Additional raw morphometric data are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest. The sponsors had no role in the design of the study, the collection, analysis, or interpretation of the data, the writing of the manuscript, or the decision to publish the results.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used AI-assisted language-editing tools to support proofreading and English-language revision of the manuscript text. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

References

Abril-Saltos, R. V., Ruiz-Vázquez, T. E., Alonso-Lazo, J., Cabrera-Murillo, G. M., & Meric, O. A. (2018). Initial growth of *Eugenia stipitata*, *Inga spectabilis*, and *Inga edulis* in Napo, Ecuador. *Agronomía Mesoamericana, 29*(2), 275–291. https://doi.org/10.15517/ma.v29i2.28759.

Brienen, R. J. W., & Zuidema, P. A. (2006). Lifetime growth patterns and ages of Bolivian rain forest trees obtained by tree ring analysis. *Journal of Ecology, 94*(2), 481–493. https://doi.org/10.1111/j.1365-2745.2005.01080.x.

Cannavo, P., Sansoulet, J., Harmand, J.-M., Siles, P., Dreyer, E., & Vaast, P. (2011). Agroforestry associating coffee and *Inga densiflora* results in complementarity for water uptake and decreases deep drainage in Costa Rica. *Agriculture, Ecosystems & Environment, 140*, 1–13. https://doi.org/10.1016/j.agee.2010.11.005.

Collantes-González, R. D., Jerkovic, M., & Santos-Murgas, A. (2024). Insectos herbívoros asociados a *Inga spectabilis* y *Cajanus cajan* (Fabaceae) en Bugaba—Chiriquí, Panamá. *Revista Científica Guacamaya, 8*(2), 8–17. https://doi.org/10.48204/j.guacamaya.v8n2.a5006.

De Oliveira, A. V., Kersting, M., da Costa, A. B., & Schneider, R. de C. S. (2024). Biotechnological and environmental education potential of Inga edulis Martius: Seed collected in the Amazon, Brazil. The Southeast Asian Journal of Tropical Biology, 31(3), 316–329. https://doi.org/10.11598/btb.2024.31.3.2201.

Doland Nichols, J., & Lynn Carpenter, F. (2006). Interplanting *Inga edulis* yields nitrogen benefits to *Terminalia amazonia*. *Forest Ecology and Management, 233*(2–3), 344–351. https://doi.org/10.1016/j.foreco.2006.05.031.

Food and Agriculture Organization of the United Nations. (2026). *About agroforestry*. https://www.fao.org/agroforestry/about-agroforestry/overview/en.

Koptur, S. (1983). Flowering phenology and floral biology of *Inga* (Fabaceae: Mimosoideae). *Systematic Botany, 8*(4), 354–368. https://doi.org/10.2307/2418355.

Leblanc, H. A., Nygren, P., & McGraw, R. L. (2006). Green mulch decomposition and nitrogen release from leaves of two *Inga* spp. in an organic alley-cropping practice in the humid tropics. *Soil Biology and Biochemistry, 38*(2), 349–358. https://doi.org/10.1016/j.soilbio.2005.05.012.

Martins, A. M., Malafaia, C. R. A., Nunes, R. M., Mecenas, A. S., de Moura, P. H. B., Muzitano, M. F., de Barros Machado, T., da Silva Carneiro, C., & Leal, I. C. R. (2024). Nutritional, chemical and functional potential of *Inga laurina* (Fabaceae): A barely used edible species. *Food Research International, 178*, 113751. https://doi.org/10.1016/j.foodres.2023.113751.

Molino, J., Corella, F., Matus, E., Matus, L., Diaz, A., García, A., Martínez, L., Vaña, M., Tuñón, E., & Valles, N. (2021). Growth of pigeon pea (*Cajanus cajan*) using auxin irrigation in a home garden in Panama. *Agricultura*, 120(3–4). https://journals.usamvcluj.ro/index.php/agricultura/article/view/14337.

Pereira, L. C. V., Mayrinck, R. C., Zambon, C. R., José, A. C., & Faria, J. M. R. (2020). Storage of short-lived seeds of *Inga vera* subsp. *affinis* in osmotic medium. *Seed Science Research, 30*(2), 156–160. https://doi.org/10.1017/S0960258520000185.

Quesada-Roman, A., Ballesteros-Canovas, J. A., George, S. S., & Stoffel, M. (2022). Tropical and subtropical dendrochronology: Approaches, applications, and prospects. *Ecological Indicators*, *144*, 109506. https://doi.org/10.1016/j.ecolind.2022.109506.

Quijia-Quijia, M., Castillo-Torres, S., Vásquez-Castillo, W., & Racines-Oliva, M. (2020). Ice cream bean (*Inga edulis*) flower phenology in Ecuadorian inter-Andean valley. *Enfoque UTE, 11*(3), 25–34.

Ramírez, N., & Briceño, H. (2024). Allometry and the distribution of fruit and seed traits across tropical plant species. *Austral Ecology, 49*(9), e13589. https://doi.org/10.1111/aec.13589.

Rodrigues, J. K., Cavalcanti, J. H. F., Silva, P. O., de Lima e Borges, E. E., Nina Junior, A. da R., & Gonçalves, J. F. de C. (2021). Unraveling relationships of prompt germination among four species of *Inga* Mill detected by morpho-anatomical and histochemical traits. *Flora, 285*, 151941. https://doi.org/10.1016/j.flora.2021.151941.

Rollo, A., Ribeiro, M. M., Costa, R. L., Santos, C., Clavo, P. Z. M., Mandák, B., Kalousová, M., Vebrová, H., Chuqulin, E., Torres, S. G., Aguilar, R. M. V., Hlavsa, T., & Lojka, B. (2020). Genetic structure and pod morphology of *Inga edulis* cultivated vs. wild populations from the Peruvian Amazon. *Forests, 11*(6), 655. https://doi.org/10.3390/f11060655.

Royal Botanic Gardens Kew. (2026). *Inga spectabilis (Vahl) Willd.* Royal Botanic Gardens Kew.

Sánchez Mendoza, N. A., Jiménez Martínez, C., Cardador Martínez, A., Martín del Campo Barba, S., & Dávila Ortiz, G. (2016). Physical, nutritional and non nutritional characterization of *Inga paterno* seeds. *Revista Chilena de Nutrición, 43*(4), 400–407. https://doi.org/10.4067/S0717-75182016000400010.

Sautu, A., Baskin, J. M., Baskin, C. C., & Condit, R. S. (2006). Studies on the seed biology of 100 native species of trees in a seasonal moist tropical forest, Panama, Central America. *Forest Ecology and Management, 234*(1–3), 245–263. https://doi.org/10.1016/j.foreco.2006.07.006.

Smithsonian Tropical Research Institute. (2026). *Inga spectabilis (Vahl) Willd*. https://panamabiota.org/stri/taxa/index.php?taxon=65737&clid=64.

Stevenson, P. R., Acosta-Rojas, D. C., Cárdenas, S., & Henao-Díaz, L. F. (2023). Variation in fruit and seed dimensions is better explained by dispersal system than by leaf size in a tropical rainforest. *American Journal of Botany, 110*(8), e16211. https://doi.org/10.1002/ajb2.16211.

Vargas Jiménez, L. M. (2010). *Morfología, fenología, taxonomía y distribución geográfica de las especies de Inga en Chiriquí, Panamá* [Thesis, Universidad Autónoma de Chiriquí]. http://jadimike.unachi.ac.pa/handle/123456789/127.

Worbes, M. (1995). How to measure growth dynamics in tropical trees: A review. *IAWA Journal, 16*(4), 337–351. https://doi.org/10.1163/22941932-90001420.