FLOVET
FLORA • VEGETAÇÃO • ETNOBOTÂNICA

Germination and morphology of fruits, seeds and seedlings of six abundant species of *Philodendron* Schott in the Central Amazon, Brazil

Caio Augusto dos Santos Batista[1]
Instituto Nacional de Pesquisas da Amazônia

Isolde Dorothea Kossmann Ferraz[2]
Instituto Nacional de Pesquisas da Amazônia

Geângelo Petene Calvi[3]
Instituto Nacional de Pesquisas da Amazônia

Maria de Lourdes da Costa Soares[4]
Instituto Nacional de Pesquisas da Amazônia

ABSTRACT

This study provides insight on seed germination and seedling morphology of species of *Philodendron* Schott, from Central Amazonia. Germination trials were done with 4x50 seeds on germination paper at 25 °C with 12h fluorescent light or in complete darkness. *Philodendron* infructescences were composed of berries with ca. 7–71 seeds per fruit. Seeds could be distinguished by variation in colour, macules and presence or not of aril. Seeds germinated only in light. Final germination was highest in *P. goeldii* (99%) with a Mean Germination Time of 4.5 days, followed by *P. fragrantissimum* (90%) in 123 days. Based on hypocotyl elongation, three patterns were described: elongated (3-6 mm) in *P. goeldii*, medium (1-2 mm) in *P. melloi* and *P. melinonii* and reduced (<1 mm) in *P. fragrantissimum*; *P. tortum* and *P. elaphoglossoides*.

[1] Mestre em Ciências Biológicas (Botânica) – Instituto Nacional de Pesquisas da Amazônia (INPA). Doutorando em Ciências Biológicas (Ecologia) – Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, Amazonas, Brasil. Av. Bem te vi, 2223, Manaus, Amazonas, Brasil, CEP: 69.057-970. ORCID: https://orcid.org/0000-0001-7216-2904. Lattes: https://lattes.cnpq.br/3332071756852967. E-mail: caioaugustobatista@gmail.com.

[2] Doutora em Fisiologia Vegetal – Universidade de Freiburg – Alemanha. Pesquisadora Titular III do Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brasil. Av. Bem te vi, 2223, Manaus, Amazonas, Brasil, CEP: 69.057-970. ORCID: https://orcid.org/0000-0003-3299-7856. Lattes: http://lattes.cnpq.br/9125127898290625 E-mail: isolde.ferraz@gmail.com.

[3] Doutor em Ciências de Florestas Tropicais (CFT) – Instituto Nacional de Pesquisas da Amazônia (INPA). Técnico do laboratório de Sementes do Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brasil. Av. Bem te vi, 2223, Manaus, Amazonas, Brasil, CEP: 69.057-970. ORCID: https://orcid.org/0000-0002-8631-2325. Lattes: http://lattes.cnpq.br/3129084768943101. E-mail: gpcalvi@gmail.com.

[4] Doutora em Ciências Biológicas (Botânica) – Instituto Nacional de Pesquisas da Amazônia (INPA). Pesquisadora Titular III do Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brasil. Av. Bem te vi, 2223, Manaus, Amazonas, Brasil, CEP: 69.057-970. ORCID: https://orcid.org/0000-0003-1337-0943. Lattes: http://lattes.cnpq.br/2941765741246392. E-mail: soaresinpa@gmail.com.

Morphological characteristics of seeds, seedlings and germination revealed to be valuable tools to distinguish the species of this study.
Keywords: Araceae; hemi−epiphytic; light; seed germination; seedling development.

Germinação e morfologia de frutos, sementes e plântulas de seis espécies abundantes de *Philodendron* Schott na Amazônia Central, Brasil

RESUMO

Este estudo fornece informações sobre germinação de sementes e morfologia de plântulas de *Philodendron* Schott, da Amazônia Central. Testes de germinação foram realizados com 4x50 sementes em papel de germinação a 25°C com 12 horas de luz ou no escuro. As infrutescências de *Philodendron* eram compostas por bagas com ca. 7–71 sementes/fruto. As sementes foram distinguidas pela cor, máculas e presença ou não de arilo. As sementes germinaram apenas sob luz. A germinação final foi maior em *P. goeldii* (99%) com Tempo Médio de Germinação de 4,5 dias, seguido por *P. fragrantissimum* (90%) em 123 dias. Com base no alongamento do hipocótilo, foram descritos três padrões: alongado (3-6 mm) em *P. goeldii*, médio (1-2 mm) em *P. melloi* e *P. melinonii* e reduzido (<1 mm) em *P. fragrantissimum*, *P. tortum* e *P. elaphoglossoides*. Características morfológicas das sementes, plântulas e germinação revelam-se ferramentas valiosas para distinguir as espécies deste estudo.
Palavras-chave: Aráceas; hemi-epífita; luz; germinação da semente; desenvolvimento de plântulas.

Germinación y morfología de frutos, semillas y plántulas de seis especies abundantes de *Philodendron* Schott en la Amazonía Central, Brasil.

RESUMEN

Este estudio proporciona información sobre germinación de semillas y morfología de plántulas de *Philodendron* Schott. Pruebas de germinación se realizaron con 4x50 semillas sobre el papel germinador a 25°C con 12 horas de luz o en total oscuridad. Inflorescencias de *Philodendron* estaban compuestas de bayas (7–71 semillas/fruto). Las semillas distinguense por el color, manchas y presencia o ausencia de arilos. Las semillas germinaron sólo bajo luz. Germinación fue mayor en *P. goeldii* (99%) con tiempo promedio de germinación de 4.5 días, seguida por *P. fragrantissimum* (90%) en un promedio de 123 días. En función del alargamiento del hipocótilo, fue descrito tres patrones: alargado (3-6 mm) en *P. goeldii*; medio (1-2 mm) en *P. melloi* y *P. melinonii*; y reducido (<1 mm) en *P. fragrantissimum*, *P. tortum* y *P. elaphoglossoides*. Las características morfológicas de las semillas, plántulas y germinación resultan ser herramientas valiosas para distinguir las especies de este estudio.
Palabras clave: Aráceas; hemi-epífita; luz; germinación de semillas; desarrollo de plántulas.

INTRODUCTION

Philodendron Schott is the second most diverse genus of Araceae Juss., currently with 487 species (BOYCE and CROAT, 2020), found predominantly in the Neotropics (MAYO et al., 1997). Now 169 species are listed with 97 for the Amazon biome, where the state of Amazonas is the region with the highest number of species, approximately

80% of the total (FLORA DO BRASIL, 2020). *Philodendron* is divided into the subgenera *Philodendron* Schott, *Pteromischum* (Schott) Mayo and *Meconostigma* (Schott) Engler (CANAL et al., 2018; CANAL et al., 2019), however infrageneric issues are still being discussed in this group (SAKURAGUI et al., 2018; VASCONCELOS et al., 2018).

Characteristics of fruits, seeds and seedlings can facilitate species identification in the field (FERRAZ et al., 2019). In addition, seed germination features combined with seedling morphology and development are useful to understand plant regeneration. Nevertheless, the germination process and seedling development were mostly done on species with terrestrial habits (SCOTT; SARGANT, 1898; BOODLE; HILL, 1929; SHAW, 1998; YANG et al., 1999; FUKAI et al., 2002; TILLICH, 2003), whereas *Philodendron* spp. are nomadic vines (ZOTZ, 2013) and more difficult to collect.

Seeds of *Philodendron* are generally small (<2 mm), being considered one of the smallest for the family (MAYO et al., 1997). Small seeds may be light dependent for germination (AUD and FERRAZ, 2012). However, light requirement for seed germination is not known for *Philodendron*. Some studies on *Arisaema* spp., a terrestrial genus of Araceae with larger seeds than *Philodendron*, revealed that *Arisaema dracontium* (L.) Schott did not need light for germination (YANG et al., 1999), and *Arisaema sikokianum* Franch. and Sav. germinated faster in the dark than in light (FUKAI et al., 2002).

Several species of *Philodendron* are of increasing ornamental use due to the beauty of the leaves, and here, local people make many items such as hats, baskets and handicrafts for home use or as additional income with the plant parts. Plant material is usually collected by rural populations in the natural habitat. For these people, the handling of seeds and seedlings could open possibilities for sustainable management and conservation of the species. Their propagation might become of economic importance for traditional communities in the future.

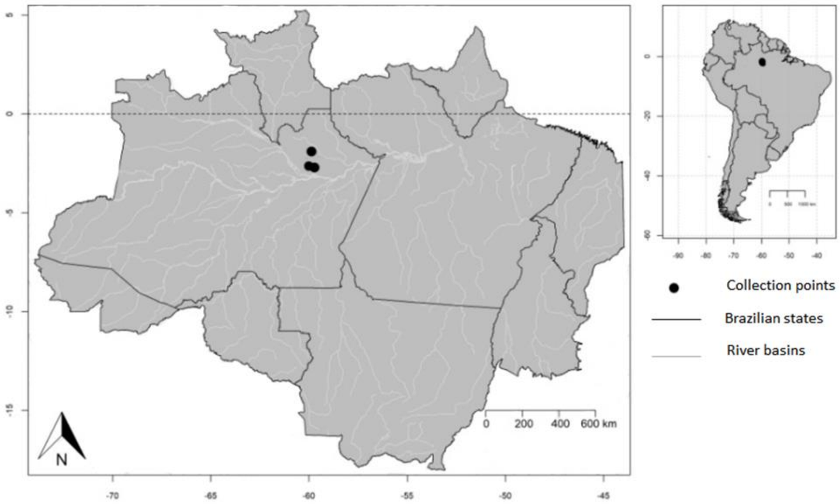
This study is a first approach to provide information on fruits and seeds of the six most abundant species of *Philodendron* in the Central Amazon, Brazil. Furthermore, it gives new insights on the germination process, seedling morphology and development.

MATERIAL AND METHODS

Description of the study area

Infructescences were collected near Manaus (Amazonas, Brazil) at (1) Tarumã, in a poor soil scrub forest (*campinarana*), (2) unflooded forest (*terra firme*) of the Adolpho Ducke Forest Reserve or (3) in the (*terra firme*) area of the Biological Dynamics of Forest Fragments Project (BDFFP) (Figure 1). Specimens with flowers were deposited in the National Institute for Amazon Research (INPA) herbarium. Three collections bearing only infructescences were used for the germination studies and were not deposited, since these species have no taxonomic difficulties and are already well represented in INPA´s herbarium (Table 1).

Figure 1 - Map showing the collection points of the six *Philodendron* species under study.



Source: Authors' collection. 2017.

Table 1 - Fruit collection sites (*campinarana* on Tarumã BR-174, km 12, Number 874, Manaus, 02°51'50.2" S 060°13'48.4" W; Adolpho Ducke Forest Reserve, AM-010, km 26, 02°55'41.3" S 059°58'12.8" W; Dynamic Biology Fragments Forestry Project (DBFFP), BR–174, 80 km north of Manaus, 2°26'30.00" S 59°47'8.00" W) collection periods and deposit numbers at the National Institute of Amazon Research´s herbarium.

Species	Collection Site	Collection Period (2017)	Collector	Herbarium INPA
Philodendron goeldii G.M.Barroso	Tarumã - Manaus	Nov/Dec	Batista, CAS 13	INPA 279916
Philodendron fragantissimum (Hook.)G.Don	RD - Manaus	Jun/Jul	Batista, CAS 11	INPA 270014
Philodendron tortum M.L.Soares and Mayo	RD - Manaus	Jun/Jul	Batista, CAS 10	Not deposited
Philodendron elaphoglossoides Schott	RD - Manaus	Jul/Aug	Batista, CAS 12	INPA 279915
Philodendron melloi Irume and M.L. Soares	BDFFP - Rio Preto da Eva	Apr/Jun	Batista, CAS 14	Not deposited
Philodendron melinonii Brongn. ex Regel	RD - Manaus	Jul/Aug	Batista, CAS 15	Not deposited

Source: Authors' collection. 2017.

Description of fruits, seeds and seedlings

Randomly chosen samples of 30 fruits, seeds and seedlings were described morphologically. Dimensions were measured with a digital calliper. A stereoscope (Leica® model S8APO) coupled to a digital camera (Leica® DFC295) was used for measuring small structures and capturing images. Biomass was assessed with a digital balance (0.0001 g).

Fruit description addressed colour, shape, texture, hairiness, weight, length, width, thickness and number of seeds. Seed description included colour, shape, texture, hairiness, weight, length, width, thickness, presence or absence of aril, and endosperm after longitudinal– and cross–sections. Seedling description included characteristics of the root, hypocotyl, cotyledon and euphyll. Seedlings were considered as healthy when they had a well root system, total expansion of the first, and appearance of the second euphyll. Plant characteristics for descriptions were based on Garwood et al., (1996), Mayo et al., (1997), Tillich (2000, 2003, 2007), and Ferraz et al., (2019).

Seeds were processed by manual compression of the fruits within a thin, small–mesh microfiber bag and then washed in running water for up to 3 minutes to eliminate pulp residues. After superficial drying with paper towels, seeds were kept in paper bags at 15 ± 1 ºC and RH 97 ± 3% until the beginning of the experiments.

For comparison between seed germination of apical and basal portions, the infructescence was cut into two equal parts, considering the basal section as connected to the peduncle. Seeds from apical and basal parts were processed separately. For other germination tests, seeds of the whole infructescence were combined after processing.

Seed germination

Seeds were sown above two layers of germination paper (10.5 x 10.5 cm, 250 $g.m^{-2}$) moistened with distilled water in transparent boxes (11 x 11 x 4 cm). Gerboxes were kept in thin transparent plastic bags (8 micr) to reduce moisture loss. Germination was tested in germination chambers (FANEM® MOD. 347 CDG, São Paulo, Brazil) with 12-h photoperiod using cold-cathode fluorescent lamps (70 $\mu mol\ m^{-2}\ s^{-1}$), constant 25 °C were maintained, as this is the average temperature in pristine forest near Manaus (ALVARES et al., 2013).

Statistical analyses

Germination variables were final germination success (G %), Germination Speed Index (GSI, after Maguire, 1962) and Mean Germination Time (MGT, after Laboriau, 1983). Relative Light Germination (RLG) was calculated after Milberg et al., (2000). Germination in darkness was achieved by wrapping each gerbox in two layers of aluminium foil. This treatment was assessed only when germination in light was stabilized. Radicle protrusion (≥ 2 mm) with positive geotropic curvature was assessed three times a week during 150 days.

Each germination treatment consisted of four replicates with 50 seeds. Results were evaluated through analyses of variance (ANOVA), with a comparison of means by Tukey's test at 0.05 significance. A *t*-test for independent samples at 0.05 significance was performed to verify possible differences among germinative performance of seeds taken from the apical and basal parts of the infructescences.

RESULTS

Infructescences of all species were composed of succulent berries with yellowish–white, orange, red or dark red colour. Berries of *P. goeldii* were significantly larger (16 mm length and 1.3 g) and had more seeds per fruit (71 on average) than the other species of this study, where seed numbers per fruit varied between 7 – 44 and the berries measured between 4 – 7 mm with about 0.1 g in weight (Table 2).

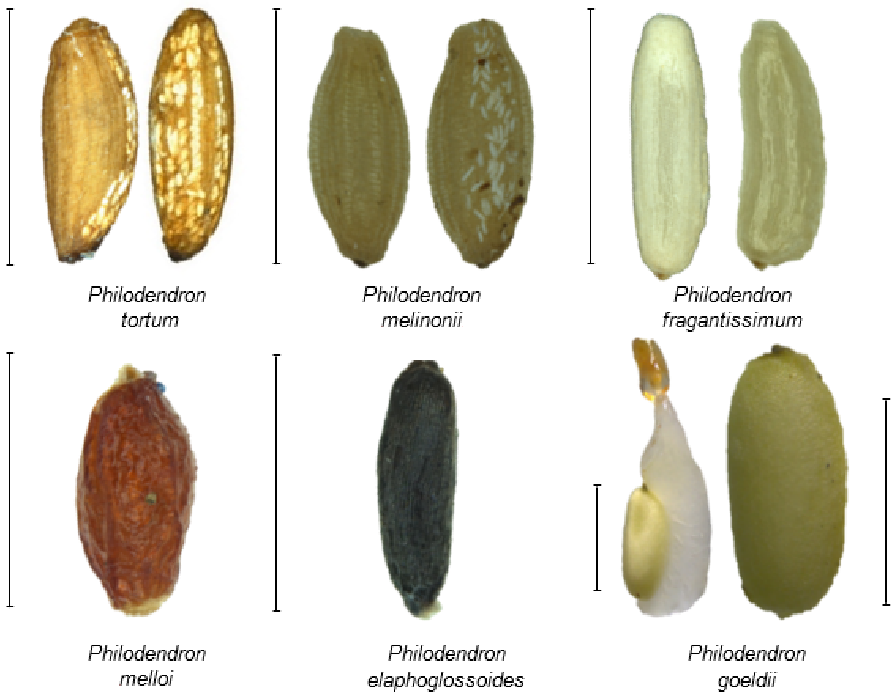
Table 2. Morphometric variables of the fruits and seeds of six species of *Philodendron* in this study.

	P. goeldii			***P. fragantissimum***			***P. tortum***			***P. elaphoglossoides***			***P. melloi***			***P. melinonii***		
	x̄	min-max	dp	**x̄**	min-max	dp	x̄	min-max	dp	x̄	min-max	dp	x̄	min-max	dp	x̄	min-max	dp
Fruit																		
Length (mm)	**16.1**	13.1-18.4	±1.3	**6.9**	3.17-8.39	±1.43	**3.7**	3.27-4.03	±0.23	**5.8**	3.48-7.63	±0.97	**3.8**	2.17-5.16	±0.84	**4.7**	3.65-6.13	±0.48
Width (mm)	**10.2**	9.05-12.2	±0.8	**4.5**	3.04-7.61	±0.88	**2.0**	1.65-2.29	±0.16	**4.2**	3.18-5.92	±0.59	**2.5**	1.54-4.09	±0.51	**3.3**	2.17-5.51	±0.58
Thickness (mm)	**10.2**	8.66-12.2	±0.8	**4.0**	2.51-5.78	±0.72	**1.8**	1.48-2.15	±0.15	**3.8**	2.59-5.45	±0.62	**2.3**	1.54-3.07	±0.34	**2.6**	1.42-4.51	±0.52
Weight (g)	**1.3**	0.88-1.75	±0.2	**0.1**	0.01-0.13	±0.03	**0.1**	0.01	0.0	**0.1**	0.02-0.22	±0.03	**0.1**	0.01-0.94	±0.16	**0.1**	0.01-0.38	±0.10
Seed (n)	**71**	0-115	±4.0	**44**	1-200	±50.1	**7**	4-12	±1.92	**64**	1-170	±42.2	**8**	1-31	±8.54	**30**	1-73	±15.3
Colour	Yellowish-white			Red			Light brown			Reddish			Orange			Yellowish-white		
Seed																		
Length (mm)	**1.4**	1.11-1.62	±0.1	**0.9**	0.81-0.88	±0.01	**1.1**	1.05-1.22	±0.05	**0.8**	0.75-0.89	±0.03	**0.7**	0.62-0.77	±0.04	**1.0**	0.39-1.14	±0.19
Width (mm)	**0.6**	0.48-0.78	±0.1	**0.3**	0.22-0.28	±0.01	**0.4**	0.36/0.51	±0.03	**0.2**	0.18-0.28	±0.02	**0.4**	0.32-0.42	±0.02	**0.5**	0.36-1.02	±0.17
Thickness (mm)	**0.8**	0.53-1.14	±0.1	**0.2**	0.18-0.24	±0.01	**0.5**	0.38-0.63	±0.04	**0.2**	0.14-0.25	±0.02	**0.3**	0.20-0.31	±0.02	**0.4**	0.37-0.50	±0.03
Form	Subcylindrical			Elliptic			Subglobose			Elliptic			Oblong			Oblong		
Colour	Yellowish-white			Yellowish-white			Light brown			Glossy black			Orange			Yellowish-white		
Macules	Absent			Present			Present			Absent			Absent			Present		
Area (%)	...			25-37			30-36			...			...			30-45		

Source: Authors' collection. 2017

Seeds of *Philodendron* spp. were very small, up to 1.62 mm (Table 2). Seed shape was elliptical, oblong or subcylindrical (Figure 2). Macules (possible needle–shaped calcium oxalate crystals, also called raphides) on the testa of *P. tortum*, *P. melinonii* and *P. fragrantissimum*, varied in shape, colour and percentage of area occupied per species (Figure 2). With the stereomicroscope, longitudinal to horizontal grooves could be detected on *P. melloi* and *P. elaphoglossoides* (Figure 2). Testa of *P. goeldii* was firm and the seeds had a large lateral aril (Figure 2). After horizontal cutting of the seeds, endosperm was visible in all species.

Figure 2 - Seed coat characteristics. *Philodendron tortum, P. melinonii, P. fragrantissimum* have seeds with macules on one longitudinal side (both sides shown); seeds of *P. melloi* have grooves, and *P. elaphoglossoides* have striations on the whole surface (only one seed side shown) and *P. goeldii* shown with and without lateral white aril. Bars: 1 mm.

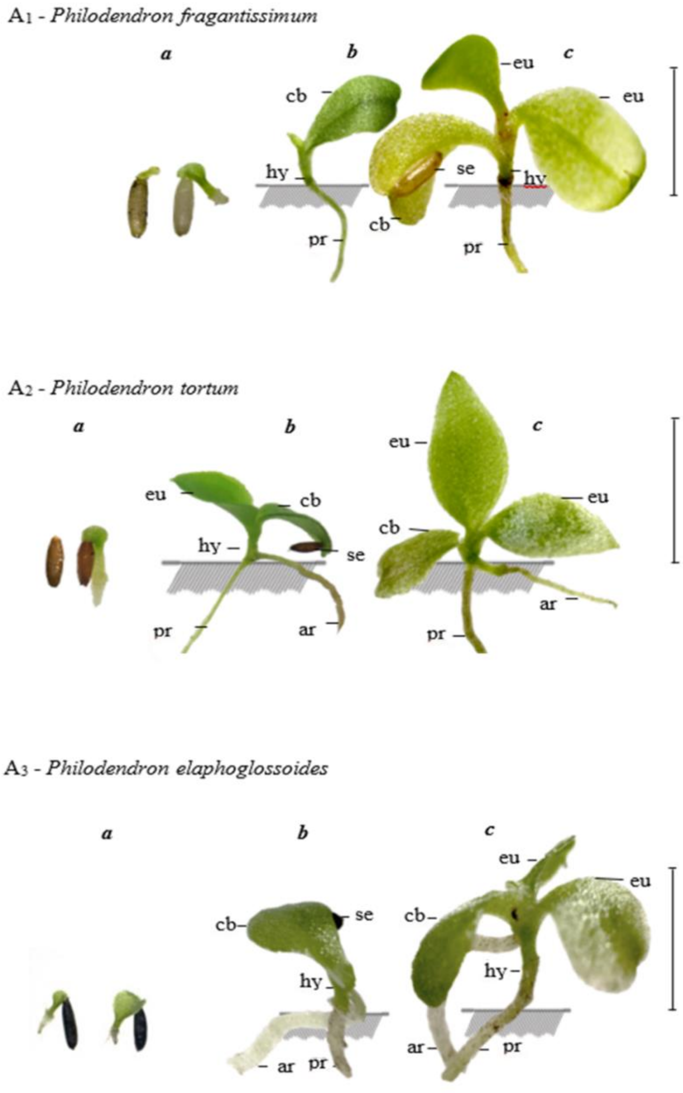


Source: Authors' collection. 2017.

The primary root of the seedlings was white to light green and covered with numerous to scarce, fine brown trichomes. Root growth was positively geotropic. During initial development of *P. melinonii* and *P. goeldii*, one of the first adventitious roots turned into the main root (Figure 3, 4).

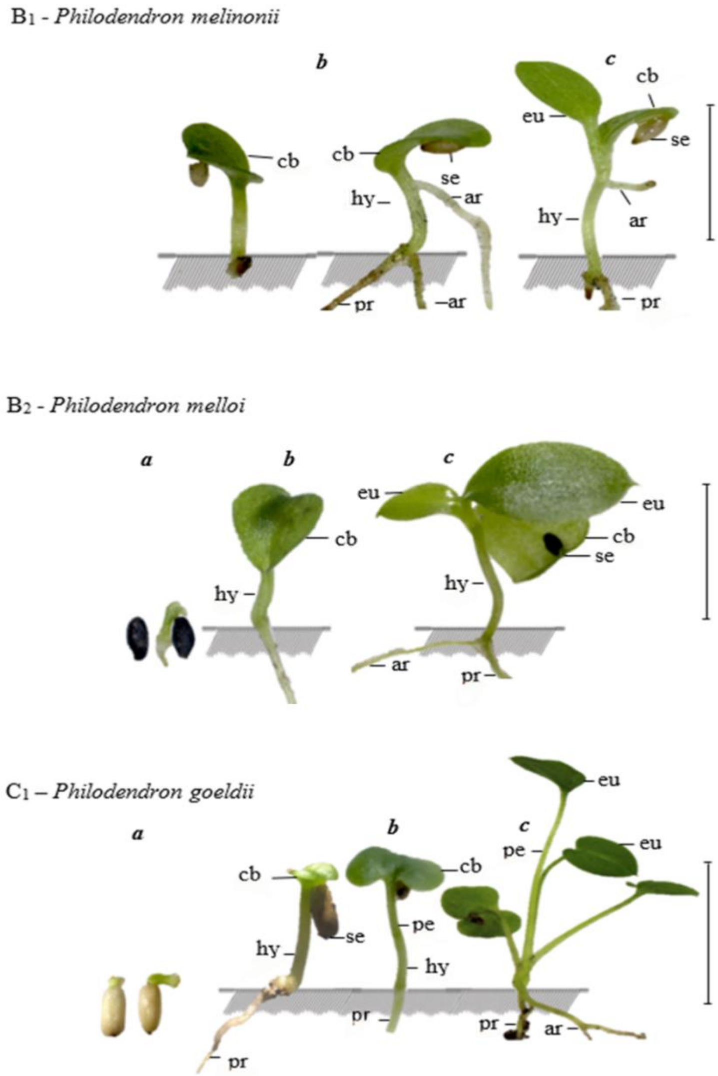
Hypocotyls were light green, cylindrical to grooved and ranged within the species from 0.2 – 6.0 mm in length; at its base (collar), glands and a ring of fine trichomes were registered (Figure 3, 4). Cotyledon sheaths were discrete or fleshy. Cotyledon blades were lanceolate to eight–shaped, and at the base were usually cuneate to rounded. The major part of the cotyledon was foliaceous, however, a persistent haustorial portion at the apex was observed, which was acuminate if freed from the seed. Cotyledon venation was hemi-eucampidodromous to acrodromous; petioles sessile to elongated (Figure 3, 4). Euphyll blades were ovoid to cordate, base cuneate, apex apiculate to acuminate with a short, single, simple, unicellular trichome, persistent or not in adult plants (Figure 3, 4).

Figure 3 - Morphology of germination and seedlings, hypocotyl length. **A**: reduced hypocotyl (A_1) *Philodendron fragantissimum*, (A_2) *P. tortum*; (A_3) *P. elaphoglossoides*; ***a***) root protrusion and expansion of the cotyledon blade; ***b***) hypocotyl elongation and further expansion of cotyledon blade; ***c***) seedling with several leaves; ar) adventitious root; cb) cotyledon blade; eu) euphyll; hy) hypocotyl; pr) primary root; se) seed. Bars: 1 cm



Source: Authors' collection. 2017.

Figure 4 - Morphology of germination and seedlings, hypocotyl length. **B**: medium length hypocotyl, (B_1) *Philodendron melinonii*, (B_2) *P. melloi*; **C**: elongated hypocotyl, (C_1) *P. goeldii*. ***a***) seed and root protrusion; ***b***) hypocotyl elongation and expansion of cotyledon blade; ***c***) seedling with several leaves; ar) adventitious root; cb) cotyledon blade; eu) euphyll; hy) hypocotyl; pe) petiole; pr) primary root; se) seed. Bars: 1 cm.



Source: Authors' collection. 2017.

Final germination was highest in *P. goeldii* (99%) with an MGT of 4.5 days, followed by *P. fragrantissimum* (90%); however the last one needed 123 days, on average. High germination success in a short period was also revealed by GSI in *P. goeldii* (5.9). In contrast, the long germination period reduced GSI to 0.3 in *P. fragrantissimum* (Table 3). Germination success of the other species was ≤ 25%, with MGT ranging between 7 – 15 weeks, and GSI between 0.2 – 0.5 (Table 3). None of the species germinated in darkness, which were classified as positively photoblastic (Table 3). No difference was detected in germination traits between seeds from apical and basal regions of the infructescences (Table 4).

Table 3 - Germination characteristics of a combined seed sample from the whole infructescence, comparing six species of *Philodendron*, arranged in order of germination success: Final Germination (G), Mean Germination Time (MGT), Germination Speed Index (GSI) and Relative Light Germination (RLG).

Species	**G (%)**		**MGT (d)**		**GSI**		**RLG**
P. goeldii	99.0	a	4.5	a	5.9	a	1
P. fragrantissimum	90.5	a	123.0	d	0.3	bc	1
P.elaphoglossoides	25.0	c	90.0	c	0.2	cd	1
P. tortum	15.0	cd	72.1	bc	0.2	d	1
P. melinonii	5.3	d	47.5	b	0.5	b	1
P. melloi	20.0	b	105.7	cd	0.1	e	1
	F = **1.51**		F = **1.51**		F = **1.57**		
	W =**0.95**		W = **0.96**		W = **0.98**		

* Different letters in columns denote statistical differences between species (Tukey test 5%). W; F: statistics of the Shapiro-Wilk and Levene tests, respectively. All data had normal distribution and homogeneous variance at 0.05 significance.
Source: Authors' collection. 2017.

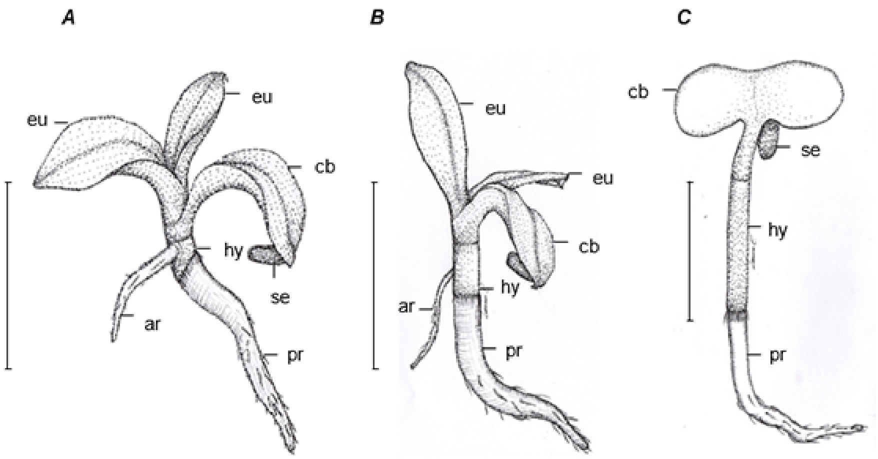
Table 4 - Germination characteristics of seeds extracted from apical (Api) and basal (Bas) parts of the infructescence, comparing six species of *Philodendron*. Final Germination (G), Mean Germination Time (MGT) and Germination Speed Index (GSI).

Species	**G (%)**		**MGT (d)**		**GSI**	
	Api	Bas	Api	Bas	Api	Bas
P. goeldii	97.0	99.0	5.5	6.2	4.5	4.1
P. fragrantissimum	96.0	94.0	112.4	95.0	0.5	0.5
P.elaphoglossoides	18.0	13.0	93.2	74.7	0.1	0.1
P. tortum	12.5	15.0	91.3	72.1	0.1	0.1
P. melinonii	11.0	10.0	74.7	58.7	0.1	0.1
P. melloi	22.0	20.0	121.1	111.1	0.1	0.1

*No statistical difference between seeds from apical and basal parts within species was observed with *t-test* at 5%.
Source: Authors' collection. 2017.

A significant distinction in seedling morphology was the hypocotyl length and we suggested three patterns: reduced (<1 mm); medium length (1 – 2 mm) and elongated (3 – 6 mm; Figure 5). According to this classification, three species had a reduced hypocotyl: *Philodendron fragantissimum*, *P. tortum*, *P. elaphoglossoides* (Figure 3), two species *P. melinonii* and *P. melloi* had a medium length hypocotyl and only *P. goeldii* an elongated hypocotyl (Figure 4).

Figure 5 - Three distinct seedling patterns by hypocotyl length: **A)** reduced hypocotyl (0.2–0.5 mm); **B**) medium length hypocotyl (1.3–2.3 mm); **C**) elongated hypocotyl (2.6–6.0 mm); eu: euphyll; hy: hypocotyl; cb: cotyledonar blade; ar: adventitious root, pr: primary root. Bars: 1 mm.



Source: Authors' collection. 2017

DISCUSSION

Infructescences, composed of berries with several seeds and ephemeral when ripe, agree with earlier studies on these species (MAYO et al., 1997). Spontaneous abortion and severe predation by insects were the major causes of short-lived fruits of *Philodendron* spp. in this study. An exception was *P. goeldii*, its infructescence did not abort the fruits and most of the seeds remained viable, even when predated. We might conclude that abortion may be a response to insect predation since this species has no other way of propagation, such as flagella. A similar hypothesis has already been formulated by GIBERNAUT et al., (2002) for the same genus.

Field observations indicated maturation from apex to base for the infructescence of *P. goeldii* and from base to apex for the other species in this study. A continuous increase of the infructescence circumference beginning at the basal portions during fruit maturation had been reported in a phenological study of three species of Amazonian *Philodendron* (LINS et al., 2013). This led us to suppose that seed maturation may be related to the location of the fruit in the infructescence. However, no significant difference was detected between germination traits of seeds from basal and apical parts of mature infructescences. Perhaps with a higher seed number per repetition, or with collections before complete maturation of the infructescence, statistical differences between fruit locations during maturation could be detectable.

Philodendron is known to have the smallest seeds in Araceae (BOWN, 1988; MAYO et al., 1997; COELHO, 2000), and we confirm small seeds (0.7 – 1.4 mm) for the six species of this study of which *P. tortum*, *P. melinonii* and *P. elaphoglossoides* are described here for the first time. Tiny seeds in succulent berries organized in an infructescence may lure a variety of animals and be dispersed endozoochorously and exozoochorously, when maintained in the fruit pulp attached to animals.

Comparatively larger seeds with an aril were a characteristic of *P. goeldii*. Generally, an aril is meant to attract seed dispersers and are associated with dry fruits (FERRAZ et al., 2019). Laboratory observations in this study suggested that the aril may function as well as a moisture reserve throughout the germination process. Compared to the species of this study, *P. goeldii* occurs in open areas or higher in the canopy (CALAZANS et al., 2014) than the others species of this study, and an additional moisture reservoir may be an advantage for the early establishment in a more xeromorphic habitat.

Seed macules in *P. tortum*, *P. melinonii* and *P. fragrantissimum* are helpful for distinction between these species. Macules may possibly be raphides of calcium oxalate as defence against potential predators. We observed that seeds of *P. goeldii*, which do not have macules, were frequently infested by insects. A similar observation was made in *P. solimoesense* A.C.Sm. (GIBERNAU et al., 2002). Our description on *P. melloi* differs from IRUME et al., (2017), as we did not detect macules. We suppose that macules observed in the former description were remnants of oxidized pulp, since in this study a magnifier with a high resolution was available.

Differences between germination capacity may be related to the species' habitat. *P. fragrantissimum* and *P. goeldii* with high final germination (91% and 99%; respectively), are known as generalists in the forests near Manaus, and the others are specialists of a certain habitat (SOARES and MAYO, 1999). Interestingly, MGT was several months (123 d) in *P. fragrantissimum* compared to few days (4.5 d) in *P. goeldii*. As *P. goeldii* is a species of drier areas (CALAZANS et al., 2014) than the others, fast germination and additional moisture provided by the aril may be of advantage for its establishment. Different from *P. fragrantissimum*, which occurs in shaded and constantly moist habitat, here germination time may not be crucial for survival, and its seeds have no aril. A germination time of more than several weeks was assessed for the other four species of *Philodendron* also occurring in shaded habitat. Future studies on germination temperature may elucidate habitat preferences of these species.

Perhaps the low germination success of four species and the long germination time of five species could be related to some type of dormancy. In this study, germination was assessed for 150 days and possibly the process was not completed. Under favourable conditions, long germination time may indicate a dormancy (BASKIN and BASKIN, 2004). Physical and morphological seed dormancy are known for *Arisaema dracontium* (L.) Schott (YANG et al., 1999) from the same family. No reports on seed dormancy are known for *Philodendron* species.

All species of this study needed light for germination. Light requirement is generally associated with pioneer plants, which establish at the beginning of ecological succession (SWAINE and WHITMORE, 1988). This is not the case for these species. Dependence on light has been related to seed size in several plant groups, where small-seeded species were more dependent on light for germination than large-seeded species (MILBERG et al., 2000; AUD and FERRAZ, 2012). Seeds of *Philodendron* are considered the smallest in the family, in comparison to the larger seeds of *Arisaema* Mart. *Arisaema dracontium* (L.) Schott needed no light for germination (YANG et al., 1999) and *Arisaema sikokianum* Franch. and Sav. germinated even faster in darkness than under light (FUKAI et al., 2002). We suggest that a combined dormancy could be acting in the photoblastic positive seeds of *Philodendron* species of this study, which needed several months to germinate.

Seedling morphology of Araceae is poorly understood and of the 144 genera (BOYCE and CROAT, 2020), only a few germination studies are available. Seedlings of monocotyledons may have two types of roots (primary and adventitious), both with similar structures, but differing in function and origin (BENZING, 2000). The primary root may be ephemeral and replaced by an adventitious root (TILLICH, 2000), which in Araceae is usually associated with an epiphytic habit (MAYO, 1988). Both types of roots were still present at the initial development of all seedlings in this study.

Differentiation of the dicotyledon seedlings in cryptocotylar or phanerocotylar may be inadequate to describe monocotyledon germination, because the cotyledon or its petiole may be only partially visible, turning green and becoming photosynthetically active, while part of its blade maintains haustorial and stays cryptocotylar. A well-known example of this is the germination of garlic, where the cotyledon apex remains in the seed (BEWLEY and BLACK, 1983). In the present study, the cotyledon apex remained inside the seed with haustorial function, despite the major part of the cotyledon blade being expanded and exposed. This led us to consider the cotyledon as more similar to phanerocotylar than to cryptocotylar seedlings.

Epigeal germination was described in Araceae for *Xanthosoma* Schott, *Caladium* Vent. (GARWOOD, 2009) and *Colocasia* Schott (MAYO et al., 1997). All six species of *Philodendron* in this study had epigeal germination, as hypocotyl length was possible to measure and was used to categorize the seedlings in three patterns.

The proposed grouping of species by hypocotyl elongation may underpin molecular phylogenetic studies grouping *P. fragrantissimum* and *P. elaphoglossoides* in one clade and *P. goeldii* in another (LOSS-OLIVEIRA et al., 2016). The current infrageneric classification of the genus *Philodendron* is still under discussion. The reestablishment of species of the genus *Elopium* Schott, as proposed by SAKURAGUI et al., (2018), previously was belonging to the subgen. *Pteromischum*, and the re-circumscription of subgen. *Meconostigma* of the genus *Thaumatophyllum* Schott, as proposed by VASCONCELOS et al., (2018) are not yet fully accepted. Furthermore, other studies disagree since the monophyly of the genus *Philodendron* is a consensus (CANAL et al., 2018, 2019).

Seed and seedling morphological characters are rarely listed for the Araceae. However, they have been shown to be valuable tools for evolutionary and ecological approaches in southern African tree/shrub species (ZANNE et al., 2005) and in neotropical dry forests (CORTÉS-FLORES et al., 2020). In this sense, the proposed grouping by hypocotyl elongation may be a keystone for phylogenetic relationships. However, more studies on *Philodendron* seedlings are needed.

Conclusion

This is the first study on seed germination of the six most abundant species of *Philodendron* in the Central Amazon, accomplished with morphometric data on fruits and seeds. All fruits were berries with few to many seeds. Seeds could be distinguished by colour, macules and grooves and *P. goeldii* by its aril. We suggest that the aril functions predominantly as a moisture reservoir for seed germination. Seedling morphology was epigeal and hypocotyl length was a distinguishing feature; the cotyledon assumed two functions as its base becomes visible and green (phanerocotylar) and the apex remains haustorial enclosed in the seed (cryptocotylar).

A large variation in germination capacity was observed and all seeds needed light for germination. MGT varied between few days to several months, which suggest for some of these species a combined seed dormancy. No difference was detected in germination features between seeds from the apical and basal portions of the infructescences. Further studies on fruit maturation patterns across the infructescence related to seed germination and on a possible combined seed dormancy are encouraged.

Acknowledgements
This work is part of C.A.S.B. MSc. dissertation in the Botany Programme (PPG-BOT) of the Instituto Nacional de Pesquisas da Amazônia – INPA, supported by a 24-month fellowship from Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM), and received additional support of Cooordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Financial code 001. IDKF was a research fellow of Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen’s climate classification map for Brazil. *Meteorologische Zeitschrift*, 22: 711–728. 2013.

AUD, F. F.; FERRAZ, I. D. K. Seed size influence on germination responses to light and temperature of seven pioneer tree species from the central amazon. *Anais da Academia Brasileira de Ciências*, 84: 759–766. 2012.

Baskin, J. M.; Baskin, C. C. A classification system for seed dormancy. *Seed Science Research*, 14: 1–16. 2004.

BENAVIDES, A. M.; WOLF, J. H.; DUIVENVOORDEN, J. F. Colonization of forest clearings and tree-fall gaps in lowland rain forests of Colombia by hemiepiphytic aroids: Experimental and transect studies. *Journal of Tropical Ecology*, 29: 123–130. 2013.

BENZING, D. H. Bromeliaceae: Profile of an adaptive radiation. Cambridge University Press, Melbourne Australia. 2000.

BEWLEY, J. D.; BLACK, M. Physiology and biochemistry of seeds in relation to their germination. 2nd ed. Springer-Verlag, New York. 1983.

BOODLE, L.; HILL, A. W. *Typhonodorum lindleyanum*: The development of the embryo and germination of the seed. *Annals of Botany*, 43: 437–450. 1929.

BOWN, D., Aroids: plants of the Arum Family. Timber Press, Portland, Oregon. 1988.

BOYCE, P. C.; CROAT, T. B. The Überlist of Araceae, Totals for Published and Estimated Number of Species in Aroid Genera, 2: 1–3. 2014. http://www.aroid.org/genera/140601uberlist.pdf (Accessed 07 June 2020).

CALAZANS, L. S. B.; SAKURAGUI, C. M.; MAYO, S. J. From open areas to forests? The evolutionary history of *Philodendron* subgenus *meconostigma* (araceae) using morphological data. *Flora —Morphology, Distribution, Functional Ecology of Plants*, 209: 117–121. 2014.

CANAL, D.; KÖSTER, N.; CELIS, M.; CROAT, T. B.; BORSCH, T.; JONES, K. E. Out of Amazonia and Back again: Historical Biogeography of the Species-Rich Neotropical Genus *Philodendron* (Araceae). *Annals of the Missouri Botanical Garden*, 104: 49-68. 2019.

CANAL, D.; KÖSTER, N.; JONES, K. E.; KOROTKOVA, N.; CROAT, T. B.; BORSCH. T. Phylogeny and diversification history of the large Neotropical genus *Philodendron* (Araceae): Accelerated speciation in a lineage dominated by epiphytes. *American Journal of Botany*, 105: 1035–1052. 2018.

COELHO, M.A.N. *Philodendron S*chott (Araceae): Morfologia e taxonomia das espécies da Reserva Ecológica de Macaé de Cima–Nova Friburgo, Rio de Janeiro, Brasil. *Rodriguesia*, 51: 21–68. 2000.

CORTÉS-FLORES, J.; CORNEJO-TENORIO, G.; SÁNCHEZ-CORONADO, M. E.; OROZCO-SEGOVIA, A.; IBARRA-MANRÍQUEZ, G. Disentangling the influence of ecological and historical factors on seed germination and seedling types in a Neotropical dry forest. *PLoS ONE*, 15, e0231526. 2020. https://doi.org/10.1371/journal.pone.0231526.

FERRAZ, I. D. K.; CAMARGO, J. L. C.; MESQUITA, M. R.; SANTOS, B. A.; BRUM, H. D.; ALBUQUERQUE, M. C. F. E. Guide to Amazonian Fruits, Seeds & Seedlings. 1. ed. Editora INPA, Manaus. 226p. 2019.

FLORA DO BRASIL 2020. Jardim Botânico do Rio de Janeiro. http://floradobrasil.jbrj.gov.br/ Accessed on 08 July 2020.

FUKAI, S.; HASEGAWA, A.; GOI, M.; YAMASAKI, N. Seed propagation of *Arisaema sikokianum* (Araceae). *VIII international symposium on flowerbulbs*, 570: 327–330. 2000.

GARWOOD, N. C. Functional morphology tropical tree seedlings. In: Swaine, M.D., (Eds.) The ecology of tropical forest tree seedlings. Parthenon Publishing Group, New York, pp. 59-129. 1996.

GARWOOD, N. C.; TEBBS, M. C. Seedlings of Barro Colorado Island and the Neotropics. In association with the Natural History Museum, London. 2009.

GIBERNAU, M.; ALBRE, J.; DEJEAN, A.; BARABÉ, D. Seed predation in *Philodendron solimoesense* (Araceae) by chalcid wasps (Hymenoptera). *International journal of plant sciences*, 163: 1017–1023. 2002.

IRUME, M.V.; SOARES, M. D. L.; MAYO, S. J.; CARVALHO, R. B. de; ZARTMAN, C. E. *Philodendron melloi* (Araceae), A New Species from Central Amazonia, Brazil. *Phytotaxa*, 319: 184–190. 2017.

LABOURIAU, L. G. A germinação das sementes. Secretaria Geral da Organização dos Estados Americanos, Washington. 1983.

LINS, A. L. F. A.; NETO, S. V. C.; CASTRO, R. M. C. Considerações fenológicas, morfológicas e anatômicas das infrutescências e sementes de três espécies de *Philodendron* Schott (Araceae) In: LISBOA, P. L. B. (Eds.) Caixiuanã: paraíso ainda preservado. v.2. Museu Paraense Emílio Goeldi, Belém, Pará, pp. 298-309. 2013.

LOSS-OLIVEIRA, L.; SAKURAGUI, C.; SOARES, M. L.; SCHRAGO, C. G. Evolution of *Philodendron* (Araceae) species in Neotropical biomes. *PeerJ*, 4: 1–18.
MAGUIRE, J.D., 1962. Speed of germination-aid in selection and evaluation for seedling emergence and vigor 1. *Crop science*, 2: 176–177. 2016.
MAYO, S. J.; BOGNER, J.; BOYCE, P. C. The Genera of Araceae. Continental Printing, Houthalen-Helchteren, Belgium. 1997.
MAYO, S. J. Aspectos da evolução e da geografia do gênero *Philodendron S*chott (Araceae). *Acta Botanica Brasilica*, 1: 27–40. 1987.
MILBERG, P.; ANDERSSON, L.; THOMPSON, K. Large-seeded species are less dependent on light for germination than small-seeded ones. *Seed Science Research*, 10: 99–104. 2000.
SAKURAGUI, C. M.; CALAZANS, L. S. B.; LOSS-OLIVEIRA, L.; MORAIS, E. B.; BENKO-ISEPPON, A. M.; VASCONCELOS, S. et al., Recognition of the genus *Thaumatophyllum* Schott – formerly *Philodendron* subg. *Meconostigma* (Araceae) − based on molecular and morphological evidence. *PhytoKeys*, 98: 51–71. 2018.
SHAW, D.E. *Gymnostachys anceps* R.BR.: Fruit, germination, and a discussion of the possible means of dispersal. *Aroideana*, 20: 71–78. 1998.
SOARES, M. L. C.; MAYO, S. J. Araceae. In: RIBEIRO, J. E. L. S.; VICENTINI, A.; SOTHERS, C. A.; COSTA, M. A. S.; BRITO, J. M.; SOUZA, M. A. D.; MARTINS, L. H. P.; LOHMANN, L. G.; ASSUNÇÃO, P. A. C. L.; PEREIRA, E. C.; SILVA, C. F.; MESQUITA, M. R.; PROCÓPIO, L. (Eds). Flora da Reserva Ducke: Guia de identificação das plantas vasculares de uma floresta de terra–firme na Amazônia Central. Instituto Nacional de Pesquisas da Amazônia, Manaus, pp.672-687. 1999.
SCOTT, R.; SARGANT, E. On the development of *Arum maculatum* from the seed. *Annals of Botany*, 12: 399–414. 1898.
SWAINE, M.; WHITMORE, T. C. On the definition of ecological species groups in tropical rain forests. *Vegetation*, 75: 81-86. 1988.
TILLICH, H.-J. Ancestral and derived character states in seedlings of Monocotyledons. In: WILSON, K. L.; MORRISON, D. A. (Eds.) Monocots: Systematics and Evolution. Melbourne, pp. 221–228. 2000.
TILLICH, H.-J. Seedling diversity in Araceae and its systematic implications. *Feddes Repertorium: Zeitschrift für botanische Taxonomie und Geobotanik*, 114: 454–487. 2003.
TILLICH, H.-J. Seedling diversity and the homologies of seedling organs in the order Poales (Monocotyledons). *Annals of Botany*, 100: 1413–1429. 2007.
VASCONCELOS, E. V.; VASCONCELOS, S.; RIBEIRO, T.; BENKO-ISEPPON, A. M.; BRASILEIRO-VIDAL, A. C. Karyotype heterogeneity in *Philodendron* s.l. (Araceae) revealed by chromosome mapping of rDNA loci. *PloS one*, 13, e0207318. 2018. https://doi.org/10.1371/journal.pone.0207318.
ZANNE, A. E.; CHAPMAN, C. A.; KITAJIMA, K. Evolutionary and ecological correlates of early seedling morphology in east African trees and shrubs. *American Journal of Botany*, 92: 972–978. 2005.
ZOTZ, G. “Hemiepiphyte”: a confusing term and its history. *Annals of botany*, 111: 1015–20. 2013.

YANG, J.; LOVETT-DOUST, J.; LOVETT-DOUST, L. Seed germination patterns in green dragon (*Arisaema dracontium*, Araceae). *American Journal of Botany*, 86: 1160–1167. 1999.

HISTÓRICO
Submetido: *10 de outubro de 2023.*
Aprovado: *31 de outubro de 2023.*
Publicado: *09 de novembro de 2023.*

COMO CITAR O ARTIGO - ABNT

BATISTA, C. A. S.; FERRAZ, I. D. K.; CALVI, G. P.; SOARES, M. L. C. Germination and morphology of fruits, seeds and seedlings of six abundant species of *Philodendron* Schott in the Central Amazon, Brazil. **FLOVET - Flora, Vegetação e Etnobotânica**, Cuiabá (MT), v. 12, n. 1, *e*20230004, 2023.