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Biometry of fruits and seeds of three species of *Solanum* (Solanaceae) from Amazonia

Biometria de frutos e sementes de três espécies de *Solanum* (Solanaceae) da Amazônia

Biometría de frutos y semillas de tres especies de *Solanum* (Solanaceae) de la Amazonía

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Abstract
This study aimed to describe and characterize the biometry of the fruits, and seeds of three species of *Solanum* (Solanaceae) from the Amazonia. Biometry can help the development of efficient techniques for the management and understanding of the species. The morphometric characterization of the structures was performed from 100 fruits and 100 seeds, collected in the Metropolitan Region of Belém from the Amazonia. And analysis of the ornamentation of the seed scanning electron microscopy (SEM). The fruits are polyspermic, fleshy, berry-type, dehiscent, consisting of one or two locules with the seeds attached to the axial placenta, with five lobes on the end, glabrous, green when immature, purple and red in *S. americanum* and *S. stramoniifolium* and pulbescent greens in *S. crinitum*, when ripe. The seeds are obovoid to subdiscoid, little to very compressed. The forehead ornamentation is reticulated with straight to sinuous walls and the presence of filiform projections. Internally, the seeds are albuminous with a gelatinous endosperm surrounding the entire embryo of the axial type, continuous linear circined to imbricate. The weight of 1,000 seeds was higher for those in *S. crinitum* 2.36 g, followed by *S. stramoniifolium* with 1.67 g and *S. americanum* with 0.4 g.
Keywords: Berries; Jurubeba; Wild plants.

Resumo
Este estudo teve como objetivo descrever e caracterizar a biometria dos frutos e sementes de três espécies de *Solanum* (Solanaceae) da Amazônia. A biometria pode auxiliar no desenvolvimento de técnicas eficientes para o manejo e compreensão dessas espécies. A caracterização morfométrica das estruturas foi realizada a partir de 100 frutos e 100 sementes, coletados na Região Metropolitana de Belém na Amazônia. E análise da ornamentação da semente por microscopia eletrônica de varredura (MEV). Os frutos são polispérmicos, carnosos, tipo baga, deiscentes, constituídos por um ou dois lóculos com as sementes aderidas à placenta axial, com cinco lóbulos na extremidade, glabros, verdes

quando imaturos, roxos e vermelhos em *S. americanum* e *S. stramoniifolium* e verdes pulbescentes em *S. crinitum*, quando maduros. As sementes são obovóides a subdiscoides, pouco a muito comprimidas. A ornamentação da testa é reticulada com paredes retas a sinuosas e presença de projeções filiformes. Internamente, as sementes são albuminosas com um endosperma gelatinoso circundando todo o embrião do tipo axial, linear contínuo circundado a imbricado. O peso de 1.000 sementes foi maior em *S. crinitum* 2,36 g, seguido de *S. stramoniifolium* com 1,67 g e *S. americanum* com 0,4 g.
Palavras-chave: Bagas; Jurubeba; Plantas silvestres.

Resumen
Este estudio tuvo como objetivo describir y caracterizar la biometría de los frutos y semillas de tres especies de *Solanum* (Solanaceae) de la Amazonía. La biometría puede ayudar al desarrollo de técnicas eficientes para el manejo y conocimiento de las especies. La caracterización morfométrica de las estructuras se realizó a partir de 100 frutos y 100 semillas, recolectados en la Región Metropolitana de Belém de la Amazonía. Y análisis de la ornamentación de la semilla al microscopio electrónico de barrido (SEB). Los frutos son polispérmicos, carnosos, tipo baya, dehiscentes, constituidos por uno o dos lóculos con las semillas adheridas a la placenta axial, terneros con cinco lóbulos en el extremo, glabros, verdes cuando inmaduros, morados y rojos en *S. americanum* y *S. stramoniifolium* y verdes pulbescentes en *S. crinitum*, cuando están maduros. Las semillas son obovoides a subdiscoides, poco a muy comprimidas. La ornamentación de la frente es reticulada con paredes rectas a sinuosas y presencia de proyecciones filiformes. Internamente, las semillas son albuminosas con un endospermo gelatinoso que rodea todo el embrión de tipo axial, continuo lineal circinado a imbricado. El peso de 1.000 semillas fue mayor para las de *S. crinitum* con 2,36 g, seguida de *S. stramoniifolium* con 1,67 g y *S. americanum* con 0,4 g.
Palabras clave: Bayas; Jurubeba; Plantas salvajes.

1. Introduction

With the territorial expansion of agricultural areas due to the growth of agriculture, there was a rapid evolution of pioneer plants, emerging new species, resulting in greater diversification and specialization of weeds as well as their interference in agricultural activities (Holm et al., 1997; Merotto Junior et al., 2002; Pitelli, 2015).

Studies over the biology of these plant communities are of great importance in research on integrated management (Deuber, 2003; Lacerda et al., 2005). In this context, there is a need for methods of identification and morphological characterization of plants that directly interfere in competition with cultivated plants, since each species can develop adaptive characteristics in the different phases of the life cycle (Camargo et al., 2008; Ferreira & Barretto, 2015; Kozlowski et al., 2009, Mourão et al., 2007).

Some kinds of studies on the morphology of fruits and seeds have been developed, however, information is still lacking, on the number of seeds per fruit, fruit weight, size, and shape of the seeds, as well as other information of technological interest (Ramos & Ferraz, 2008). In addition, the biometric studies of fruits and seeds that can provide important data on variability of these characteristics among individuals in each area (Rodrigues et al., 2015; Souto et al., 2008).

The genus *Solanum* L. is the largest within the family Solanaceae Juss., presents a great diversity of invasive species, which colonize several environments, and demands a hard work of taxonomy in the group (Gouvêa et al., 2019; Knapp, 2002; Silva et al., 2003). In Brazil its genus is represented by 291 species, being 143 endemics (BFG, 2021; Flora e Funga do Brasil, 2022). There are few publications on the morphology of fruits, seeds, aspects on germination and seedlings of *Solanum*, with mention to the works of Groth (1989) and Castellani et al. (2008).

There are few publications that address the interspecific differences of fruits, seeds and seedlings of *Solanum* in the Amazonia, highlighting species of high interference in crops such as *S. americanum* Mill which can be found in agricultural areas, gardens and wasteland; *S. crinitum* Lam. pioneer in the invasion of clearings in forests, pastures and abandoned agricultural areas; and *S. stramoniifolium* Jacq. a species that can cause shading in cultivated plants up to 3m high (Dias-Filho, 1997; Falcão-da-Silva et al., 2016; Fontes & Nascimento Filho, 2013; Lorenzi, 2008).

Studies with seeds from plants in unwanted areas are necessary to find ways to management it (Viana et al., 2018). In addition, that the rich and diverse Amazonia's flora represents an excellent source of resources (Gurgel et al., 2019).

So, the biometric study of fruits and seeds is an indispensable tool that assists in the identification and presents basic characteristics that allow differentiating them or grouping in families, subfamilies, genera, and species, besides assisting in the management of these species of great interference (Leonhardt et al., 2008; Rodrigues et al., 2015; Santos et al., 2014).

2. Methodology

This study was conducted in anthropic areas, located in the Metropolitan Region of Belém (RMB), in the municipalities of Ananindeua (1°21'59"S 48°22'20"W), Belém (01º27'20" S 48º30'15"W), Santa Barbara (01º13'25"S 48º17'40"W) and Castanhal (1°29'78"S 47º95'42"W). The soil of the region was classified as a dystrophic yellow latosol of medium texture (Gama et al., 2020). And the climate is tropical rainy type Af according to the Köppen classification, with an average annual temperature of 27 °C, relative humidity around 85% and average annual rainfall of 3,000 mm (Bastos et al., 2002; Peel et al., 2007).

The collections were concentrated in agricultural areas located on the campus of the Federal Rural University of the Amazonia – UFRA (Belém) and the Federal Institute of Pará – IFPA (Castanhal), public parks located in the Marambaia neighborhood (Belém), Marajoara and West Forests, located in the Julia Seffer Complex (Ananindeua), conservation unit of the Utinga Park (Belém) and near the Iraci River Basin (Santa Barbara).

The fruits of four herbaceous-shrubby matrices of *S. americanum*, *S. crinitum* and *S. stramoniifolium* were transported to the Biotechnology Laboratory of Propagules and Seedlings (LBPM), located in the Goeldi Museum (MPEG) in Belém, and eliminating the poorly formed fruits with mechanical injuries, as well as their seeds. The definition of the fruit maturation phase for collection was determined by monitoring the individuals, analyzing the type of dehiscence and color change.

Morphometry of fruits and seeds

The number of 100 fruits and 100 seeds were randomly used for morphometric characterization, classification, color determination in maturation, texture, consistency, hair, brightness, shape, and dehiscence (Brasil, 2009). The seeds were used in water for 12 h and sectioned crosswise and longitudinally with steel blade for observation of the embryo, as well as its position inside the seed. The user characteristics were analyzed for identification (Brito et al., 2014; Castenllani et al., 2008; Groth, 1989; Pimenta et al., 2013; Trindade et al., 2021)

For the analysis of the ornamentation of the seed cout, a repetition with three seeds for each species, extracted from ripe fruits, after moisture removal was fixed in stubs and metallized with pale gold and examined under scanning electron microscopy (SEM).

The morphological characters of the fruits, seeds, were recorded with the aid of a digital camera and a stereomicroscope.

The biometrics of fruits and seeds were performed, at first, recording the diameter for the fruits and length, width, and thickness for the seeds, measured with the aid of a digital caliper with 0.01 mm precision. The quantification of fruit and seed mass was obtained with the aid of an analytical scale with four decimal places (AY 120 Shimadzu). Means and minimum values, maximums and standard deviations were recorded. In addition, the weight of 1,000 seeds was quantified according to the rules to analysis in seeds (Brasil, 2009).

3. Results and Discussion

The fruits of the species can be differentiated after maturation by the size, indument and color of the epicarp and through the indument, apex and adhesion of the lobes of the calyx (Table 1).

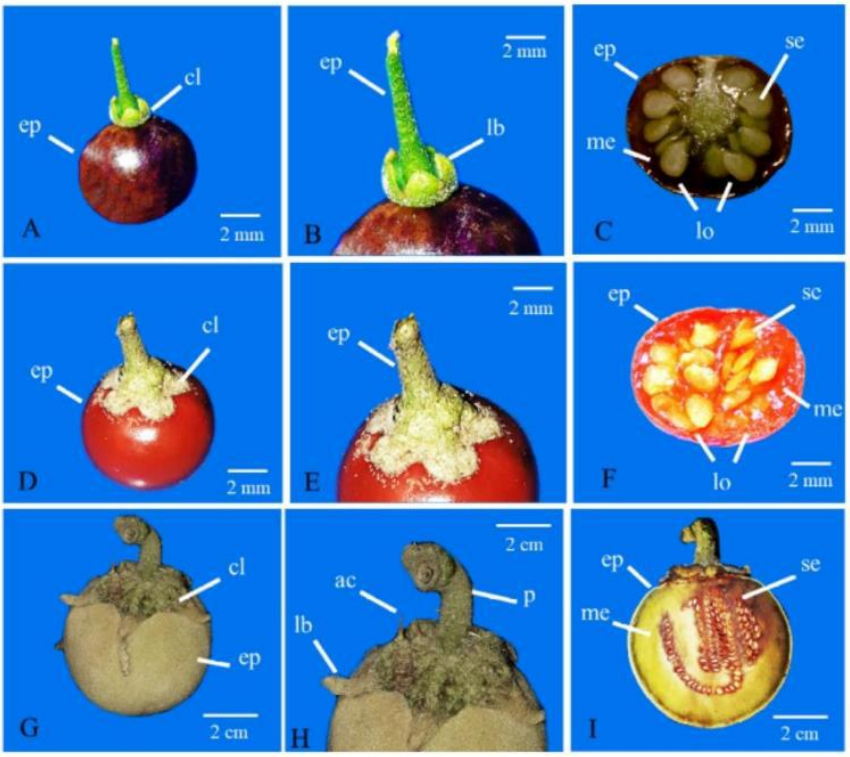
Table - Qualitative data that presented distinction of fruits and seeds of *S. americanum*, *S. crinitum* and *S. stramoniifolium*.

Structure	Characters	*S. americanum*	*S. crinitum*	*S. stramoniifolium*	Figures
Fruit	epicarp color	Purple	Green	Red	1A, 1D and 1G
	epicarp indument	Glabrous	pulbescent	Glabrous	
	calyx indument	Glabrous	starry and aculleos trichas	star-studded tricha	
	lobes adherence	Loose	Loose	Adhered	1B, 1E and 1H
	lobes apex	Rounded	Acute	Truncated	
	longitudinal contour	Obovoid	Ellipsoid	Ellipsoid	2D, 2E and 2F
	cross contour	little compressed	little compressed	Compressed	2G, 2H and 2I
Seeds	seed coat color	yellow to light orange	Black	yellow to opaque orange	2A, 2B and 2C
	hilo position	basal extremity	marginal median	marginal median	
	embryo shape	linear continuous imbricated	linear contincinatate	linear continuous imbricated	
	apex of cotyledons	Oblong	Oblong	Acute	2D, 2E and 2F
	radicle base	Oblong	Oblong	Acute	
	longitudinal section	oval wide	Oval	oval wide	2G, 2H and 2I

Source: Authors.

The fruits were classified as polyspermic, carnosous, berry or solanidia, globose, deiscentes, consisting of one or two locules with carnosum pericarp involving the entire central cavity with seeds attached to the axial placenta, glabrous in *S. americanum* and *S. stramoniifolium* and pulbescent in *S. crinitum*, gamossepal chalice with five lobes at the end (Figure 1C, 1F and 1I).

Figure 1 - (A, B and C) *S. americanum* Mill Fruits; (D, E and F) *S. stramoniifolium* Jacq: (G, H and I) *S. crinitum* Lam; (B, E and H) details of the chalice and wolves; (C, F and I) longitudinal section; ac-aculleo pe-peduncle, lb-lobe, cl-chalice, ep-epicarp, me-mesocarp, se-seed, lo-locule.



Source: Authors.

The fruits of *Solanum* are fleshy with a carnosous consistences. With attractive colors when ripe, in *S. americanum* purple; strong red in *S. satramoniifolium* and pale green in *S. crinitum*. Probabelly it feature is to be attractive to the animals, and so to favors the dispersion of seeds.

The fruits are polyspermic, fleshy, berry-type, dehiscent, consisting of one or two locules with the seeds attached to the axial placenta, with five lobes on the end, glabrous in *S. americanum* and *S. stramoniifolium*, but pulbescent in *S. crinitum*.

These descriptions fall into the genus *Solanum* described by Barroso et al. (1999), observed in Solanaceae (Castellani et al., 2008; Brito et al., 2014).

The *Solanum* seeds were classified as obovoide to ellipsoid, albuminous, with well-defined endosperm, peripheral, gelatinous and whitish, the embryo is axial, continuous linear, with micropyle difficult to visualize and inconspicuous plumule (Figure 2).

Figure 2 - (A, B and C) *S. americanum*, *S. crinitum* and *S. stramoniifolium*; (D, E and F) front view in cross-section, showing the position of the cotyledons and the hypocotyl axis; (G. H and I) longitudinal section showing the position of the embryo; ta-testa h-hilo, rad-radicle, ct-cotyledon, end-endosperm, in-embryo, tg-tegmen, rad-radicle.

Source: Authors.

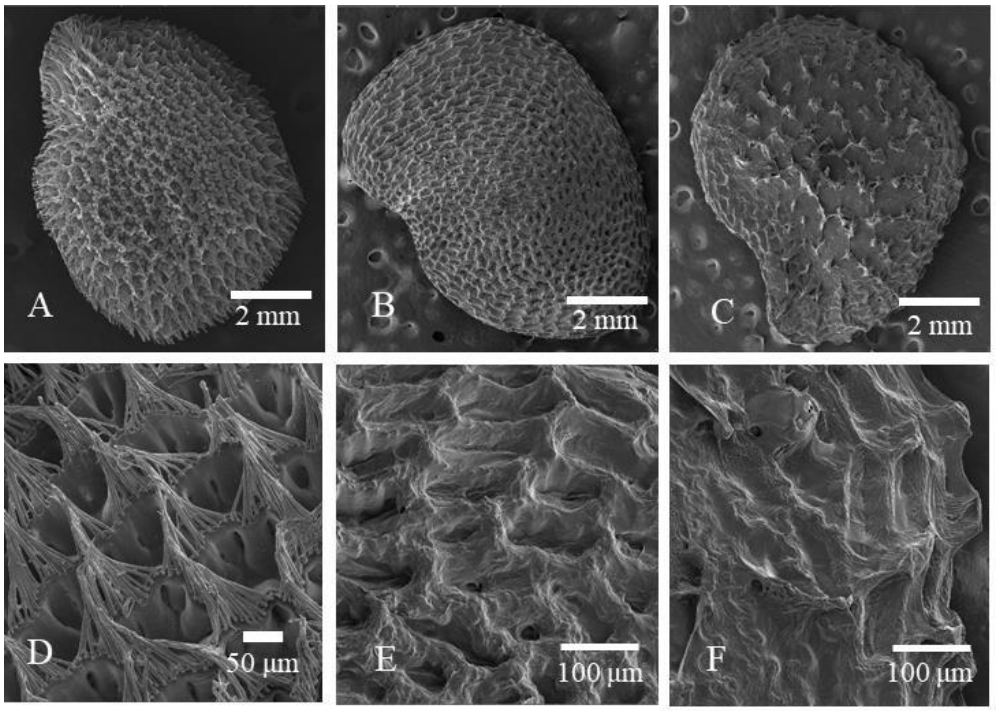
For the species studied here, the differences were presented in the longitudinal and transverse contour, ornamentation, presence or absence of filiform projections, seed coat color, hilum position, embryo shape and longitudinal section (Table 1).

In particular, the cross-section revealed that the cotyledons and the hypocotyl-radicle axis of *S. crinitum* seeds are like those seen in *S. pseudodoquina* A.St.-Hil. (Castellani et al., 2008) however, different in *S. stramoniifolium*, thus concluding that there may be a difference in the symmetry of cotyledons and hypocotyl-radicle axis in the same genus. Barroso et al. (1999) described the embryo of S*olanum* as curved, but studies conducted by the Ministry of Agriculture (Brasil, 2009) with species of Solanum the embryo can be characterized as circinated or emtwined.

The weight of 1,000 seeds was higher for those of *S. crinitum* 2.36 g, followed by *S. stramoniifolium* with 1.67 g and *S. americanum* with 0.4 g. The species of *Solanum* are very useful in the recovery of degraded areas, due to their large number of seeds per fruit, which makes the production of seedlings continuous (Silva et al., 2001).

Under scanning electron microscopy (SEM), it was possible to visualize the ornamentation of the forehead of the seeds studied, which allowed to separate the species as a function of three types of ornamentation found. The presence of filiform projections, the shape and arrangement of structures such as walls and walls, constituted important diagnostic characters for the three species (Figure 3).

Figure 3 - *S. americanum* seeds: A and D, ventral view; D, lateral seed coat showing parallel filiform projections arising at the end of the walls and grouping at the apex, walls with grooves. *S. crinitum*: B and E, front view; and detail of the ornamentation showing a mesh with straight to sinuoswalls forming apiculus at the angles. *S. stramoniifolium*: C and F, ventral view; F, frontal detail of the ornamentation with meshes with straight walls with apiculus at the angles.



Source: Authors.

In *S. stramoniifolium* and *S. crinitum* presented structures in the form of straight to sinuous walls in their ornamentation, the presence of apiculus at the angles of the walls of *S. stramoniifolium* was the relevant characteristic to differentiate it, while in *S. americanum* presented groove-shaped structures on the walls of its walls, the presence of filifomes projections that cluster at the apex was also a very remarkable characteristic compared to those of the other species.

Variations in seed forehead structure such as filiform projections were also reported in *S. campaneiform* Roem & *Schult leucoparcum* Dunal, *S. nundum* Dunal, *S. sinuatiexcisum* Bitter, *Schwenckia paniculata* (Raddi) Carvalho (Solanaceae), *S. sessile* R. & P (Barboza & Hunziker, 2005; Carvalho et al., 2000; Knapp, 2002) may be specific to seeds of the genus or family. The importance of scanning electron microscopy to establish patterns of forehead ornamentation, seen in Acanthaceae Juss. (Indriunas et al., 2014), Poaceae Barnhart (Salariato et al., 2008) and to several other families, being a remarkable character in taxonomic distinction (Potiguara et al., 2013).

Through the biometric results of fruits and seeds presented in Table 2, it was possible to notice great variation among the studied species. For the seeds, the highest values of length, width and seed mass were presented by *S. stramoniifolium*, while for the thickness the species that obtained the highest value was *S. crinitum* seed mass of the three species ranged from 1.04 g to 2.21 g.

Table 2 - Quantitative data related to samples of fruits (n= 100) and seeds, seeds (n=100) of *S. americanum*, *S. crinitum* and *S. stramoniifolium*.

Features	Variables	*S. americanum*	*S. crinitum*	*S. stramoniifolium*
fruit length (mm)	Minimum	3.73	33.25	10.00
	Maximum	6.65	43.16	10.40
	Average	5.28	38.40	10.10
	standard deviation	0.59	3.24	1.13
diameter of fruit (mm)	Minimum	4.93	32.06	10.00
	Maximum	7.53	42.99	10.30
	Average	6.34	37.82	11.00
	standard deviation	0.60	3.31	3.02
fruit mass (g)	Minimum	0.07	26.00	0.10
	Maximum	0.98	76.00	1.10
	Average	0.16	52.93	0.60
	standard deviation	0.06	15.89	0.25
seeds by fruit		60	217	147
seed length (mm)	Minimum	1.12	2.19	2.09
	Maximum	1.42	3.50	3.55
	Average	1.42	2.86	3.02
	standard deviation	0.12	0.25	0.25
seed thickness (mm)	Minimum	0.21	0.73	0.53
	Maximum	0,46	0.18	0.09
	Average	0.34	0.41	0.27
	standard deviation	0.05	0.13	0.11
seed width (mm)	Minimum	0.36	1.63	3.07
	Maximum	1.37	2.67	1.95
	Average	1.10	2.29	2.39
	standard deviation	0.12	0.21	0.21
seed mass (g)		1.04	1.84	2.21

Source: Authors.

For the studied in species of *Solanum* there was a great correlation between the measurements of length, diameter, and number of seeds per fruit with the fresh mass of the fruits, where fruits with greater length and diameter are heavier and have a higher number of seeds, this same correlation was observed in *Byrsonima verbascifolia* Rich. Ex A. Juss. (Gusmão et al., 2006)

The morphological and biometric data of fruits, seeds, and ornamentation of the microsculpture of the seed forehead were associated in keys to describe the three species (Key 1 and 2).

Another important character in the differentiation of fruits was the weight of a thousand seeds. *S. crinitum* reached the highest value with 2.36 g, followed by *S. stramoniifolium* with 1.67 g and *S. americanum* with 0.4 g.

The analysis of the water content of the seeds revealed that *S. americanum* and *S. stramoniifolium* obtained similar values with 79%, while *S. crinitum* reached the lowest value corresponding to 51%. The degree of humidity and temperature can directly influence the physiological quality of the seeds, due to the acceleration of internal metabolism and other factors that can cause the loss of germination capacity. For the seeds of *Solanum* some studies have shown that the alternating temperature regime benefited the germination process (Castellani et al., 2009; Costa et al., 2003).

The presence of tricha found in fruit inducment in the studied species is common in the genus, which can influence susceptibility to post-emergent herbicides and biological control with the use of pests or pathogens, besides serving as a characteristic in the distinction of species of the genus (Costa et al., 2010; Tunes et al., 2019; Mentz & Oliveira, 2004).

The morphological and biometric data of fruits, seeds, and ornamentation of the microsculpture of the seed forehead were associated in keys to describe the three species (Key 1 and 2).

Keys to three species of *Solanum* from Amazonia.

Key 1. *Solanum*'s fruits:

1. Calyx do not add to the fruit.

1. Fruit with black epicarp, 6.34 mm in diameter, glabrous calyx does not add to the fruit, apex of the lobes not adhered to the pericarp……..... *S. americanum*

1'. Calyx add to the fruit.

2. Fruit with green epicarp, pulbescent; 37.82 mm in diameter, pulbescent goblet; acicular aculeans and star trichocons, acute apex lobes not adhered to the pericarp.....*S. crinitum*

3. Fruit with glabrous red epicarp;11 mm in diameter, goblet with subsesis star trichomies, truncated lobes adhered to the pericarp…….....*S. stramoniifolium*

Key 2. *Solanum*'s seeds:

1. Imbricated embryo

2. Obovoid seed to subdiscoid; little compressed; 1.3 to 1.4 mm long; 0.34 mm thick; reticulated surface, with parallel filiform projections at the end of the walls forming grooves, grouping at the apex; linear hilum at the basal end, cross-section cotyledons and hypocotyl radicle axis visualized once.....*S. americanum*

2'. Ellipsoid seed to subdiscoid; very long; 3.0 to 3.6 mm long; 0.27 mm thick; reticulated surface with meshes with straight walls with apculi at angles; linear hilum in median-marginal position; cross-section cotyledons and hypocotyl radicle axis visualized once.....*S. stramoniifolium*

1'. Circinated embryo

3. Ellipsoid seed to little compressed subdiscoid; 2.7 to 3.1 mm long; 0.41 mm thick; reticulated surface, meshes with straight to sinue walls forming apículos at angles; linear hilum in the marginal median position; cross-section; cotyledons visualized twice and the hypocotyl-radicle axis once.....*S. crinitum*

4. Conclusion

The combination of the biometric and descriptive characters presented through this work can facilitate the early

identification of these three species (*S. americanum*, *S. crinitum and* and *S. stramoniifolium*) and their differentiation from other species of the genus *Solanum*.

Laboratory data from seed and fruit analyses like this may also be useful for more effective management practices, seed analysis studies, as well as for the cultivation and use of the species.

The database of the biometric characters from the three species of *Solanum* presents here, are useful to realize other studies over the species and in the group, through the methodology. The results shows that more research over the group is necessary, due be a great genus with large number of species in the Amazonia.

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