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

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**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* inflorescences 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*.

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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 distinguíense 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 population 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 Adolfo 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.

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

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 μmol m⁻² s⁻¹), constant 25 ºC 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>
<thead>
<tr>
<th></th>
<th>P. goeldii</th>
<th>P. fragantissimum</th>
<th>P. tortum</th>
<th>P. elaphoglossoides</th>
<th>P. melloi</th>
<th>P. melinonii</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x; min-max; dp</td>
<td>x; min-max; dp</td>
<td>x; min-max; dp</td>
<td>x; min-max; dp</td>
<td>x; min-max; dp</td>
<td>x; min-max; dp</td>
</tr>
<tr>
<td><strong>Fruit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (mm)</td>
<td>16.1; 13.1-18.4; ±1.3</td>
<td>6.9; 3.17-8.39; ±1.43</td>
<td>3.7; 3.27-4.03; ±0.23</td>
<td>5.8; 3.48-7.63; ±0.97</td>
<td>3.8; 2.17-5.16; ±0.84</td>
<td>4.7; 3.65-6.13; ±0.48</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>10.2; 9.05-12.2; ±0.8</td>
<td>4.5; 3.04-7.61; ±0.88</td>
<td>2.0; 1.65-2.29; ±0.16</td>
<td>4.2; 3.18-5.92; ±0.59</td>
<td>2.5; 1.54-4.09; ±0.51</td>
<td>3.3; 2.17-5.51; ±0.58</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>10.2; 8.66-12.2; ±0.8</td>
<td>4.0; 2.51-5.78; ±0.72</td>
<td>1.8; 1.48-2.15; ±0.15</td>
<td>3.8; 2.59-5.45; ±0.62</td>
<td>2.3; 1.54-3.07; ±0.34</td>
<td>2.6; 1.42-4.51; ±0.52</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>1.3; 0.88-1.75; ±0.2</td>
<td>0.1; 0.01-0.13; ±0.03</td>
<td>0.1; 0.01; 0.0</td>
<td>0.1; 0.02-0.22; ±0.03</td>
<td>0.1; 0.01-0.94; ±0.16</td>
<td>0.1; 0.01-0.38; ±0.10</td>
</tr>
<tr>
<td>Seed (n)</td>
<td>71; 0-115; ±4.0</td>
<td>44; 1-200; ±50.1</td>
<td>7; 4-12; ±1.92</td>
<td>64; 1-170; ±42.2</td>
<td>8; 1-31; ±8.54</td>
<td>30; 1-73; ±15.3</td>
</tr>
<tr>
<td>Colour</td>
<td>Yellowish-white</td>
<td>Red</td>
<td>Light brown</td>
<td>Reddish</td>
<td>Orange</td>
<td>Yellowish-white</td>
</tr>
<tr>
<td>Seed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (mm)</td>
<td>1.4; 1.11-1.62; ±0.1</td>
<td>0.9; 0.81-0.88; ±0.01</td>
<td>1.1; 1.05-1.22; ±0.05</td>
<td>0.8; 0.75-0.89; ±0.03</td>
<td>0.7; 0.62-0.77; ±0.04</td>
<td>1.0; 0.39-1.14; ±0.19</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>0.6; 0.48-0.78; ±0.1</td>
<td>0.3; 0.22-0.28; ±0.01</td>
<td>0.4; 0.36-0.51; ±0.03</td>
<td>0.2; 0.18-0.28; ±0.02</td>
<td>0.4; 0.32-0.42; ±0.02</td>
<td>0.5; 0.36-1.02; ±0.17</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.8; 0.53-1.14; ±0.1</td>
<td>0.2; 0.18-0.24; ±0.01</td>
<td>0.5; 0.38-0.63; ±0.04</td>
<td>0.2; 0.14-0.25; ±0.02</td>
<td>0.3; 0.20-0.31; ±0.02</td>
<td>0.4; 0.37-0.50; ±0.03</td>
</tr>
<tr>
<td>Form</td>
<td>Subcylindrical</td>
<td>Elliptic</td>
<td>Subglobose</td>
<td>Elliptic</td>
<td>Oblong</td>
<td>Oblong</td>
</tr>
<tr>
<td>Colour</td>
<td>Yellowish-white</td>
<td>Yellowish-white</td>
<td>Light brown</td>
<td>Glossy black</td>
<td>Orange</td>
<td>Yellowish-white</td>
</tr>
<tr>
<td>Macules</td>
<td>Absent</td>
<td>Present</td>
<td>Present</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Area (%)</td>
<td>...</td>
<td>25-37</td>
<td>30-36</td>
<td>...</td>
<td>...</td>
<td>30-45</td>
</tr>
</tbody>
</table>

**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.

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 (A₁) *Philodendron fragrantissimum*, (A₂) *P. tortum*; (A₃) *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

*A₁ - Philodendron fragrantissimum*

*A₂ - Philodendron tortum*

*A₃ - Philodendron elaphoglossoides*

**Source:** Authors' collection. 2017.
Figure 4 - Morphology of germination and seedlings, hypocotyl length. B: medium length hypocotyl, (B₁) *Philodendron melinonii*, (B₂) *P. melloi*; C: elongated hypocotyl, (C₁) *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).

<table>
<thead>
<tr>
<th>Species</th>
<th>G (%)</th>
<th>MGT (d)</th>
<th>GSI</th>
<th>RLG</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. goeldii</td>
<td>99.0</td>
<td>4.5</td>
<td>5.9</td>
<td>a</td>
</tr>
<tr>
<td>P. fragrantissimum</td>
<td>90.5</td>
<td>123.0</td>
<td>0.3</td>
<td>bc</td>
</tr>
<tr>
<td>P. elaphoglossoides</td>
<td>25.0</td>
<td>90.0</td>
<td>0.2</td>
<td>cd</td>
</tr>
<tr>
<td>P. tortum</td>
<td>15.0</td>
<td>72.1</td>
<td>0.2</td>
<td>d</td>
</tr>
<tr>
<td>P. melinonii</td>
<td>5.3</td>
<td>47.5</td>
<td>0.5</td>
<td>b</td>
</tr>
<tr>
<td>P. melloi</td>
<td>20.0</td>
<td>105.7</td>
<td>0.1</td>
<td>e</td>
</tr>
</tbody>
</table>

* 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).

<table>
<thead>
<tr>
<th>Species</th>
<th>G (%)</th>
<th>MGT (d)</th>
<th>GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. goeldii</td>
<td>97.0</td>
<td>5.5</td>
<td>6.2</td>
</tr>
<tr>
<td>P. fragrantissimum</td>
<td>96.0</td>
<td>112.4</td>
<td>95.0</td>
</tr>
<tr>
<td>P. elaphoglossoides</td>
<td>18.0</td>
<td>93.2</td>
<td>74.7</td>
</tr>
<tr>
<td>P. tortum</td>
<td>12.5</td>
<td>15.0</td>
<td>91.3</td>
</tr>
<tr>
<td>P. melinonii</td>
<td>11.0</td>
<td>74.7</td>
<td>58.7</td>
</tr>
<tr>
<td>P. melloi</td>
<td>22.0</td>
<td>121.1</td>
<td>111.1</td>
</tr>
</tbody>
</table>

*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 fragrantissimum, 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

Infrauctescences, 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. solimoense* 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) 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 VASCONCELLOS 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 Coordenção 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).

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

**COMO CITAR O ARTIGO - ABNT**  