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RESEARCH ARTICLE

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Feeding habits of marmosets: A case study of bark anatomy and chemical composition of *Anadenanthera peregrina* gum

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Primates of the genus *Callithrix* often obtain exudates from plants of the family Fabaceae. This study characterizes the chemical composition of exudates, and the anatomy and hystochemistry of the secretory ducts in the bark of *Anadenanthera peregrina* (L.) Speg. var. *peregrina* (Fabaceae). Exudates from this tree species represent an important component of the diet of hybrid marmosets, *Callithrix* spp. (Primates: Cebidae). *A. peregrina* was selected as the focal study tree because it is the only gum tree species exploited by *Callithrix* groups present within five urban forest fragments in the municipality of Viçosa, Minas Gerais State, Brazil. Gum samples were obtained directly from gouges made by the marmosets, while bark samples were obtained from *A. peregrina* plants, whether or not they were damaged by the marmosets. Constitutive secretory ducts were present in the bark of ungouged *A. peregrina*, whereas, marmoset damage caused induced secretory duct formation and an increase in the size of these ducts. The gum produced in the gouges made by the marmosets and in ungouged plants reacted positively to tests for polysaccharides, pectin, mucilage, and proteins. The gum from the gouges exhibited high water (41.0%), carbohydrate (38.2%), protein (19.0%), and mineral (Ca 0.4% and K 0.3%) content. We argue that the relatively high calcium content of *A. peregrina* gum plays an important nutritional role in, balancing a diet that is otherwise rich in phosphorous and poor in calcium.

KEYWORDS
calcium, *Callithrix*, Callitrichinae, food resource, mineral, vegetable exudates

1 | INTRODUCTION

The diet of primates may include vegetable exudates, such as gums and saps, which are produced by the secretory ducts of plants (Harrison & Tardif, 1994; Ushida, Fugita, & Ohashi, 2006). Marmosets of the genus *Callithrix* Erxleben, 1,777 (Cebidae) are reported to consume exudates from several species in the plant family Fabaceae (Smith, 2010), including *Anadenanthera colubrina* (Vell.) Brenan (= *A. macrocarpa* (Benth) Brenan.) (Amora, Beltrão-Mendes, & Ferrari, 2013; Scanlon et al., 1989; Stevenson & Rylands, 1988) and *Anadenanthera peregrina* (L.) Speg. (Corrêa, Coutinho, & Ferrari, 2000; Francisco et al., 2014; Rizzini & Coimbra-Filho, 1981; Thompson et al., 2013).

Callithrix is characterized by a set of derived dental and mandibular traits that enable individuals to gouge holes in tree bark and damage the ducts in plant tissues that secrete gum (Canton, Hill, Hume, & Crook, 1996; Coimbra-Filho & Mittermeier, 1976; Ferrari & Martins, 1992). These traits include procumbent lower incisors and incisor form lower canines. In addition the lower incisors lack lingual enamel and therefore maintain a sharp gouging edge as the teeth wear (Natori & Shigehara, 1992; Rosenberger, 1978). Moreover, the marmoset masticatory architecture is characterized by relatively long muscle fibers (masseter and temporalis) resulting in high muscle extension (Taylor & Vinyard, 2004) facilitating a wide gap necessary for tree gouging (Vinyard, Wall, Williams, & Hylander, 2003; Vinyard & Ryan, 2006). The genus *Callithrix*, along with *Cebuella* (pygmy marmosets),

Calibella (dwarf marmosets) and to a lesser degree *Mico* (*Amazonian marmosets*) are the only genera of Neotropical primates that have the ability to gouge holes in bark to obtain exudates. Exudates are sources of water, sugars, structural carbohydrates, proteins, and minerals for primate consumers (Bearder & Martin, 1980; Garber, 1984; Power, 2010; Ushida et al., 2006).

Gum secretory ducts occur naturally or are induced by physical and/or biological stimuli. Ducts that arise in response to injury are termed induced secretory ducts (Evert, 2006; Fahn, 1988; Hanavan, Adams, & Allen, 2012). The synthesis of gums, saps, and resins in secretory ducts may occur in response to plant age, stress, and injuries caused by insects, pathogens, birds and mammals (Christiansen et al., 1999; Evert, 2006; Fahn, 1988, 2000; Hanavan et al., 2012; Koutsoudaki, Krsek, & Rodger, 2005; Rajput, Sanghvi, Koyani, & Rao, 2009). Sap is transported in the plant by the xylem and phloem, and is commonly produced in conifers and some angiosperm (Fahn, 2000). In contrast, gum is synthesized by secretory cells in ducts similar to resin ducts from conifers (Babu & Shah, 1987; Fahn, 2000; Hanavan et al., 2012). Gum, sap and resins also differ in chemical composition. Gum is water soluble, and contains complex polysaccharides that are difficult to digest and require fermentation by gut microbes before its nutrients can be absorbed by the host. Sap also is water soluble and contains soluble minerals, photosynthesis products, and easily digested polysaccharides (Bearder & Martin, 1980; Nash, 1986; Nash & Burrows, 2010; Power, 2010). Resins are water insoluble and contain high levels of phenols and terpens, however, whether marmosets feed on resin remains unknown (Bearder & Martin, 1980; Nash, 1986; Power, 2010) Plant secretory tissues have evolved to perform significant ecological functions, such as protecting against herbivores and pathogens and attracting pollinators (Fahn, 2002; Lange, 2015). A comprehensive study of these secretory structures may help elucidate the benefits they offer to the plant as well as relationships between plants, animals and their environment.

Gum products are released by ducts formed by cell detachments (schizogenous), rupture of the cells (lysigenous) or both (initially schizogenous becoming lysigenous) (Evert, 2006; Fahn, 2000; Pickard, 2008), depending on how the ducts are produced (Pickard, 2008; Roshchina & Roshchina, 1993). Induced secretory ducts in plants caused by insect damage or pathogens have been relatively well studied (Babu et al., 1987; Rajput et al., 2009), however, how the mechanical damage caused by primates affects exudate production requires more detailed study.

Exudativory has been reported in approximately 69 primate species across 12 families (Smith, 2010). Primates feed on exudates produced in legume pods, tree roots, trunks, and tree branches (Garber & Porter, 2010; Porter, Garber, & Nacimento, 2009). The nutritive quality of exudates differs across plant species (Porter et al., 2009; Smith, 2000; Ushida et al., 2006), but, generally, they are reported to have a relatively high calcium content (Garber, 1984; Passamani & Rylands, 2000; Smith, 2000). Finally, plant secondary compounds such as tannins and phenols may affect exudate-feeding behavior, with monkeys such as vervets, *Chlorocebus aethiops* feeding mainly from exudates with low phenol content (Wrangham & Waterman, 1981).

Anadenanthera peregrina var. *peregrina* (Fabaceae) is an exudate producing tree species widely distributed in the Caatinga, Cerrado, and Atlantic rain forest of Brazil (Lorenzi, 2008). This plant contains tannins in the bark (Carneiro et al., 2012), and is used for wood products (Valente, Evangelista, Silva, & Lucia, 2013), as well as for medicinal purposes such as antibiotic, anti-tumor (Ott, 2001) and as a detoxificant (Johns, Nagarajan, Parkipuny, & Jones, 2000). The exudate of *A. peregrina* represents an important food resource for marmosets (Amora et al., 2013; Francisco et al., 2014; Rizzini & Coimbra-Filho, 1981; Thompson et al., 2013).

This study identified the physical responses of *A. peregrina* var. *peregrina* bark to injury and the chemical composition of its exudate. Active gouging by *Callithrix* spp. on the trunk or branches may stimulate plant defenses such as induced secretory duct formation and an increase in the size of these ducts. Plants are not only passive receptors of gouging but may respond by tissue modifications in the gouged tree holes to increase protection and defense against pathogens (Verbeken, Dierckx, & Dewettinck, 2003). In this regard, the gouging of *Callithrix* may modify tree anatomy or increase exudate abundance, allowing marmosets to control spatial and temporal exudate availability (Garber & Porter, 2010). We hypothesized that marmoset gouged tree holes (these are hybrid individuals with intermediate characteristics of *C. penicillata* × *C. jacchus* and *C. penicillata* × *C. geoffroyi*) to induce anatomical changes in the bark of *A. peregrina* trees including stimulating the proliferation of secretory ducts and secretions, favoring increased exudate production. In addition, it has been proposed that the high ratio of calcium to phosphorus in exudates may provide marmosets with a nutritionally complementary resource needed to balance a diet which is assumed to be otherwise high in phosphorous, presumably from the consumption of invertebrate (Garber, 1984; Power, 2010; Ushida et al., 2006). To test this hypothesis, the primary objective of this study was to characterize the chemical composition of the gum and the anatomy and hystochemistry of the secretory ducts in the bark of *A. peregrina* associated with the feeding habits of hybrid marmosets (*Callithrix* spp.).

2 | METHODS

2.1 | Study area

The study was conducted in five urban forest fragments in Viçosa, Minas Gerais, Brazil: (1) 20°45′34.71″S, 42°51′57.84″W; 2) 20°45′13.85″S, 42°52′26.90″W; 3) 20°45′11.16″S, 42°52′16.80″W; 4) 20°45′22.28″S, 42°52′23.81″W; 5) 20°46′17.41″S, 42°52′37.03″W. Altitudes varied from 675 to 709 m. The forest formation in this region is classified as semi-deciduous, mountainous (Veloso, Rangel Filho, & Lima, 1991), with the influence of a Cwb (highland tropical climate) climate, characterized by wetter summers and colder, drier winters according to the Köppen system of classification (Golfari, 1975). Average annual precipitation is 1,221 mm, with an average temperature of 19 °C (Vianello and Alves, 1991).

2.2 | Sample collection and analysis

Ten *A. peregrina* plants were sampled, two per urban forest fragment. Ten branches, five with and five without gouge holes made by the marmosets were collected from each of the ten plants sampled. Samples taken from branches with and without holes were transferred to a formaldehyde, glacial acetic acid and 50% ethanol (1:1:18 v/v) fixative solution for 48 h, stored in 70% ethanol (Johansen, 1940), dehydrated in a graded ethanol series (70%, 80%, 90%, 95%), and embedded in methacrylate Historesin (Leica Instruments, Heidelberg, Germany). Cross and longitudinal sections, 8 mm thick, were stained with toluidine blue, pH 4.0, and observed in a light microscope.

Three slides (replicates) were mounted per plant and used for the histological analysis. The larger and nearby secretory ducts were selected for measurement. An average of 24 ducts per replicate were sampled. The image-processing system Image Pro Plus 5.0 was used to measure area, perimeter and the area/perimeter ratio of the secretory ducts in cross sections for a total of 73 samples.

Due to the non-normality and non-homoscedasticity of the data, as determined by Shapiro–Wilk and Levene's tests respectively, a Mann–Whitney *U*-test (Zar, 1999) was used to analyze differences in the area, perimeter and the area/perimeter ratio of constitutive versus induced secretory ducts in cross section. Statistical analyses were performed using software R (R Development Core Team, 2015). Differences were considered significant at $p < .05$.

Twelve cross-sections of *A. peregrina* holes were submitted to histochemical tests and evaluated using a light microscope. The periodic acid Schiff test (PAS) (McManus, 1948) was used to detect neutral polysaccharides and glycoconjugates. Ruthenium red (Johansen, 1940) was used to detect pectins and mucilage, and Ponceau xylidine (O'Brien & McCully, 1981) was used to detect total protein.

In July 2012, fresh exudates characterized as semi-gelled were collected weekly, after the overnight period of gouging and before the marmosets fed in the early morning, and stored in sterile containers for chemical analysis. These samples were obtained from the holes gouged and exploited by marmosets on the stem and branches of *A. peregrina*. Twenty-four samples of exudates from plants gouged by marmosets were evaluated.

The percentage wet weight of carbohydrate, water (Pregnollatto & Pregnollatto, 1985) and protein (Biuret method) (Gornall, Bardawill, & David, 1949) in the exudate samples was determined. The concentrations of calcium, copper, sulfur, iron, phosphor, magnesium, manganese, nickel, potassium, and zinc were obtained by inductively coupled plasma spectrometry (ICP), with three replications. Some compounds may have degraded during the overnight period; however, this is the exudate the marmosets would have consumed in the morning and the accuracy of the procedures utilized a reasonable evaluation of the gum nutrients available to the marmosets.

Voucher plant specimens were deposited at the Herbarium of the Universidade Federal de Viçosa, with the numbers VIC 38.241; VIC 38.240; VIC 38.239; VIC 38.615. This research adhered to the American Society of Primatologists (ASP) Principles for the Ethical Treatment of Primates.

3 | RESULTS

Measurements of median diameter at breast height (DBH) and total height of 10 *A. peregrina* trees were 28.8 ± 14 cm (ranging from 17.3 to 64.9 cm) and 19.0 ± 8.1 m (from 10.0 to 28.5 m), respectively. The holes gouged by marmosets in *A. peregrina* were identified according

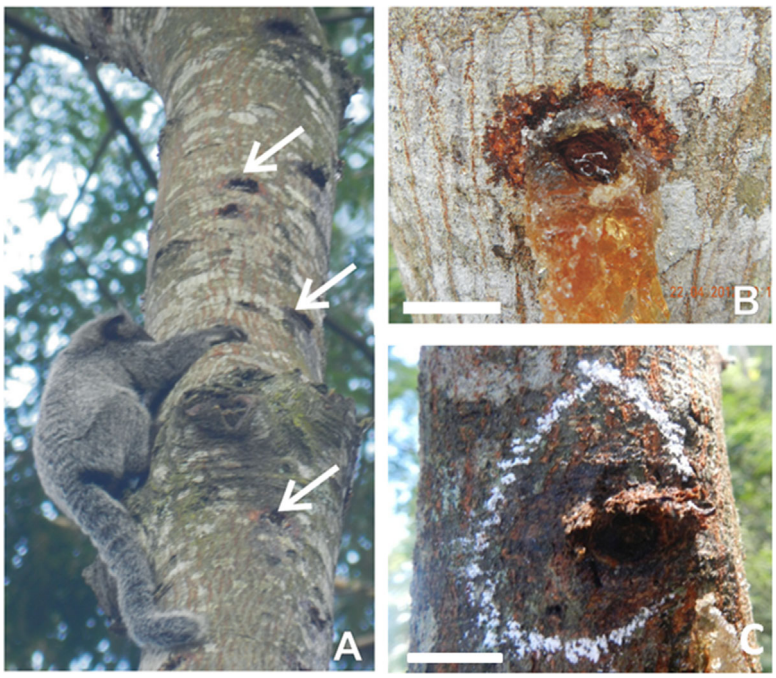

FIGURE 1 (A–C) Holes in damaged *Anadenanthera peregrina* trees. (A) Holes (arrows) opened by hybrid marmosets (*Callithrix* spp.). (B and C) Image of the holes with exudates; Scale bars = 7.5 mm (B) and 9 mm (C)

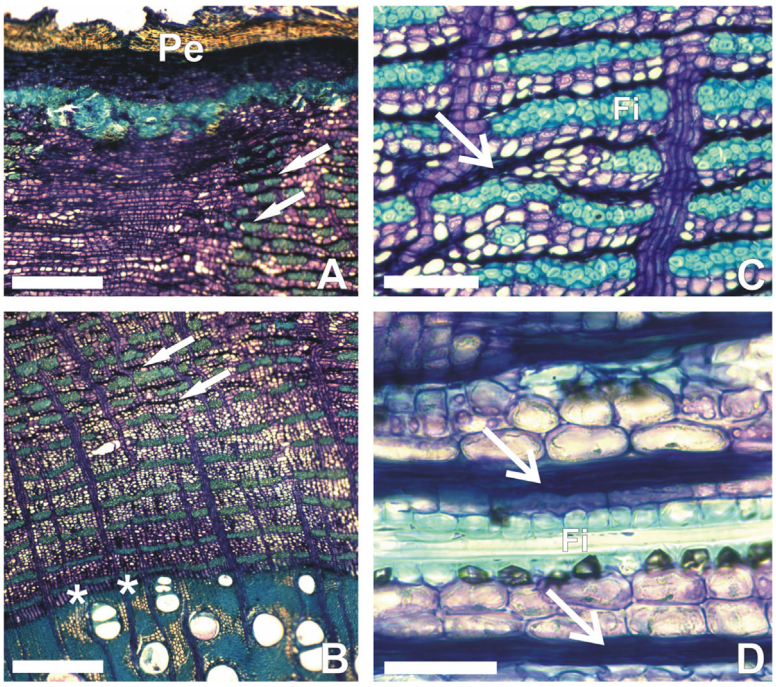

FIGURE 2 (A–D). Cross (A–C) and longitudinal (D) sections of regions of *Anadenanthera peregrina* bark without gouge holes (A and B) Images of the secretory ducts (white arrows) in the bark. (C) Image of a branched duct (white arrow), associated with secondary phloem fibers. (D) Image of the ducts (white arrows) associated with the secondary phloem fibers. Pe, periderm; Fi, fibers; and *Vascular cambium. Scale bars = 100 μm (A); 400 μm (B); 200 μm (C); 50 μm (D)

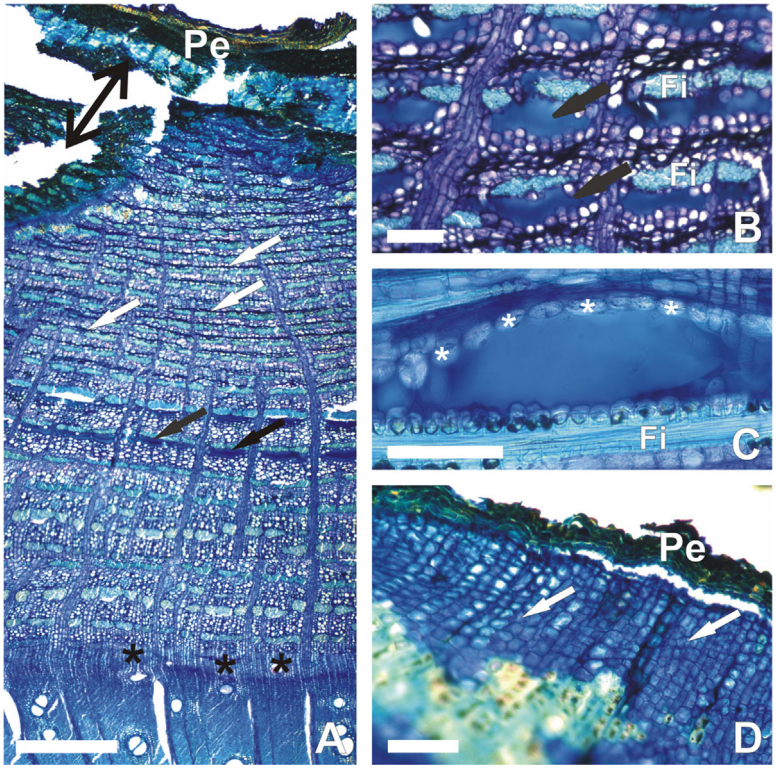

FIGURE 3 (A–D). Cross (A, B, D) and longitudinal (C) sections of the *Anadenanthera peregrina* bark regions in gouged holes. (A) View of the bark showing ducts (white arrows), induced ducts (black arrows) and the periderm scarified by marmoset gouging (double arrow). (B) Image of the induced ducts (black arrows) associated with secondary phloem fibers. (C) Image of the induced ducts and epithelial cells (*). (D) Image of healing tissue in the periderm with parenchymal cell proliferation, with meristematic characteristics (white arrows). Pe, periderm; Fi, fibers; and *Vascular cambium. Scale bars = 550 μm (A); 100 μm (B–D)

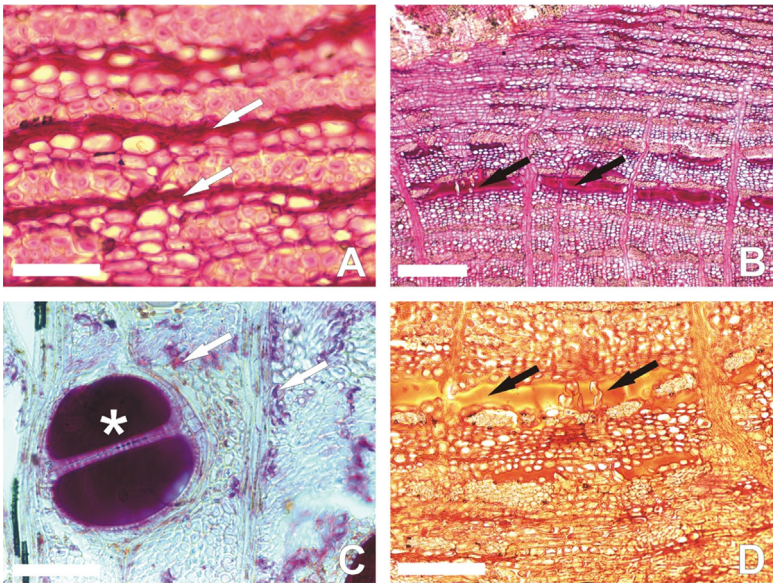

FIGURE 4 (A–D). Histochemical characterization of *Anadenanthera peregrina* var. *peregrina* bark exudate. Positive reaction for polysaccharides evidenced by periodic acid Schiff reagent (A–C). (A) Image of exudates present in the ducts (white arrows). (B) Image of exudates in the induced ducts (black arrows). (C) Image of the obstruction of the vessels (*) and axial secondary xylem parenchyma (white arrows) near the exudate. (D) Total proteins (black arrows) detected by Ponceau xylidine. Scale bars = 100 µm (A, C, and D); 400 µm (B)

to Francisco et al. (2014) (Figure 1A–C). The holes sampled were approximately 7.1 ± .09 mm deep.

The holes gouged by marmosets in the branches of *A. peregrina* (Figure 1A–C) exhibited a viscous exudate flow and were light-brown in color (Figure 1B and C). The secretory ducts were observed in tangential and discontinuous rows along the bark of the tree, without (Figure 2A–D) or with gouged holes (Figure 3A–C) made by marmosets. These layers of secretory ducts ranged from 14 to 21 rows. The secretory ducts exhibited long intercellular spaces delimited by a secretory epithelium (Figure 2C and D) and were generally branched (Figure 2c) from which cells occasionally peeled in association with phloem fibers (Figure 2C and D).

Longitudinal and cross sections of the induced ducts in the tree bark of *A. peregrina* (Figure 3A–C) showed highest amounts of gum. The induced ducts had a wider area in their cross sections (61,787 μm^2) compared to the ducts from non-gauged samples (14,930 μm^2). The induced ducts had larger, irregular, and disorganized lumens in the cytoplasm, delimited by debris and epithelial cells on the induced ducts. This damage is consistent with injuries caused by the lower incisor/canine dental battery of the marmosets (Figure 3A–C). Scar tissue in the damaged regions of the bark of *A. peregrina* trees showed parenchymal cell proliferation, with meristematic characteristics (Figure 3D).

Plants with gouged holes had larger ducts in the three layers closest to the meristem, whereas samples without gouged holes had larger peripheral ducts from the 7th to 14th duct layers (Figure 3). Because non-gouged plants had smaller ducts whereas the gouged holes were characterized by larger structures, they were classified as constitutive and induced ducts, respectively. The constitutive and induced secretory ducts differed in transversal section areas (Mann–Whitney *U*-test, $z = 81$, $p = .001$), perimeters (Mann–Whitney *U*-test, $z = 64$, $p = .03$) and different area/perimeter ratios (Mann–Whitney *U*-test, $z = 81$, $p = .001$).

The exudate in the ducts of the *A. peregrina* bark reacted positively to PAS tests for polysaccharides (Figure 4A and B); ruthenium red for pectins and mucilage; and Ponceau xylidine for proteins (Figure 4D). The induced secretory ducts were wider in cross section compared to the constitutive ducts, as well as had a higher cross section/perimeter ratio (51.7 and 17.8, respectively). The exudates accumulated in the intercellular spaces of the axial and radial parenchyma of the xylem (Figure 4C). We did not find evidence of marked differences across sampled trees. The exudates of *A. peregrina* contained 41.0% (range 47–56%) water, soluble 11.0% (range 10–12%), and complex 27.2% (range 26–28%) carbohydrates, protein 19.0% (range 15–24 %), calcium 0.4% (range 0.4–0.5%), potassium 0.3% (range 0.3–0.4%), as well as other unidentified compounds (Tables 1 and 2).

TABLE 1 Chemical composition (% of fresh matter) (mean ± standard error) of the secretion on the *Anadenanthera peregrina* var. *peregrina* bark, used as food resource by hybrid marmosets

Constituents	Composition (%)
Water	41.0 ± 2.52
Total carbohydrates	38.2 ± 0.72
Soluble carbohydrates	11.0 ± 0.58
Total proteins	19.0 ± 2.60
Minerals	0.8
Others	1.0
Total (%)	100.0

Municipality of Viçosa, Minas Gerais State, Brazil.

TABLE 2 Concentration of selected minerals (Conc. Min.) found in fresh (Fresh) and dry (Dry) secretions (mg/100 g) from the *Anadenanthera peregrina* var. *peregrina* bark, used as food resource by hybrid marmosets

Con. Min.	Fresh	Dry	Conc. Min.	Fresh	Dry
Calcium	2.958	613.046	Manganese	.082	18.255
Potassium	2.619	561.672	Phosphorus	.042	9.402
Sodium	0.945	196.310	Iron	.019	4.047
Magnesium	0.634	131.556	Copper	.009	2.097
Sulfur	0.402	82.879	Zinc	.005	1.116

Municipality of Viçosa, Minas Gerais State, Brazil.
Fresh, equivalent to fresh gum, that is, hydrated gum. Dry, dry gum, that is, dehydrated gum.

4 | DISCUSSION

In this study, we examined the chemical composition of the exudate and the anatomy and histochemistry of the secretory ducts in the bark of *A. peregrina*. These trees are actively gouged for exudates by hybrid marmosets (display intermediate characteristics of *Callithrix penicillata* × *C. jacchus* and *C. penicillata* × *C. geoffroyi*) at our field site. Marmoset gouging induced anatomical changes in the *A. peregrina* bark (Fabaceae). We found that induced secretory ducts in *A. peregrina* bark, in response to damage by marmosets, differed from the constitutive ducts, in being more than 400% wider in area. This suggests that marmoset damage stimulated the proliferation of secretory ducts and secretions. Although it has not been empirically verified, the larger area of the marmoset induced ducts may result in an increased rate of exudate production (Fahn 1988, 2000, 2002).

In our study, marmosets gouged holes in particular *A. peregrina* trees. This is a behavior common to other *Callithrix* spp. (Stevenson & Rylands, 1988), such as *Callithrix jacchus* (Thompson et al., 2013). For example, Thompson et al. (2013) speculated that factors such as nutritional content, tree size/age and/or mechanical features of tree as bark thickness (Vinyard et al., 2009) may affect gouging choice. In additions, Francisco et al. (2014) argued that the intensity of tree exploitation by marmosets varies positively according to tree diameter at breast height (DBH) and total tree height, suggesting that larger and older trees produce larger amounts of exudates. Although the present study was not designed to evaluate marmoset preferences for *A. peregrina* a study of vervet monkeys, *Chlorocebus aethiops*, indicated a preference for the exudades of individual *Acacia trees (A. xanthophloea)* that contained low levels of phenols (0.09–0.23%) and tannins (0.23–0.31%) (Wrangham & Waterman, 1981).

The induced secretory ducts of *A. peregrina* are located in tangential and discontinuous rows in the bark and have long intercellular spaces surrounded by a secretory epithelium that may be branched and associated with fibers, as reported for the secondary phloem of many plant families (Evert, 2006; Fahn, 1988; Roshchina & Roshchina, 1993). Constitutive secretory ducts, although smaller, occur in the bark of *A. peregrina*, and marmoset damage was found to stimulate their production. The increased production of constitutive secretory ducts is assumed to result in pine trees resistant to bark beetles that would have many resin ducts, in which more resin ducts should result into high resin production, storage and flow during insect attack (Ferrenberg, Kane, & Mitton, 2014).

Changes in the number of secretory duct rows documented in the present study may be induced by the gouging damage caused by the marmosets. The older ducts, distant from the damaged area, differed from the newer ducts which were located closer to the cambium. The recently formed ducts were significantly wider. Based on our data, the strongest explanation is that marmoset gouges stimulate earlier and larger development of secretory ducts. Given that the exudates were scattered among the intercellular spaces in the non-damaged tissues, we argue that gouged *Anadenanthera* trees produces greater amounts of gum, in response to continuous gouging stimuli compared to non-gouged trees.

Histochemical tests showed that secretory ducts are rich in polysaccharides, pectins, mucilages and proteins, and in the intercellular spaces of the axial parenchyma of the phloem and secondary xylem in *A. peregrina* exudates. Similar compounds also are reported for *Azadirachta indica* (Meliaceae) (Rajput et al., 2009) and of *Ailanthus excels* (Simaroubaceae) (Shah & Babu 1986), gum trees exploited by *Microcebus griseorufus* (Smith, 2010). This suggests that these exudates are mainly composed of proteins, polysaccharides, probably pectin.

The presence of 41.0% water, 38.2% carbohydrates, 19% proteins, 0.4% calcium and 0.3% potassium indicates that the gum from *A. peregrina* represents an important food source for *Callithrix* spp., and this is consistent with data on the nutritional composition of gums consumed by other primate taxa (e.g. *Callithrix geoffroyi* with *Acacia paniculata* (Fabaceae), *Bauhinia angulosa* (Fabaceae), *Dyctioloma incanensis* (Rutaceae) and *Paulinia carpopoda* (Sapindaceae) (Passamani & Rylands, 2000); *Leontocebus nigrifrons* and *Saguinus mystax* (Spix, 1823) feeding on exudates of *Oenocarpus bataua* (Arecaceae), *Parkia igneiflora* (Fabaceae) and *Sloanea floribunda* (Elaeocarpaceae) (Smith, 2000); *Saguinus geoffroyi* feeding on *Anacardium excelsum* (Anacardiaceae) (Garber, 1984); and *Galago senegalensis* feeding on *Acacia karroo* (Fabaceae) (Bearder & Martin, 1980) (Table 3). In this regard, our data may help to explain the preference of *Callitrix* spp. for exudates from *A. peregrina* trees. The high percentage of water (41.0%) found in its gum suggests that this plant may be an important source of water resource, especially during periods when ripe fruits or floral nectar are scarce or in hot and dry habitats. A similar hypothesis has been suggested for *Saguinus geoffroyi* feeding on the gum of *A. excelsum* (Garber, 1984) and *C. penicillata* feeding on the gum of *Hancornia speciosa* trees (Rizzini & Coimbra-Filho, 1981).

A. peregrina gum contained 38.2% complex carbohydrates. The gut anatomy and physiology of common marmosets (*C. jacchus*) appears to ensure efficient digestion and absorption of proteins and complex carbohydrates. The relatively small size of the small intestines (49.0 cm) permits rapid digestion of high quality foods, such as animal prey and fruits, whereas an allometrically large cecum facilitates the microbial fermentation of complex carbohydrates (Canton et al., 1996). Given that the gums of *A. peregrina* contain 27.2% insoluble carbohydrates that are difficult to digest (Nash, 1986; Power & Oftedal, 1996); future studies of the marmoset microbiome (cecum and colon) are needed (Canton et al., 1996; Power, 2010; Power & Oftedal, 1996).

TABLE 3 Nutrient content of exudates

Primate	Tree	Nutrient content					References
		Water (%)	Carbohydrates (%)	Protein (%)	Calcium	Ca:P	
Callithrix spp.	*Anadenanthera peregrina*	41.0	38.2	19.0	613	65:1	This study
Callithrix geoffroyi	*Acacia paniculata*	5.3	79.7	10.8	—	—	Passamani and Rylands (2000)
Callithrix geoffroyi	*Bauhinia angulosa*	7.6	81.4	6.3	—	—	Passamani and Rylands (2000)
Callithrix geoffroyi	*Dyctioloma incanensis*	6.5	81.1	7.1	—	—	Passamani and Rylands (2000)
Callithrix geoffroyi	*Paulinia carpopodia*	6.6	73.5	15.2	—	—	Passamani and Rylands (2000)
Saguinus fusciocllis and *S. mystax*	*Oenocarpus bataua*	—	—	—	465.8	82:1	Smith (2000)
Saguinus fusciocllis and *S. mystax*	*Parkia igneiflora*	—	—	—	273.8	29:1	Smith (2000)
Saguinus fusciocllis and *S. mystax*	*Sloanea floribunda*	—	—	—	194.7	44:1	Smith (2000)
Saguinus geoffroyi	*Anacardium excelsum*	49.9[a]	—	5.7[a]	546[a]	66:1[a]	Garber (1984)
Galago senegalensis	*Acacia karroo*	9.9[b]	76.7[b]	0.9[b]	1,000[b]	95:1[b]	Bearder and Martin (1980)

Ca and Ca:P in mg/l00 g dry weight.
[a]Mean values (n = 3).
[b]Mean values (n = 7).

TABLE 4 Nutritional content of food resources

Primates	Food resources	Nutrient content					References
		Water (%)	Carbohydrates (%)	Protein (%)	Calcium	Phosphorus	
Callithrix spp.	Exudate of *Anadenanthera peregrina*	41.0	38.2	19.0	613.0	9.4	This study
Saguinus geoffroyi	*Schistocerca paranensis* (Orthoptera)	—	—	51.0	01	70	Garber (1984)
Saguinus geoffroyi	*Schistocerca gregaria* (Orthoptera)	—	—	61.7	59	120	Garber (1984)
Saguinus geoffroyi	Fruits of *Anacartlium occidentale*	—	—	—	02	—	Garber (1984)
Saguinus geoffroyi	Fruits of *Inga preusii*	—	—	—	15	—	Garber (1984)
Saguinus geoffroyi	Fruits of *Vitis vinifera*	—	—	—	78	—	Garber (1984)
Callithrix jacchus	Fruits of *Spondias tuberosa*	91.3[a]	7.5[a]	0.6[a]	136[a]	—	Amora et al. (2013)
Callithrix jacchus	Fruits of *Pilosocereus gounelleia*	85.9[b]	8.7[b]	2.1 [b]	—	—	Amora et al. (2013) and Abreu, Fuente, Schiel, & Souto, 2016
Callithrix jacchus	Fruits of *Pilosocereus pachycladus*	92.0[b]	4.8[b]	0.25 [b]	—	—	Amora et al. (2013) and Abreu et al. (2016)
Callithrix jacchus	Fruits of *Cereus jamacaru*	86.2[b]	9.9[b]	2.35 [b]	—	—	Amora et al. (2013) and Abreu et al. (2016)

Water, Carbhydrates, and Protein = wet of weight. Ca and P in mg/l00 g dry weight.
[a]Cited by Santos, Cardoso, Fonseca, and Conceição (2010).
[b]Cited by Nascimento, Moura, Vasconcelos, Maciel, and Albuquerque (2011).

Finally, one hypothesis that might explain the marmoset preference for exudates of *A. peregrina* compared to other exudate species at our site is its mineral content. Calcium content ranged from 544.1–672.8 (mg/100g dry weight) which is reported to be higher than in fruits and animal prey consumed by other callitrichines (Table 4). The gum of *Anacardium exelsum*, used by *Saguinus geoffroyi*, has higher calcium content (310–710 mg/100 g dry weight) that is generally reported for fruit (2 mg/100 g dry weight) and insects (Garber, 1984). Although some insects (e.g., orthopteran) consumed by callitrichines, contain calcium in their chitinous exoskeleton, these parts are discarded prior to ingestion (Garber, 1984). Plant exudates have been suggested as a complementary food source to balance a diet otherwise poor in calcium and high in phosphorus (Garber, 1984). Exudates of other plants also have been reported to be rich in calcium and poor in phosphorous (Bearder & Martin, 1980; Garber, 1984; Passamani & Rylands, 2000; Power, 2010; Smith, 2000) (Table 3). We conclude that *A. peregrina* gum is an important food resource for marmosets, due to its richness in carbohydrates, proteins, calcium, and water.

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CONFLICT OF INTEREST

The authors have declared that no competing interests exist.

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