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# The Brazil nut tree (*Bertholletia excelsa* Humb. & Bonpl. (Lecythidaceae)): Importance and biological interactions

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**Abstract:** The Brazil nut (*Bertholletia excelsa*) is a species of tree native to the Amazon region. The exploitation of its wood and fruit provides significant economic value. Due to this important economic value, different studies related to the Brazil nut tree provide relevant information about the beneficial and harmful relationships between the tree and other organisms. However, such information is scattered and difficult to access. The objective of this study was to compile the available information on the different relationships between the Brazil nut tree and other organisms to support future studies and strategies to better manage the resources and benefits of this tree. We found 194 species that interact with the Brazil nut tree. These species consisted of predators, dispersers, competitors, pollinators, floral visitors, pathogens and microorganisms. Although exploitation of the Brazil nut has occurred for many decades in native forests, the production of seedlings and cultivation of the species are relatively recent events, with few occurrences of pests and diseases recorded for *B.excelsa* in native forests and plantations. In contrast, pollinators, floral visitors and dispersers were recorded in abundance, as well as contaminating fungi that deteriorate the nut. Considering the volume and diversity of records it is possible to infer that there is a need for constant monitoring of the Brazil nut in plantations and natural areas, as well as to encourage research related to the specific biotic interactions of Brazil nuts.
**Keywords**: Dispersers, diseases, pollinators, pests, floral visitors.

## Introduction

The Brazil nut tree, *Bertholletia excelsa* Humb. & Bonpl. (Lecythidaceae), is native to the Amazon region, and the only species of the genus *Bertholletia* Bonpl. It is a large tree, reaching up to 50 meters in height and three meters in diameter with a dominant crown, straight and cylindrical shaft, hard shell and cracked gray-brown color (Mori & Prance, 1990; Zudeima, 2003). Its trough-shaped leaves have a petiole of five to six centimeters in length, coriaceous texture with an acute base and undulating margins (Cavalcante, 1976). The flowers are hermaphrodite, with both the androecium and the gynoecium protected by a structure called a ligule or hood that restricts the entrance of floral visitors, selecting organisms that are of sufficient physical size and vigor to lift this structure and pollinate the flower (Maués, 2002).

In relation to extractive exploitation in the Amazon, the Brazil nut is one of the most important species, generating employment and income for thousands of rural, urban, indigenous and riverine communities (Shepard Jr. & Ramirez, 2010; Tonini, 2011; Nogueira et al., 2014). The Brazil nut is a food source which is rich in various beneficial substances (Yang, 2009). The commercial extraction of its non-timber forest products (NTFP) such as the nut for the food and cosmetics industries and the use of the dry fruit husk as a combustible fuel source (Freitas-Silva & Venâncio, 2011, Nogueira et al., 2014) are important components in forest conservation strategies, making them an economically productive and sustainable natural resource (Myers et al., 2000; Tonini & Pedrozo, 2014).

Studies in relation to nuts are generally related to socioeconomics (Camargo, 2010; Shepard Jr. & Ramirez, 2010). Among these studies, the benefits of Brazil nuts on health (Yang, 2009), as well as the harmful effects caused by mycotoxin-producing fungi contamination due to incorrect storage, should be highlighted (Arrus et al., 2005; Kwiatkowski & Alves, 2007; Freitas-Silva &

Venâncio, 2011). In addition, studies on the aspects of the ecology of *B. excelsa*, such as phenology, distribution, pollinators and main dispersants (Peres & Baider, 1997; Zudeima, 2003; Maués, 2002; Tonini, 2011), as well as their increasing use in the recovery of degraded areas, crop consortia and incentive for the valuation of rural areas (Fernandes & Alencar, 1993; Costa et al., 2009; Ferreira & Tonini, 2009) should be encouraged.

There is a large amount of relevant information about the Brazil nut, however this information is dispersed across many studies, with large knowledge gaps concerning the species and its relationship with other organisms. Taking into account the importance of the Brazil nut tree in the maintenance of natural forest environments, its commercial exploitation in natural and cultivated ecosystems, as well as its use in the recovery of degraded areas, this study compiles data on the tree and its relationships with other organisms available within the literature, to serve as a basis for future studies and strategies to better manage the features and benefits of *B. excelsa*.

**Contextualization and Analysis**

A total of 194 species were found that have some type of interaction with *B. excelsa* (Table 1). The interactions identified were separated into two categories; category one corresponds to organisms harmful to the tree and its seeds, primarily represented by insects, pathogenic fungi and some families of lianas (woody vines), which when in excess can compete with the Brazil nut tree.

Category two corresponds to the beneficial organisms, considered as the true pollinators, floral visitors and dispersers, including humans, who either intentionally or accidentally contribute to the dissemination of Brazilian nut tree seeds.

**Pests and diseases of the Brazil nut.**

Despite the high consumption rate of Brazil nuts in the national and international market, little is known about insect pests that affect them. Brazil nuts are discarded by the population when occasionally contaminated by insects, usually in immature forms, without checking the organism causing the damage, nor to report the information to the scientific community. An additional situation mentioned is when the identification of insects predating on Brazil nuts are not recorded specifically (Peres et al., 1997; Athié & Paula, 2002; Scussel et al., 2014), instead only referring to the insect group in a superficial manner, in view of the great diversity, characteristics and habits presented by insects within the ecosystems (e. g. Triplehorn & Jonnson, 2011).

Records of insects that prey on the Brazil nut are scarce and linked to storage sites with poor ventilation and humidity, such as Gumier-Costa (2009), who reports the occurrence of *Hypothenemus hampei* (Ferrari, 1867) ) (Coleoptera) in stored Brazil nuts in the southwest of Pará, where the insect was successful in infesting and breeding in Brazil nuts. Gomes et al. (2015, 2016) recorded a severe attack by the flour moth *Plodia interpunctella* (Hubner, 1813) (Lepidoptera) on Brazil nuts in the Amazon. In the state of Pará, Sefer (1961) cites *Tribolium castaneum* (Herbst, 1797) (Coleoptera) attacking stored Brazil nuts, however there was only minimal harm. In laboratory studies performed to test whether the nut's shell can protect the kernel from the attack of *T. castaneum*, Pires et al. (2017) found that the beetle has great potential to cause significant losses to stored nuts with a damaged shell. Finally, in studies with aflatoxin-producing fungi on Brazil nuts, Castrillón & Purchio (1988) found Curculionidae Latreille, 1802 (Coleoptera) larvae in the shell, resulting in a brittle and pulverulent shell, promoting shallow ridges in the mesocarp.

Regulation of the temperature, processing, ventilation, and especially humidity in the storage of *B. excelsa* nuts is important in order to avoid infestations and damage caused by insects (Gumier-Costa, 2009; Gomes et al., 2015, Pires et al. 2017), as well as contamination by microorganisms that act to totally or partially deteriorate the kernel by filamentous fungi that cause further damage by leaving mycotoxins as a byproduct of its contamination (Castrillón & Purchio, 1988; Freitas-Silva & Venâncio, 2011; Baquião et al., 2012), which present a risk to the health of the consumer (Kwiatkowski & Alves, 2007; Costa et al., 2009).

**Table 1:** Data compilation of the organisms, their interactions, record of occurrence and bibliographic sources related to Brazil nut tree.

| Táxons | Interação Biológica | Parte da Planta | Local de Ocorrência | Referência |
|---|---|---|---|---|
| Capnodiales: Mycosphaerellaceae<br>*Cercospora bertholletiae* Albuquerque, 1960<br>Dothideomycetes: Asterinaceae,<br>Yamamotoa sp.<br>Peronosporales:Pythiaceae<br>*Phytophthora heveae* Thompson (1929)<br>Sordariales: Glomerellaceae<br>*Colletotrichum gloesporioides* Weir & Johnst, 2012<br>*Colletotrichum* sp. | Pathogenic fungi | Leaves and young stems | Amazonas, Acre, Pará and Roraima (Brazil) | Albuquerque et al. (1974)<br>Andrade & Cardoso (1984)<br>Halfeld-Vieira & Nechet (2010)<br>Ferreira & Tonini (2009)<br>De Assis et al. (2010) |
| Botryosphaeriales:Botryosphaeriacaeae<br>*Macrophomina phaseolina* (Tassi) Goid.,1947<br>Capnodiales:Davidiellaceae<br>*Cladosporium cladosporioides (*Fresen,1952)<br>*Cladosporium sphaerospermum* Link,1816<br>*Cephalosporium* sp.<br>*Cladosporium* sp.<br>Chaetothyriales:Herpotrichiellaceae<br>*Exophiala* sp.<br>*Phialophora* sp.<br>Cryptococcales:Crypotococcaceae<br>*Candida* sp.<br>Eurotiales:Elaphomycetaceae<br>*Monascus* sp.<br>Eurotiales:Trichocomaceae<br>*Aspergillus flavus* Link, 1809<br>*Aspergillus fresenii* Subram, 1971<br>*Aspergillus fumigatus* Fresenius, 1863<br>*Aspergillus parasiticus* Speare, 1912<br>*Aspergillus niger* van Terghem, 1867<br>*Aspergillus nomius* Kurtzman, Horn & Hesselt, 1987<br>*Aspergillus oryzae* (Ahlburg) Cohn, 1884<br>*Aspergillus* sp.<br>*Aspergillus tamarii* Kita, 1913<br>*Emericella nidulans* Eidam, 1927<br>*Paecilomyces* sp.<br>*Paecilomyces variotii* Bainier, 1907<br>*Penicillium citrinum* Thom, C. 1910<br>*Penicillium glabrum* (Wehmer) Westling, 1911<br>*Penicillium* sp.<br>Hypocreales: Hypocreaceae<br>*Fusarium oxysporum* Schlecht, Snyder & Hansen<br>*Fusarium verticilloides* Link & Grey, 1821<br>*Fusarium* sp.<br>*Trichoderma citrinoviride* Bissett, 1984<br>*Trichoderma* sp. | Fungi decomposers | Chestnuts | Manaus-AM (Brazil) | Castrillón & Purchio (1988)<br>Costa et al. (2009)<br>Freitas-Silva & Venâncio (2011)<br>Baquião et al. (2012) |

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| Hypocreales: Plectosphaerellaceae<br>*Verticillium* sp.<br>Kickxellales:Kichxellaceae<br>*Coemansia brasiliensis* Thaxt. Ex Linder, 1943<br>Micriascales: Microascaceae<br>*Graphium putredinis* (Corda) S. Huhes, 1958<br>Microascales:Microascaceae<br>*Pseudallescheria boydii* (Shear) McGinnis, Padhye & Ajello, 1982<br>*Scopulariopsis* sp.<br>Mucorales:Choanephoraceae<br>*Poitrasia circinans* (Naganishi & Kaeakami,1984)<br>Mucorales:Cunninghamellaceae<br>*Cunninghamella elegans* Lendner, 1907<br>*Cunninghamella* sp.<br>Mucorales:Mucoraceae<br>*Absidia* sp.<br>*Gongronella butleri* (Lendner)<br>*Mucor* sp.<br>*Rhizopus oryzae* Went & Prins. Geerl. , 1895<br>*Rhizopus* sp.<br>*Rhizopus stolonifer* (Ehrenb:. Fr.) Vuill.<br>Mucorales:Saksenaeaceae<br>*Saksenae vasiformis* S.B. Saksena, 1953<br>Mucorales:Syncephalastraceae<br>*Syncephalastrum racemosum Cohn,1886*<br>*Syncephalis sphaerica* Tiehg, 1875<br>*Syncephalastrum* sp.<br>Pleosporales:Pleosporaceae<br>*Curvularia lunata* Boedijn, 1933<br>Pleosporales:Incertae sedis<br>*Phoma* sp.<br>Saccharomycetales:Endomycetaceae<br>*Geotrichum* sp.<br>*Saccharomyces* sp.<br>Sporidiales:*Incertae sedis*<br>*Rhodotorula* sp.<br>Sordariales:Chaetomiaceae<br>*Chaetomium brasiliensis* (Batista & Pontual)<br>*Humicola* sp.<br>*Thielavia terricola* (Gilman & Abbott) Emmons, 1930<br>Sordariales:Sordariaceae<br>*Neurospora* sp. | | | | |
| Dilleniales:Dilleniaceae<br>Fabales: Fabaceae<br>Caesalpiniaceae<br>Lamiales: Bignoniaceae<br>Myrtales: Combretaceae<br>Malpighiales:Malpighiaceae | Competition and inquilinism | Tree canopy, branches and twigs | Acre (Brazil) | Zudeima (2003)<br><br>Kainer et al. (2006)<br><br>Kainer et al. (2014) |

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| Ranunculales:Menispermaceae | | | | |
| Orthoptera: Tettigoniidae<br>Phaneropterinae<br>Conocephalinae | Herbivory | Plant leaves | Peru | Ricordi (1963) |
| Hemiptera: Aphididae<br>*Aphis* sp. | Herbivory | Branches, twigs, leaves | Peru | Ricordi (1963) |
| Isoptera | Herbivory (Xilófagos) | Bark and trunk | Oriximiná, PA (Brazil) | Scoles et al. (2015) |
| Coleoptera: Attelabidae<br>*Hybolabus amazonicus* Voss,1925<br>*Hybolabus columbinus* Erichson, 1848 | Winders of leaves | Plant leaves | Itacoatiara, Manaus, AM and Nova California, AC (Brazil) | Garcia et al. (1996) |
| Coleoptera: Cerambycidae | Herbivory | Bark | Peru | Ricordi (1963) |
| Coleoptera: Cerambycidae<br>*Baryssiniella hieroglyphica (Berkov & Monné, 2010)* | Herbivory | Twigs | Peru | Berkov & Monné (2010) |
| Coleoptera: Chrysomelidae | Floral visitors and pollination | Flowers | Belém, PA (Brazil) | Maués (2002) |
| Coleoptera: Curculionidae | Herbivory | Bark | Peru | Ricordi (1963) |
| Coleoptera: Curculionidae | Herbivory | Hedgehogs | Manaus-AM (Brazil) | Castrillón & Purchio (1988) |
| Coleoptera<br>Coleoptera: Scarabaeidae<br>*Cyclocephala* | Floral visitors and pollination | Plant leaves | Mato Grasso, Brazil | Camargo (2010)<br><br>Maués et al. (2015) |
| Coleoptera: Scolytidae<br>*Hypothenemus hampei* (Ferrari,1867) | Herbivory | Chestnuts | Marabá, PA (Brazil) | Gumier-Costa (2009) |
| Coleoptera: Tenebrionidae<br>*Tribolium castaneum* (Herbst, 1797) | Herbivory | Chestnuts | Pará and Mato Grosso (Brazil) | Sefer (1961)<br>Pires et al. (2017) |
| Hymenoptera: Apidae<br>*Bombus (Fervidobombus) brevivillus* Franklin, 1913<br>*Bombus (Fervidobombus)transversalis* (Olivier, 1789)<br>*Bombus transversalis* (Oliver, 1789)<br>*Bombus brevivillus* Franklin, 1913<br>*Centris (Ptilotopus) americana* (Klug, 1810)<br>*Centris (Ptilotopus) denudans* Lepeletier, 1841<br>*Centris (Trachina) carrikeri* Cockerell, 1919<br>*Centris similis* (Fabricius, 1804)<br>*Epicharis affinis* Smith, 1874<br>*Epicharis (Epicharana) flava* Friese, 1900<br>*Epicharis (Epicharana) rústica* Olivier, 1789<br>*Epicharis (Epicharis) umbraculata* Fabricius, 1804<br>*Epicharis (Hoplepicharis) affinis* Smith, 1874<br>*Epicharis* sp. Klug, 1807<br>*Eufriesea flaviventris* (Friese, 1899)<br>*Eufriesea purpurata* (Mocsáry,1896)<br>*Eufriesea* sp. Cockerell, 1908<br>*Eulaema (Apeulaema) cingulata* (Fabricius, 1804)<br>*Eulaema (Eulaema) meriana* (Olivier, 1789)<br>*Eulaema (Eulaema) bombiformis* (Packard, 1869)<br>*Eulaema (Apeulaema) mocsaryi* (Friese, 1899)<br>*Eulaema (Apeulaema) nigrita* Lepeletier, 1841 | Pollination | Flowers | Itacoatiara-AM, Tomé-Açu, Capitão-Poço and Belém-PA (Brazil) | Maués (2002)<br><br>Santos & Absy (2010)<br><br>Cavalcante et al. (2012)<br><br>Maués et al. (2015) |

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| *Eulaema mocsaryi* (Friese, 1899)<br>*Eulaema nigrita* Lepeletier, 1841<br>*Xylocopa frontalis* (Olivier, 1789)<br>*Xylocopa (Neoxylocopa) aurulenta* (Fabricius, 1804)<br>*Xylocopa (Neoxylocopa) frontalis* (Olivier, 1789) | | | | |
| Hymenoptera: Apidae<br>*Aparatrigona impunctata* (Ducke,1916)<br>*Apis mellifera scutellata* (Lepeletier,1836)<br>*Apis mellifera* (Linnaeus, 1758)<br>*Bombus transversalis* (Olivier, 1789)<br>*Cephalotrigona femorata* (Smith,1854)<br>*Centris americana* (Klug, 1810)<br>*Centris carrikeri* (Cockerell, 1919)<br>*Centris dimidiata* (Olivier,1789)<br>*Centris denudans* (Lepeletier, 1841)<br>*Centris flavifrons* (Fabricius,1775)<br>*Centris flavilabris* (Mocsáry, 1899)<br>*Centris ferruginea* (Lepeletier, 1841)<br>*Centris similis* ( Fabricius, 1804)<br>*Centris* sp.<br>*Centris (Trachina) similis* (Fabricius, 1804)<br>*Centris (Xanthemisia) ferruginea* Lepeletier, 1841<br>*Epicharis conica* (Smith, 1874)<br>*Epicharis (Epicharana) cônica* Smith, 1874<br>*Epicharis flava* (Friese, 1900)<br>*Epicharis (Parepicharis) zonata* Smith, 1854<br>*Epicharis rustica* (Oliver, 1789)<br>*Epicharis umbraculata* (Fabricius, 1804)<br>*Epicharis zonata* ( Smith, 1854)<br>*Eufrisea flaviventris* (Friese, 1899)<br>*Eufrisea purpurata* (Mocsáry, 1896)<br>*Eufriesea* sp.<br>*Euglossa intersecta* (Latreille, 1838)<br>*Euglossa* sp.<br>*Eulaema bombiformis* (Packard,1869)<br>*Eulaema cingulata* (Fabricius,1804)<br>*Eulaema meriana* (Olivier, 1789)<br>*Exomalopsis analis* (Spinola, 1853)<br>*Frieseomelitta longipes* (Smith,1854)<br>*Frieseomelitta trichocerata* (Moure,1990)<br>*Geotrigona subgrisea* (Cockerell,1920)<br>*Melipona lateralis* (Erichson, 1848)<br>*Melipona (Michmelia) lateralis* Erichson, 1848<br>*Partamona vicina* (Camargo, 1980)<br>*Tetragona clavipes* (Fabricius, 1804)<br>*Tetragona goettei* (Friese,1900)<br>*Tetragona kaieteurensis* (Schwarz,1938)<br>*Trigona branneri* (Cockerell,1912) | Floral visitors and pollination | Flowers | Itacoatiara-AM, Tomé-Açu, Capitão-Poço and Belém-PA (Brazil) | Müller (1980)<br><br>Maués (2002)<br><br>Camargo (2010)<br><br>Maués (2010)<br><br>Santos & Absy (2010)<br><br>Cavalcante et al. (2012)<br><br>Maués et al. (2015) |

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| *Trigona chanchamayoensis* Schwarz, 1948<br>*Trigona dimidiata* (Smith. 1854)<br>*Trigona fuscipennis* (Friese,1900)<br>*Trigona guianae* (Cockerell,1912)<br>*Trigona hyalinata* (Lepeletier, 1836)<br>*Trigona pallens* (Fabricius, 1789)<br>*Trigonisca vitrifrons* (Albuquerque & Camargo, 2007)<br>*Xylocopa aurulenta* (Fabricius, 1804)<br>*Xylocopa muscaria* (Fabricius, 1775)<br>Hymenoptera: Megachilidae<br>*Megachile cf. orbiculata* Mitchell,1930<br>*Megachile* sp. Latreille, 1802<br>Hymenoptera: Vespidae<br>*Polistes infuscatus* Lepeletier,1836<br>*Polybia* sp.<br>*Synoeca surinama* (Linnaeus, 1767)<br>Hymenoptera: Sphecidae | | | | |
| Hymenoptera: Formicidae<br>*Atta cephalotes* (Linnaeus, 1758)<br>Hymenoptera: Myrmicinae | Herbivory | Seedling leaves | Bolivia | Müller et al. (1995)<br>Hurtado (2010)<br>Maués et al. (2015) |
| Hymenoptera: Myrmicinae<br>*Cephalotes atratus* (Linnaeus, 1758) | Inquilinism | Branches | Peru | Ricordi (1963) |
| Lepidoptera: Hesperiidae<br>*Chrysoplectrum perniciosus* (Herrich-Schäffer, 1869)<br>*Pyrrhopyge* sp.<br>Lepidoptera:Riodinidae<br>*Synargis mycone* (Hewitson, 1865) | Floral visitors and pollination | Flowers | Belém-PA (Brazil) | Müller (1980)<br>Maués et al. (2015) |
| Lepidoptera: Notodontidae<br>*Lusura altrix* (Stoll, 1782) | Herbivory | Leaves, flowers, developing fruits and bark | Amazonas, Rondônia (Brazil) and Bolivia | Haugaasen (2009)<br>Hurtado (2010)<br>Coimbra Junior (2012) |
| Lepidoptera: Oecophoridae<br>*Timocratica olbella* Zeller, 1839 | Herbivory | Branches and trunk | Peru | Delgado & Couturier (2004) |
| Lepidoptera: Pyrallidae<br>*Plodia interpunctella* (Hubner ,1813) | Herbivory | Chestnuts | Itacoatiara - AM (Brazil) | Gomes et al. (2015)<br>Gomes et al. (2016) |
| Apodiformes: Trochilidae | Floral visitors and pollination | Flowers | Belém-PA (Brazil) | Müller (1980)<br>Maués et al. (2015) |
| Piciformes: Picidae<br>*Campephilus rubricollis* (Boddaert, 1783)<br>Psitaciformes: Psittacidae<br>*Ara ararauna* (Linnaeus, 1758)<br>*Ara chloroptera* Gray, 1859<br>*Ara macao* (Linnaeus, 1758)<br>*Ara severa* (Linnaeus, 1758) | Dispersion and Herbivory | Chestnuts, hedgehogs and seedlings | Pará, Brazil<br>Madre de Dios, Peru | Peres & Baider (1997)<br><br>Trivedi et al. (2004) |
| Rodentia: Cuniculidae<br>*Agouti paca* (Linnaeus, 1766)<br>Rodentia: Dasyproctidae<br>*Dasyprocta leporina* (Linnaeus,1758)<br>*Dasyprocta* spp. | Dispersion and Herbivory | Chestnuts,<br>and seedlings | Pará (Brazil) | Peres & Baider (1997)<br><br>Mori & Prence (1990)<br><br>Peres et al. ( 1997) |

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| Rodentia: Sciuridae<br>*Sciurus apadiceus* Olfers, 1818<br>Rodentia: Dasyproctidae<br>*Myoprocta* spp. | | | | Peres & Baider (1997)<br><br>Zudeima (2003) |
| Primates: Atelidae<br>*Lagothrix lagotricha cana* (Humboldt, 1812)<br>Primates: Cebidae<br>*Cebus apella* Linnaeus, 1758<br>*Cebus albifrons* (Humboldt, 1812)<br>Primates: Pitheciidae<br>*Chiropotes satanas* (Hoffmannsegg, 1807)<br>Primates: Hominidae<br>*Homo sapiens* (Linnaeus, 1758) | Dispersion and Herbivory | Chestnuts, hedgehogs and seedlings | Pará (Brazil) | Peres & Baider (1997)<br><br>Trivedi et al. (2004)<br><br>Zudeima (2003)<br><br>Shepard Jr. & Ramirez (2011) |

**Pests and diseases of the Brazil nut tree**

As logging the native Brazil nut tree is prohibited by law, the cultivation of seedlings and plantations for the production of wood and non-timber forest products are extremely recent activities, resulting in scarce records of pests and diseases that affect this species in planted areas (Fernandes & Alencar, 1993; Tonini et al., 2006; Costa et al., 2009; Scoles et al., 2011). The absence of pest damage was confirmed by Fernandes & Alencar (1993) after 10 years of planting and by Costa et al. (2009) after 12 years, causing both authors to recommend *B. excelsa* as a promising species for the purposes of timber harvesting, consortia in agroecosystems, and for the rehabilitation of abandoned and degraded areas in the Amazon.

Records of potential pest insects were made for the new species *Baryssiniella hieroglyphica* (Berkov & Monné, 2010) (Coleoptera) captured in *B. excelsa* bait branches suspended in the forest canopy during an experiment in the rainy season in the Peruvian Amazon (Berkov & Monné, 2010), and also for the leaf-weaving species *Hybolabus amazonicus* Voss, 1925 and *Hybolabus columbinus* Erichson, 1848, which were destroying leaves in commercial and experimental *B. excelsa* crops in the states of Amazonas and Acre (Garcia et al. 1996). *Aphis* Linnaeus, 1758 (Hemiptera) aphids were also recorded feeding on Brazil nut trees (Ricordi, 1963). Despite these records no economic damages were identified.

However, pest insects have been reported to cause significant damage to *B. excelsa*, such as the cutter ant *Atta cephalotes* (Linnaeus, 1758) (Hymenoptera) attacking Brazil nut trees in Bolivia (Hurtado, 2010). There are other records of defoliants such as the Phaneropterinae and Conocephalinae (Orthoptera) (Ricordi, 1963). *Lusura altrix* (Stoll, 1782) (Lepidoptera) caterpillars cause severe attacks by peeling the bark from the tree, feeding on foliage and affecting developing flowers and fruits, which may reduce yields and cause the death of the tree (Haugaasen, 2009; Hurtado, 2010). *Timocratica olbella* Zeller, 1839 (Lepidoptera) causes damage by destroying the bark and opening galleries in the structure of the branches and trunk of the plant, resulting in death or limiting the tree's growth performance (Delgado & Couturier, 2004).

In the Peruvian Amazon *Cephalotes atratus* (Linnaeus, 1758) (Hymenoptera: Formicidae) are considered important insects associated with the Brazil nut tree because their nests, built in the branches of the tree, weaken these branches resulting in higher susceptibility to wind action, causing loss of leaves and fruits (Ricordi, 1963). Cerambycidae and Curculionidae larvae attack simultaneously, causing damage by ripping the bark off the tree (Ricordi, 1963). Severe Isoptera attacks on Brazil nut bark and trunks were carried out in areas where the species suffered population deterioration due to deforestation from the continuous use of fire (Scoles et al., 2015).

Other plants interact with the Brazil nut tree, and their relationship can be harmful. Studies carried out in the Amazon rainforest have shown that lianas and their complex interaction with the Brazil nut tree can influence fruit production, as their heavy weight can break branches and modify the canopy structure, inhibit the production of leaves and inflorescences, and reduce the amount of light intercepted by the leaves of the Brazil nut tree (Zudeima, 2003; Kainer et al., 2006; Kainer et al., 2014). This can be considered harmful when lianas dominate a significant portion of the crown and cause these damages, and should be eliminated to avoid damaging the production of nuts.

In regards to diseases that affect the Brazil nut tree, Halfeld-Vieira & Nechet (2010) reported the presence of the fungus *Colletotrichum gloesporioides* Weir & Johnst, 2012 (Sordariales) on Brazil nut leaves and its potential risk, as this fungus causes anthracnose in several species of fruiting plants, affecting the above-ground vegetative parts such as stems, tendrils, leaves, flowers and fruits (Hyde et al., 2009). Anthracnose causes leaf spotting or browning of the fruit, usually post-harvest (Hyde et al., 2009). In a survey of the phytosanitary status of an agroforestry system in Brazil, Ferreira & Tonini (2009) recorded Brazil nut trees with leaf spot, indicating high susceptibility to attack from the fungus *Cercospora bertholletia* Albuquerque, 1960 (Capnodiales), with no apparent damage to tree growth detected. The same fungus was also recorded with the synonymy of *Pseudocercospora bertholletiae* Braun & Freire, 2004 causing leaf spot in the Brazil nut tree in Roraima (Halfeld-Vieira & Nechet, 2010). Albuquerque et al. (1974) reported *Phytophthora heveae* Thompson (1929) (Peronosporales) causing leaf spot in an experimental plantation plot and in nurseries with grafted plants in Pará. They also emphasized that even if restricted to a small area, this fungus may present a potential hazard, hindering the development of the tree, especially when the practice of grafting begins to increase and be widely diffused throughout the Amazon region.

The Brazil nut tree has great sturdiness and apparent resistance to pests and diseases (Fernandes & Alencar, 1993; Costa et al., 2009; Hurtado, 2010). However, there is little research related to this subject, and as information on possible agents that affect the Brazil nut tree are limited by not knowing the identification of some organisms to a sufficient level, there are few records of occurrences or even new incidences of organisms reported in other references and localities of the Amazon. The height of the developed or developing tree is a limiting factor for accurate *in situ* observations of possible harmful interactions in the development and production of the Brazil nut tree. These factors hinder further studies of the biology, behavior, life cycle and damage caused by some species that may become pests, or are already considered important pests causing economic losses in the production of Brazil nuts.

**Pollination and floral visitors**

The Brazil nut tree is a species that reproduces by cross-fertilization, with fruit production dependent upon the action of pollinators – organisms that are generally very diverse and abundant in tropical forests (Maués, 2002; Camargo, 2010; Hurtado, 2010; Tonini & Pedrozo, 2014). The flowers of the Brazil nut tree have a peculiar structure called a ligule or hood, which restricts the entrance of floral visitors. This flower structure offers selective resistance by granting entrance only to visitors who have the physical vigor required to pollinate the plant (Maués. 2002). These species are considered true pollinators, with a high abundance of individuals, high frequency of flower visitation and are able to enter and remain within the flower for a sufficient amount of time and leave taking a sufficient amount of pollen (Mori & Prace, 1990; Maués, 2002). Although Brazil nut flowers make direct access of their resources to species of non-pollinating bees difficult, they do not completely prevent other species from indirectly obtaining their floral rewards (Maués, 2002; Santos & Absy, 2010; Cavalcante et al., 2012). However, there is no conclusive information detailing the relationship between pollinators and floral visitors (Santos & Absy, 2010)

The main pollinating organisms are bees of the genera *Bombus* Latreille, 1802, *Centris* Fabricius, 1804, *Epicharis* Klug, 1807 and *Xylocopa* Latreille, 1802 (Hymenoptera: Apidae) (Maués, 2002; Santos & Absy, 2010; Cavalcante et al., 2012). *Xylocopa frontalis* (Olivier, 1789) is a strong and robust bee present in the greatest quantity and frequency of visitation in the Brazil nut flower (Maués, 2002; Cavalcante, 2008; Santos & Absy, 2010, Cavalcante et al., 2012), and is perhaps the bee that carries the largest amount of pollen (Cavalcante, 2012).

Other insects, such as Chrysomelidae (Coleoptera), Sphecidae and Vespidae wasps (Hymenoptera), Lepidoptera and hummingbirds (Trochilidae) were registered as secondary agents, also visiting the flower but with less success and frequency of visits (Müller, 1980; Maués, 2002; Cavalcante et al., 2012, Maués et al. 2015). Some insects harmful to the flowers were also observed, such as *Cyclocephala* Dejean, 1821 (Coleoptera: Scarabaeidae), and *Trigona chanchamayoensis* Schwarz, 1948 (Hymenoptera: Apidae) that penetrate the floral bud, destrying the sexual organs (Camargo, 2010). *Frieseomelitta longipes* (Smith,1854) (Hymenoptera: Apidae) presented the behavior of trying to collect pollen from the corbiculae of other species of larger bees at the moment of flower visitation, often causing these bees to abandon the flower without pollination.

Brazil nut yields are regulated by the activity of its pollinators, so any imbalance affecting the pollinator population within plantations or natural areas will directly impact on fruit production (Maués, 2002; Maués et al. 2015). Therefore, it is necessary to preserve patches of native forest habitat for the pollinators that primarily nest in the forest and venture out to feed, and thus pollinate, Brazil nut plantations (Mori & Prence, 1990; Maués et al. 2015). Other measures that should be carried out alongside the preservation of natural habitats are the installation of nests for *Xylocopa frontalis* or other pollinating bees of *B. excelsa*, as well as the cultivation of other plant species alongside the Brazil nut that are attractive to pollinators, thus maintaining their populations at the plantation site (Freitas & Oliveira-Filho, 2003; Camargo, 2010; Maués et al. 2015), which will provide efficient cultivation of the species, maintain the genetic diversity and environmental quality of the plantations, and maximize gene flow between organisms (Camargo, 2010).

**Seed dispersers**

The seeds of the Brazil nut tree are predated and disseminated by rodents, mainly from the genus *Dasyprocta* Illiger, 1811 (Rodentia) (Peres & Baider, 1997; Zudeima, 2003), Acouchi (*Mioprocta* Thomas, 1903), *Agouti paca* (Linnaeus, 1766), Brazilian squirrel (*Sciurus* Linnaeus, 1758), Southern Amazon red squirrel (*Sciurus spadiceus* Olfers, 1818), Red-rumped agouti (*Dasyprocta leporina* (Linnaeus,1758)) and other rodents (Peres & Baider, 1997; Peres et al., 2007; Kainer et al., 2007). Some seeds are consumed immediately, others are dispersed up to 20 meters from the adult tree and buried individually at a depth of 1 to 3 cm for later consumption, where they are often forgotten and germinate (Peres & Baider, 1997; Peres et al., 1997). Dispersal is also occasionally performed by Tufted capuchins (*Cebus apella* Linnaeus, 1758), White-fronted capuchins (*Cebus albifrons* (Humboldt, 1812)) and Black-bearded saki (*Chiropotes satanas* (Hoffmannsegg, 1807)). Psittacines such as Macaws (*Ara ararauna* (Linnaeus, 1758)*, Ara macao* (Linnaeus, 1758), *Ara severa* (Linnaeus, 1758), *Ara chloroptera* Gray, 1859), and the Red-necked woodpecker (*Campephilus rubricollis* (Boddaert, 1783)) feed on part of the Brazil nut and act as predators and occasional dispersers.

In the past humans may have acted as a disperser of Brazil nuts, however there are hypotheses that the Brazil nut tree was part of a pre-Columbian culture incorporated into the forest and that the aggregate formations are caused by the socio-cultural habits of these populations (Mori et al., 1990; Shepard Jr. & Ramirez, 2010). Humans also currently influence the dispersion of the tree, as human presence influences the demographic structure of the native Brazil nut, with regeneration favoring areas in proximity to extractive communities, where the involuntary dispersion of the seeds occurs at the time of collection and transportation (Shepard Jr. & Ramirez, 2010; Scoles et al., 2011, Tonini et al., 2014), as well as voluntary dispersion when the production of Brazil nut seedlings and plantations occur (Albuquerque et al., 1974; Tonini et al., 2006; Costa et al., 2009; Cavalcante et al., 2012; Maués et al. 2015).

## Conclusion

The Brazil nut tree has been exploited in certain places in an unorganized and predatory manner, suffering from the advance of livestock and increased pasture areas, deforestation, illegal logging and forest fires in their regions of occurrence. Situations that put this species at risk by reducing the habitats required to maintain the appropriate numbers of pollinators and seed dispersing agents (Mori & Prence, 1990; Cavalcante et al., 2012; Maués et al. 2015), accelerate the process of genetic erosion due to population decline (Camargo, 2010; Hurtado, 2010; Scoles et al., 2015).

Although exploitation of the Brazil nut has occurred for many decades in the native forest, the production of seedlings and cultivated areas are relatively recent events. There are few recorded occurrences of pests and diseases in the Brazil nut tree in crops and native forests. These few records were performed in isolation, without further studies. This situation should be rectified by periodic monitoring of the Brazil nut tree, and maintaining the proper management and balance of biodiversity surrounding them. The study and observation of the organisms that interact with the Brazil nut tree should be performed from the outset, as well as the use of integrated management techniques when necessary to stop the appearance of pests and diseases.

The maintenance of the Brazil nut helps reduce deforestation and the pressure to advance the agricultural frontier, making economic development possible by generating income for the local population through the sustainable use of non-timber products. Thus, sustainable practices aimed at improving the use of this natural resource without compromising its regeneration and ecological stability can help in the conservation and sustainable use of the species, guaranteeing the continuous supply of Brazil nuts in the Amazon.

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