A revised classification of the sister tribes Palicoureeae and Psychotrieae (Rubiaceae) indicates genus-specific alkaloid accumulation

Andreas Berger · Karin Valant-Vetschera · Johann Schinnerl · Lothar Brecker

Received: 26 December 2020 / Accepted: 17 July 2021 / Published online: 17 September 2021 © The Author(s) 2021

Abstract Tribes Palicoureeae and Psychotrieae (Rubiaceae, Gentianales) are complex and speciose sister groups with a pantropical distribution. Since the initial studies on ipecacuanha more than two centuries ago, species of the group have been subject to numerous phytochemical studies yielding diverse specialized (“secondary”) metabolites, most of them alkaloids. However, the generic limits within the tribes have long been unclear and only recently, monophyletic genera have been delimited and segregated from a once broadly circumscribed Psychotria. Thus, a phylogeny-based and taxonomically updated review of phytochemical literature was performed which allowed assigning the bulk of phytochemical data previously reported for Psychotria to various segregate genera such as Carapichea, Eumachia and Palicourea. This review not only challenges the common perception of Psychotria as a monoterpenoidole alkaloid-rich genus. It also highlights that each of its relatives differs by accumulating specific groups of alkaloids, which is of major importance for understanding animal-plant interactions such as herbivory, as well as for drug discovery. The alkaloid complement of each of these genera is here enumerated and discussed, which should provide a framework for future studies addressing the biosynthesis, evolution, ecological and pharmacological significance of specialized metabolite differentiation in this abundant, ecologically and ethnopharmacologically important group.

Keywords Palicoureeae · Psychotrieae · Chemosystematics · Secondary metabolites · Alkaloids

Abbreviations

DMT N,N-Dimethyltryptamine
IA Indole alkaloid
MAO Monoamine oxidase
MIA Monoterpene-indole alkaloid
PA Protoalkaloid
PIA Polypyrroloindoline alkaloid
PSR Pictet-Spengler reaction
SGD Strictosidine β-glucosidase
STR Strictosidine synthase
T5H Tryptamine 5-hydroxylase
TA Tryptamine analogue
TIQA Tetrahydroisoquinoline alkaloid
βCA β-Carboline alkaloid
Introduction

Taxonomy of Palicoureeae and Psychotrieae

The Psychotria alliance is a speciose and complex group of more than 3100 species, now classified in two sister tribes Palicoureeae and Psychotrieae within the coffee family (Rubiaceae, Gentianales; Nepokroeff et al. 1999; Razafimandimbison et al. 2014; Robbrecht and Manen 2006). Most of the species included here are shrubs and understory treelets, but other growth forms are also occasionally found. They contribute a significant part to rainforest understory species diversity, abundance and biomass (Gentry 1990), and provide an important food source for frugivorous birds (Krebber et al., in prep.; Snow 1981). Furthermore, many species are of ethnobotanical importance (e.g. Rivier and Lindgren 1972) and have proven to be a rich source of various classes of alkaloids (e.g. Calixto et al. 2016; de Carvalho Junior et al. 2017; Martins and Nunez 2015; Porto et al. 2009; Yang et al. 2016).

Traditionally, an overly broad generic concept was applied in the classification of the group, which resulted in lumping most species under the large and polyphyletic genus Psychotria (e.g. Steyermark 1972). Recent DNA-phylogenetic studies and a re-evaluation of morphological characters have radically challenged the traditional circumscription of Psychotria, the largest genus of the alliance and one of the largest genera of flowering plants (e.g. Nepokroeff et al. 1999; Razafimandimbison et al. 2014; Robbrecht and Manen 2006). As a result, views shifted towards a narrower concept of Psychotria and Psychotrieae that peaked in the establishment of the sister tribe Palicoureeae and the ongoing transfer of hundreds of species of Psychotria subg. Heteropsychoptria to other genera. The new generic circumscription renders all the genera monophyletic groups, and is now widely accepted in floristic and systematic literature (e.g. Lorence and Taylor 2012; Kiehn and Berger 2020; Taylor 2014). The entire group is particularly diverse in the Neotropics, where it includes the genera Psychotria (tribe Psychotrieae), as well as Carapichea, Eumachia, Geophila, Notopleura, Palicourea and Rudgea (tribe Palicoureeae). Phylogenetic relationships among the genera are shown in a cladogram in Fig. 1.

The genera Geophila and Rudgea have long been recognized and their generic circumscription remained rather stable over time. The genera Carapichea, Notopleura and Eumachia are more problematic with respect to delimitation, but the corresponding species of these lineages have already been identified (Taylor and Gereau 2013; Taylor et al. 2017; Taylor 2001, 2005). In order to render both Palicourea and Psychotria monophyletic groups, all species of Psychotria subg. Heteropsychoptria have to be transferred to Palicourea, the oldest available name for the genus. Most of these combinations have already been provided in a number of recent publications (Berger 2017, 2018b; Borhidi 2011, 2017; Delprete and Kirkbride 2016; Delprete and Lachenaud 2018; Taylor and Hollowell 2016; Taylor et al. 2010; Taylor 2015a, b, 2017, 2018, 2019a, b), but many species still lack a formal name under Palicourea pending future studies.

Given the taxonomic complexity and recent changes in the generic placement of many species, the problem that metabolites reported from Psychotria were actually isolated from species now assigned to other genera became apparent. Consequently, it appears necessary to review data on specialized metabolite accumulation of the whole group and assign the correct generic identity to each of the previously studied species. This approach allows the re-interpretation of phytochemical data and alkaloid accumulation patterns in a phylogenetic context. Ultimately, this helps to understand the evolution of plant metabolites and their biosynthetic relationships, and is of major importance in drug discovery and for shaping animal-plant interactions such as herbivory.

Alkaloids of Palicoureeae and Psychotrieae

Species of tribes Palicoureeae and Psychotrieae are a rich source of structurally diverse alkaloids (e.g., Bernhard et al. 2011; Berger et al. 2012, 2015a, 2017; Kornpointner et al. 2018, 2020; Lopes et al. 2004; Schinnerl et al. 2012). Further described compound groups include cyclotides (Koehbach et al. 2013), flavonoids and other polyphenols (Berger et al. 2016) and iridoids (Berger 2012; Lopes et al. 2004), highlighting the chemical diversity of the tribes. Alkaloids are particularly diverse in the genus Palicourea lending the group to a more in-depth analysis.

 Springer
of alkaloid diversification and possible biosynthetic sequences (see Berger et al. 2021).

Alkaloids are a structurally diverse and ecologically important group of specialized ("secondary") metabolites showing manifold biological activities. They are present in many groups and more than 21,000 plant-derived compounds have already been identified (Cordell et al. 2001). Nowadays, alkaloids are commonly defined as natural products containing one or more nitrogen atoms that usually originate from an amino acid. Due to numerous known exceptions, however, this definition is unambiguous. As there is no sustainable definition of alkaloids, which is based on molecular structures, the compounds can only hardly be differentiated from other natural product classes. Furthermore, it is difficult to divide them into subgroups according to chemical structure. To basically divide the alkaloid discussed here into subgroups, we refer to the divisions in "true alkaloids" and "protoalkaloids" used, e.g., by Aniszewski (2015). As this division is not always unambiguous, we use these terms in quotation marks.

The bulk of alkaloids of Palicoureeae and Psychotrieae—as well as in general—are "true alkaloids" containing one or more amino acid-derived nitrogen atoms which are part of a heterocycle. By contrast...
"protoalkaloids" lack such a nitrogen-containing heterocycle (Aniszewski 2015). One of the largest and most important groups of "true alkaloids" are indole alkaloids (IA) which originate from the amino acid tryptophan and its decarboxylation product tryptamine bearing the nominate indole scaffold. This group includes simple compounds such as serotonin and harmine, but it is better known for the complex and structurally diverse monoterpene-indole alkaloids (MIA). More than 5,100 derivatives are known (Cordell et al. 2001), and all of these are formed by a stereospecific strictosidine synthase (STR)-catalysed Pictet-Spengler reaction (PSR) between the amine function of tryptamine, the decarboxylation product of tryptophan, and the aldehyde function of secologanin, a seco-iridoid derived from non-mevalonate terpene biosynthesis (Aniszewski 2015; O'Connor and Marsh 2006).

**Generic affiliation of phytochemically studied species**

During our studies on tribes Palicoureeae and Psychotrieae an extensive literature survey yielded a presumably complete list of phytochemical publications. A combination of extensive fieldwork by two of the authors (AB, JS), herbarium studies in the herbaria CR, W and WU (e.g. Berger 2018a, b) and the consultation of recent taxonomic revisions (e.g. Berger 2017, 2018b; Borhidi 2011, 2017; Delprete and Kirkbride 2016; Delprete and Lachenaud 2018; Lorenz and Taylor 2012; Taylor and Gereau 2013; Taylor and Hollowell 2016; Taylor et al. 2010; Taylor 2001, 2005, 2014, 2015a, b, 2017, 2018, 2019a, b), TROPICOS (https://www.tropicos.org) and other relevant databases (e.g. JACQ, http://jacq.org; POWO, http://www.plantsoftheworldonline.org) subsequently allowed assessing the generic placement of the studied species based on the currently accepted phylogenetic framework (Nepokroeff et al. 1999; Razafimandimbison et al. 2014; Robbrecht and Manen 2006). Using a modern generic circumscription that renders the genera monophyletic groups finally allows reviewing specialized metabolites in an evolutionary context.

A total of 180 phytochemical publications were retrieved and evaluated in the present study. Species merely reported as alkaloid-positive on basis of TLC-analyses with alkaloid-sensitive Dragendorff’s reagent or similar analyses, as well as species accumulating monofluorooacetate (Cook et al. 2014; de L Carvalho et al. 2016) are not considered in the present work. In addition, one study was excluded due to unclear taxonomic affinity of the studied material, even at the tribal level (Sandra et al. 2018, appendix, Table 11). As currently circumscribed (see above) the remaining 179 studies refer to eight genera and 102 species, if two unidentified taxa of *Psychotria* are considered as separate species.

Table 1 provides an overview on the current state of phytochemical research within the ten genera currently assigned to Palicoureeae and Psychotrieae. Most studies pertain on species of Palicoureeae, and *Palicourea* is the best studied genus of the tribe. Furthermore, the data shows gaps in knowledge and pinpoints to some groups remaining underrepresented or unstudied. Table 11 (see appendix) provides a referenced and taxonomically updated compilation of all 102 phytochemically-studied species and their alkaloid content. The list is arranged by accepted names, but also includes synonyms if they have been used in the original publications. Compounds from other biosynthetic groups (coumarins, flavonoids etc.) are not individually mentioned and subsumed under their compound groups.

**Phytochemical differentiation of genera**

As the most-significant result of the present analysis we show that tribes Palicoureeae and Psychotrieae as well as the respective genera are chemically distinct and each is characterized by a specific blend of metabolites. Briefly, Psychotrieae and *Psychotria* are largely characterized by polyphenols and tannin accumulation, with polypyrroloindoline type IA reported from a couple of Asian and Pacific species. MIA are here shown to be absent in the genus instead being restricted to the tribe Palicoureeae. As such the here-elaborated phytochemical view of the group is in strong contrast to previous analyses listing MIA as specific for *Psychotria* (Calixto et al. 2016; de Carvalho Junior et al. 2017; Martins and Nunez 2015; Yang et al. 2016).

In the tribe Palicoureeae the phytochemical situation is more diverse, and most lineages are capable of biosynthesising IA and/or MIA. *Palicourea* largely accumulates strictosidine type MIA with few species...
forming other classes of IA and/or MIA. The genera Chassalia, Geophila and Rudgea are characterized by alstrostine-type MIA. The genus Carapichea forms tetrahydroisoquinoline alkaloids (TIQA) based on tyrosine-derived dopamine and secologanin. Finally, the genus Notopleura is devoid of all of these alkaloids, instead accumulating various types of quinones. No data is currently available for the African genera Hymenocoleus and the Malagasy endemic monotypic Puffia. Minor exceptions in the retrieved patterns include a few species in alkaloid-accumulating clades that have probably lost the ability to form alkaloids. In such cases, ubiquitous iridoids or polyphenols such as flavonoids and chlorogenic acids often replace these (e.g. Benevides et al. 2005, Berger et al. 2016; Sosa Moreno 2011).

As a word of caution, however, the absence of a report of a certain class of compounds does not necessarily imply that they don’t exist in a given plant species. Probable reasons are seasonal or regional chemical and/or genetic differentiations (e.g. Berger et al. 2015; de Sousa Queiroz et al. 2011), targeted isolation efforts (e.g. bioactivity-guided fractionation, acid–base extraction) or other sampling or methodological issues. Most phytochemical publications were focused on the isolation of putatively bioactive alkaloids as evidenced by the frequent use of acid–base extraction. We therefore expect less bias against alkaloids when compared to other compound classes that have not been in focus, facilitating the chemosystematic interpretation presented here.

In order to illustrate the phytochemical differentiation of the genera, the obtained metabolite groups were plotted on a phylogeny (Razafimandimbison et al. 2014) showing relationships within the genera of tribes Palicoureeae and Psychotrieae (Fig. 1). Furthermore, the biosynthetic origin of the nitrogen atom from either of the amino acids tyrosine (in Carapichea) or tryptophan (other genera) are indicated by crossbars on the tree. In the present study a brief taxonomic introduction is given for each genus and the respective alkaloids are grouped and enumerated according to structural similarity and putative biosynthetic relationships (see also Berger et al. 2021).

### Palicoureeae

**Carapichea Aubl.**

The neotropical genus Carapichea (Palicoureeae) comprises of about 23 species of shrubs and treelets distributed from Nicaragua south to Bolivia and eastern Brazil, and its species were long included in Psychotria. The genus features great morphological diversity which makes it difficult to diagnose (Taylor and Gereau 2013): Dried leaves grayish green to brownish; stipules persistent-marcescent, entire, lobed or laciniate, with margins fragmenting with age; inflorescences terminal, (sub)capitate glomerulate or branched, green, white to purple, sessile to pedunculated, bracts well-developed to reduced, the outermost sometimes involucral; corolla straight, tubular to

---

**Table 1** Accepted genera included in tribes Palicoureeae and Psychotrieae, some of the more frequently used synonyms, and the current state of knowledge of their phytochemistry

| Accepted genus | Tribe           | Selected synonyms                        | Spp. no. | Studied | % studied |
|----------------|-----------------|------------------------------------------|----------|---------|-----------|
| Carapichea     | Palicoureeae    | Ipecacuanha                              | 23       | 3       | 13.0      |
| Chassalia      | Palicoureeae    |                                          | 140      | 6       | 4.3       |
| Eumachia       | Palicoureeae    | Chazaliella, Margaritopsis               | 83       | 10      | 12.0      |
| Geophila       | Palicoureeae    |                                          | 24       | 2       | 8.3       |
| Hymenocoleus   | Palicoureeae    |                                          | 13       | 0       | 0.0       |
| Notopleura     | Palicoureeae    | Psychotria sect. Notopleura              | 210      | 3       | 1.4       |
| Palicourea     | Palicoureeae    | Cephaelis, Psychotria subg. Heteropsychotria | 800     | 49      | 6.1       |
| Puffia         | Palicoureeae    |                                          | 1        | 0       | 0.0       |
| Rudgea         | Palicoureeae    |                                          | 200      | 3       | 1.5       |
| Psychotria     | Psychotrieae    | Gramilea, Hydnophyllum, Mapouria         | 1600     | 47      | 2.9       |

*Species numbers according to Razafimandimbison et al. (2014), only Eumachia according to Taylor et al. (2017). Spp.: species number.*
funnelliform, white, yellow, orange to purple; fruit colour ranging from white, red, blue to black; pyrenes with a smooth, 1-crested or 3–5-ridged dorsal side, and a plane or grooved ventral side, opening by a single basal ventral, or 3–4 dorsal preformed germination slits along ridges. According to molecular phylogenetic data, the genus is well-supported as sister to a clade containing *Chassalia*, *Eumachia*, *Geophila*, *Hymenocoleus* and *Puffia* (Andersson 2002; Razafimandimbison et al. 2014; see Fig. 1).

The genus *Carapichea* is the well-known source of structurally unique and pharmacologically important ipecac alkaloids otherwise known only from the unrelated genus *Alangium* (Cornaceae, Cornales). They were discovered more than two centuries ago in the historically important medicinal plant *Ipecacuanha*, which is also known as the vomiting root. Since that time, the drug has been widely used for the induction of vomiting as well as for the treatment of amoebic dysentery (e.g. Lee 2008). The drug is derived from the roots of *Carapichea ipecacuanha* (Brot.) L. Andersson, a species previously confused with the chemically distinct *Ronabaea emetica* (L. f.) A. Rich. containing asperuloside and other iridoids (Berger et al. 2011). Although the use of the vomiting root and its products has decreased due to severe side effects, some derivatives are currently under consideration as possible leads for the discovery of anticancer drugs (Uzor 2016; Akinboye et al. 2017). The emetic and antiamoebic effects of the drug are largely related to the major alkaloids emetine and cephaeline, possessing a monoterpenoid tetrahydroisoquinoline skeleton. In addition, many other alkaloids are present in minor quantities (e.g. Garcia et al. 2005; Hatfield et al. 1981).

Biosynthesis of ipecac alkaloids has been compara-

bly well-studied and starts with a stereospecific Pictet-Spengler condensation of tyrosine-derived dopamine and secologanin in a similar way as in strictosidine. The corresponding enzyme N-deacetyl isopecoside synthase forms the 1α epimer whereas N-deacetyl ipecoside synthase forms the respective 1β epimer. The latter 1β-N-deacetyl ipecoside is subject to various reactions such as O-methylation, N-acetylation or lactam formation leading to ipecoside, alangiside and related alkaloids (Nomura et al. 2008; Nomura and Kutchan 2010a, b; see Fig. 2).

By contrast, deglucosylation of 1α-N-deacetyl isopecoside by the enzyme ipecac alkaloid β-D-glucosidase (Ipeglu1) leads to an aglycon which is further processed to protoemetine. Finally, protoemetine is condensed with a second dopamine unit leading to cephaeline, emetine and related alkaloids (Nomura et al. 2008; see Fig. 3). Both groups are subject to various O-methylations by three dedicated ipecac alkaloid O-methyltransferases creating much of the observed structural diversity (Nomura and Kutchan 2010a). Finally, biosynthesis involves complex subcellular compartmentation between cytosol and vacuole (Nomura and Kutchan 2010b).

In addition to *Carapichea ipecacuanha*, ipecac alkaloids were isolated from *Carapichea affinis* (Standl.) L. Andersson (Bernhard et al. 2011; Korn-pointner et al. 2018) and *Carapichea klugii* (Standl.) C.M. Taylor (Muhammad et al. 2003, as *Psychotria klugii* Standl.). Shamma (1972) and Wiegrebe et al. (1984) also report ipecac alkaloids from what they called “Psychotria granadensis Benth.” However, they confused the latter name with *Uragoga granadensis* Baill., a name that lacks a respective combination under the genus *Psychotria* and is a synonym of *Carapichea ipecacuanha*. In turn, *Psychotria granadensis* Benth. is a synonym of *Psychotria nervosa* Sw. which lacks alkaloids instead accumulating tannins (Berger 2012). Table 11 (appendix) lists all alkaloids isolated from species of *Carapichea* and the corresponding structures are found in Figs. 2 and 3. Besides ipecac alkaloids, two iridoids glucosides were also isolated from the genus (Itoh et al. 1991).

*Chassalia* Comm. ex Poir.

*Chassalia* (Palicoureeae) is a paleotropical genus found in Africa, Asia, and the West Indian Ocean region. It includes ca. 140 species of shrubs and treelets, although a few species are epiphytic or lianescent. The genus is largely diagnosed by indurated and persistent stipules; fleshy-succulent, white or brightly coloured inflorescence axes; often winged flower buds, long-tubed and slightly curved corollas; and pyrenes possessing a large ventral excavation, as well as a dorsal, basal, median preformed germination slit. *Chassalia* is paraphyletic with respect to *Geophila* and comprises of three clades: the basal Southeast Asian ‘*Chassalia* sp.-ck25’, the small ‘East African *Chassalia* clade’ and *Chassalia* s. str. The former two clades have to be recognized at the generic level, if the morphologically
Most of the alkaloids belonging to the biosynthetic group of ipecosides, alangines and related compounds show a glucose moiety in β configuration originating from the secologanin moiety. The structure of the glucoside is shown in a frame at the bottom of the figure, and represents all “Glc” units indicated in this and other figures of the present article. The numbering of the positions of ipecoside and compounds in other figures shows the most commonly used numbering schemes of the respective substance classes. These, however, do not necessarily relate to the numbering of the IUPAC names of the corresponding compounds. The numbering of ipecoside is based on Itoh et al. (1989), but other numbering schemes are also used (e.g. Bernhard et al. 2011; see supplementary figure S1).
distinct *Geophila* (see sect. "*Geophila D. Don*") should be maintained (Razafimandimbison et al. 2014).

To date, the phytochemical constituents of the genus *Chassalia* remain largely unknown. Soobrattee et al. (2005) dealt with the characterization of polyphenols and their antioxidant activities in Mauritian species of *Chassalia*. Wang and Zhou (1999) likewise found phenolics in the widespread Asian *Chassalia curviflora* (Wall.) Thwaites, which also yielded alstrostine A, the first and only alkaloid isolated from the genus (Schinnerl et al. 2012; see Fig. 13). Alstrostines are an unusual group of monoterpenoid alkaloids possessing a polypyrroolidine core and a tryptamine to secologanin ratio of 1:2. They were first described from *Alstonia rostrata* C.E.C. Fisch. (Apocynaceae; Cai et al. 2011) and later found in single species of *Chassalia* s. str., *Rudgea* and *Palicourea* (Schinnerl et al. 2012; Kornpointner et al. 2020). As such alstrostines have a peculiar distribution being both widespread but uncommon in Palicoureeae.

*Eumachia DC.*

The pantropical genus *Eumachia* (Palicoureeae) has a long and confusing taxonomic and nomenclatural history, and includes more than 83 species found in the Neotropics, Africa, Asia and the Pacific region. Most of its species were initially placed in a broadly defined *Psychotria* although taxa showing aberrant morphological features have long been separated at the generic level. For example, African species were named *Chazaliella* E.M.A. Petit & Verdc. and a number of sclerophyllous Cuban and Hispaniolan endemics with spiny leaf tips were named *Margariopsis* C. Wright. Phylogenetic studies indicated that all form a well-supported clade, initially named

---

**Fig. 3** Ipecac alkaloids isolated from *Carapichea* species, II. The biosynthetic group of protoemetine, emetine and related alkaloids showing a 1α configuration. With two exceptions these are aglycones containing two dopamine units. The numbering of emetine is based on Shamma (1972), but other numbering schemes are also used (e.g. Bernhard et al. 2011; Uzor 2016; see supplementary figure S1)
Margaritopsis (Taylor 2005). Finally, it was shown that Eumachia—previously applied to a single species endemic to Fiji, Tonga and Samoa—is the oldest available name for the group and therefore has nomenclatural priority (Barrabé and Davis 2013; Barrabé et al. 2012; Taylor et al. 2017). The genus is well-supported as sister to a clade containing Chassalia, Geophila, Hymenocoleus and Puffia (Razafimandimbison et al. 2014).

Species of Eumachia are rather poor in diagnostic characters but are recognized by: A shrubby habit; frequently flattened and longitudinally ridged internodes; persistent stipules which become indurate and fragmented with age and sometimes show glandular appendages; leaves drying greyish or pale yellowish greenish; terminal inflorescences with green to whitish axes; actinomorphic, white, creamy to yellow-green corollas with straight base; orange to red fruits; pyrenes hemispherical in cross-section, without ventral groove or intrusion and with two basal ventral marginal preformed germination slits; seeds lacking a red ethanol-soluble seed-coat pigment; endosperm not ruminate, and frequently with small inner central ventral invagination (Barrabé et al. 2012; Delprete and Kirkbride 2015; Razafimandimbison et al. 2014; Taylor 2005; Taylor et al. 2017).

To date, nine species of Eumachia were studied phytochemically. Most originate from Asia, Australasia and the Pacific region, with a single neotropical species yet studied (see Table 2). Species of the genus accumulate a group of IA known as polypyrroloindoline alkaloids, but these are also referred to as cyclopyrroloindoline, cis-pyrrolidino[2,3-b]indoline or hexahydropyrrolo indole alkaloids (Jamison et al. 2017). They consist of two or more monomers connected by two or more quaternary carbon stereocenters that allow for a great diversity of stereoisomers, some of which have not been definitely assigned (but see Jannic et al. 1999). Most of the studied species accumulate dimers such as (+)-chimonanthine and (−)-calycanthine, but oligomers of varying chain lengths (tri- to heptamers) are also known (Fig. 4). Polypyrroloindoline alkaloids are well-known constituents from the sweetshrub family (Calycanthaceae) and have received considerable attention due to their analgesic, antibacterial, antifungal, antiviral and cytotoxic activities (e.g. Canham et al. 2015; Jamison et al. 2017). Apart from the genus Eumachia, polypyrroloindoline alkaloids are also reported from a few species of Palicourea as well as Asian and Pacific species of Psychotria (see sections "Polypyrroloindoline alkaloids" under the discussion of both genera).

Oligomers are usually composed of repeating polypyrroloindoline units joined by C3a–C7’ linkages interrupted by a single C3a–C3a’ linkage, i.e., a chimonanthine subunit. The location (between terminal vs. internal units) of the more labile C3a–C3a’ bond results in characteristic MS fragmentation patterns, and may be used to classify oligomeric polypyrroloindoline alkaloids into various subgroups. For example, in the tetrameric quadrigemine B the labile bond is located between unit 3 and 4 (“terminal”) and it belongs to the group of [3 + 1] polypyrroloindolines. By contrast the labile bond links units 2 and 3 (“internal”) of quadrigemine C and the alkaloid fragments in a [2 + 2] fashion (Jamison et al. 2017). In addition, a few compounds

Table 2 Phytochemically studied species of the genus Eumachia

| Accepted species       | Reported under†                                   | References                                           |
|------------------------|----------------------------------------------------|-----------------------------------------------------|
| Eumachia cymuligera    | Eumachia cymuligera                                | Brand et al. (2012)                                  |
| Eumachia depauperata   | = Margaritopsis carrascoana                        | Nascimento et al. (2015a, b)                         |
| Eumachia forsteriana   | = Psychotria forsteriana                            | Adjibadé et al. (1985, 1986, 1989, 1992), Roth et al. (1985, 1986) |
| Eumachia frutescens    | = Hodgkinsonia frutescens                          | Anet et al. (1961), Fridrichsons et al. (1967, 1974), Parry et al. (1978) |
| Eumachia leptothyrsa   | = Psychotria beccarioides                          | Hart et al. (1974)                                  |
| Eumachia lyciiflora    | = Psychotria lyciiflora                            | Jannic et al. (1999)                                |
| Eumachia oleoides      | = Psychotria oleoides                              | Guéritte-Voegelein et al. (1992), Jannic et al. (1999), Libot et al. (1987) |
| Eumachia rostrata      | = Psychotria rostrata                              | Lajis et al. (1993), Mahmud et al. (1993), Takayama et al. (2004) |
| Eumachia straminea     | = Psychotria straminea                             | Fu et al. (2015)                                    |

†Synonyms: = heterotypic synonyms, †= homotypic synonyms
feature unusual C–N linkages (C3a–N1' or C7–N1') between individual units. From these, psychotrimine is unusual in having a single polypyrroloindoline unit (e.g. Takayama et al. 2004). With the exception of quadrigemine C whose structure was unambiguously assigned by X-ray crystallographic analysis, the exact configuration of compounds with four or more units remains to be confirmed. It was suggested that many of the named compounds are in fact identical when stereochemistry is considered (e.g. quadrigemines A, C and E; Canham et al. 2015; Jamison et al. 2017).

*Geophila* D. Don

*Geophila* is a pantropical genus with ca. 25 species, is sister to *Chassalia* s. str., but nested within a
paraphyletic *Chassalia* s. l. (see section "*Chassalia* Comm. ex Poir."). Most of its species are found in the Neotropics and Africa, with a few occurring in Asia. The genus is easily diagnosed by creeping, stoloniferous and herbaceous habit; cordate leaves with bifid stipules; white corollas; orange/red or black fruits, and often twisted pyrenes with one to several ribs that lack preformed germination slits (Razafimandimbison et al. 2014).

To date, a single species of *Geophila* was subject to a phytochemical investigation: Based on material collected in Yunnan Province, China, Luo et al. (2011) reported the isolation of a coumarin, a triterpene and two polyphenols from "*Geophila herbacea* K. Schum." However, the taxonomic identity of the studied material is problematic for a number of reasons. *Geophila herbacea* is a nomenclaturally superfluous and therefore illegitimate later name for *Geophila repens* (L.) I.M. Johnst. The latter species was long thought to be of pantropical distribution, but Razafimandimbison et al. (2014) recently showed that *Geophila repens* is restricted to the Neotropics. In turn the name *Geophila uniflora* Hiern. applies to paleotropical populations, and the name consequently applies to the species studied by Luo et al. (2011). Likewise, Rao et al. (2017) studied material of "*Geophila repens*" from the Chinese Guangxi province and reported the composition of its essential oil, whereas Dash et al. (2019) described the isolation of a diterpene from plants collected in the Indian state Odisha. Both accessions likewise belong to *Geophila uniflora*.

According to preliminary data, the Central and South American *G. macropoda* (Ruiz & Pav.) DC. contains alstrostine-type alkaloids, which possess highly characteristic UV spectra (Berger, in prep.). Although data on alkaloids in the genus *Geophila* is scarce, the unreported record of an alstrostine derivative is in accordance with the phylogenetic position of *Geophila* as sister to the alstrostine-type alkaloid containing *Chassalia* s. str. clade (Razafimandimbison et al. 2014).

*Hymenocoleus* Robbr. and *Puffia* Razafim. & B. Bremer

The tropical African *Hymenocoleus* and the monotypic SE Malagasy endemic *Puffia* (both Palicoureeae) form a clade which is sister to the group of paleotropical *Chassalia* s. str., the ‘East African *Chassalia* clade’ and *Geophila* (see Fig. 1). Both genera are characterized by creeping, herbaceous and stoloniferous habit, as well as bifid stipules. They are therefore similar to species of *Geophila*, and have been included in that genus before *Hymenocoleus* and *Puffia* were recognized. A membranaceous sheath inside the stipules and heterostylos flowers differentiate *Hymenocoleus*, whereas *Puffia* lacks the stipular sheath and features isostylous flowers (Razafimandimbison et al. 2014; Robbrecht 1975). The phytochemistry of both genera remains unknown.

*Notopleura* (Benth.) Bremek.

The neotropical genus *Notopleura* (Palicoureeae) was long classified as *Psychotria* sect. *Notopleura* Benth. before it was finally recognized as a separate genus. As such, *Notopleura* is sister to *Rudgea* (see Fig. 1) and includes ca. 210 species distributed from Mexico and the Antilles south to Bolivia and Brazil, and it is often found in rather wet microsites or at higher elevations. The genus is generally recognized by: succulent herbaceous to subshrubby habit; stipules fused to a sheath with a single succulent glandular interpetiolar-central appendage; terminal or more often pseudoaxillary inflorescences, small white to greenish flowers; succulent white, or black mature fruits then passing through a red stage, with 2–6, sometimes dorsiventrally flattened pyrenes with two long, ventral, marginal preformed germination slits often accompanied by a short median ventral germination slit (Razafimandimbison et al. 2014). The genus includes two subgenera: the terrestrial *Notopleura* subg. *Notopleura* and the epiphytic *Notopleura* subg. *Viscagoga*. The former subgenus includes most species and is largely diagnosed by unbranched stems, pseudoaxillary inflorescences and fruits with two pyrenes, whereas the latter includes species with branched and less succulent stems, terminal inflorescences and 2–6 pyrenes (Taylor 2001).

To date, phytochemical data on the genus *Notopleura* is limited to a small number of species, but all of them are devoid of alkaloids (Berger et al. 2016; Kostyan 2017). Instead, quinones were isolated from *Notopleura camponutans* (Dwyer & M.V. Hayden) C.M. Taylor (Jacobs et al. 2008; Solís et al. 1995, as *Psychotria camponutans* (Dwyer & M.V. Hayden) Hammel), *Notopleura polyphlebia* (Donn. Sm.) C.M.
Taylor and Notopleura uliginosa (Sw.) Bremek. (Kostyan 2017). In the latter two species quinones were found together with widespread flavonoids and megastigmanes (Berger 2012; Berger et al. 2016; Kostyan 2017). Although data on additional species is urgently needed, quinones appear to characterize Notopleura.

Palicourea Aubl.

The neotropical genus Palicourea (Palicoureeae) includes at least 800 species found from the Bahamas, the Greater Antilles and Mexico south to northern Argentina. Phylogenetic studies and a re-evaluation of morphological characters have recently changed the circumscription of the genera Palicourea and Psychotria rendering both monophyletic groups (Nepokroeff et al. 1999; Razafimandimbison et al. 2014). In its ‘modern’ circumscription Palicourea includes Psychotria subg. Heteropsychotria and is diagnosed by: A rather greenish dried colour; persistent stipules with a sheath usually bearing two lobes or awns on each side; fruits that are metallic blue or purple-black when mature; pyrenes with preformed germination slits and seeds without an alcohol-soluble red seed coat pigment. Flower characters are notoriously variable in the genus, which is related to different pollination syndromes: Coloured inflorescence axes, large and long pedicellate flowers and vividly coloured corollas with well-developed tubes are found in hummingbird-pollinated species, and these were traditionally placed in Palicourea. By contrast, flowers of insect-pollinated species—traditionally placed in Psychotria subg. Heteropsychotria—usually have small, white, greenish, or yellow corollas with short tubes in bee-pollinated species, or white corollas with long tubes in hawk moth-pollinated species.

With phytochemical data available for 49 species, Palicourea is the best studied genus of tribes Palicoureeae and Psychotrieae. Whilst six species lack alkaloids and accumulate flavonoids, iridoids, triterpenoids and other compounds, various types of IAs characterize the remaining 43 species. If such a trend holds true for the remainder of the genus, that would easily make Palicourea the largest radiation of plants with IA formation. Accumulation of strictosidine and related MIA glucosides is reported for 36 species, and it is therefore the predominant chemical feature of the genus. Other alkaloids types include polypyrrolindoine IA in ten species, β-carbolines in seven species, simple tryptamine analogues in five species and protoalkaloids in three species. For each group of alkaloids present in Palicourea, individual structures and their source plants are briefly discussed, and biosynthetic considerations for these are found in Berger et al. (2021).

"Protoalkaloids"

Two “protoalkaloids” derived from the amino acid tyrosine were isolated from species of Palicourea: N-Methylyrtramine was found in Palicourea marcgravii A. St.-Hil. (Kemmerling 1996) and hordenine in Psychotria nemorosa Gardner (Calixto et al. 2017), for which no name is yet available in Palicourea. Furthermore, six hydroxycinnamic acid amides were detected by UPLC-MS in Palicourea sessilis (Vell.) C.M. Taylor (Samulski et al. 2020). These are derived from a condensation of hydroxycinnamic acids with biogenic amines such as putrescine being break-down products of amino acids (Macoy et al. 2015). Their structures are shown in Fig. 5.

Simple indole alkaloids

The group is composed of alkaloids derived from tryptamine without a condensation with an iridoid moiety. Thus, they are termed ‘simple’ IA, which stands in contrast to more complex alkaloids that are formed by the incorporation of an iridoid moiety derived from the non-mevalonate pathway. According to the mode of cyclisation and the number of monomers involved, simple IA may be divided in two subgroups, and they are discussed below. Respective biosynthetic considerations are presented by Berger et al. (2021).

Tryptamine analogues—The group includes the structurally simplest alkaloids found in the genus Palicourea: N-formyltryptamine from Psychotria nemorosa (Calixto et al. 2017), N-methyltryptamine from Palicourea hoffmannseggiana (Roem. & Schult.) Borhidi (Naves 2014) and Palicourea sessilis (Klein-Júnior et al. 2017), N,N,N-trimethyltryptamine from Psychotria nuda (Cham. & Schltdl.) Wawra (de Carvalho Junior et al. 2019) and bufotenin (5-hydroxy N,N-dimethyltryptamine), the hallucinogenic principle of cane toad skin (Rhinella marina (Linnaeus, 1758), Bufonidae), from Palicourea gracilenta (Müll.
Interestingly, N-methyltryptamine and bufotenin are related to the well-known hallucinogenic N,N-dimethyltryptamine (DMT), one of few alkaloids still known from the genus Psychotria in its modern circumscription (see Fig. 5).

**Table 3** Species of Palicourea accumulating tryptamine analogues

| Accepted species                  | Reported undera                      | References                        |
|-----------------------------------|--------------------------------------|-----------------------------------|
| *Palicourea gracilenta*           | = *Psychotria brachybotrya*          | Ribeiro et al. (2016)             |
| *Palicourea hoffmannseggiana*     |                                       | Naves (2014)                      |
| *Palicourea sessilis*             |                                       | Klein-Júnior et al. (2017)        |
| *Palicourea comb. ined*           |                                       | de Carvalho Junior et al. (2019)  |
| *Palicourea comb. ined*           |                                       | Calixto et al. (2017)             |

*aSynonymy: = heterotypic synonym; comb. ined.: combinatio inedita, nomenclatural combination under Palicourea not yet published*
bufotenin was isolated together with two of its dimers possessing a biphenyl core structure otherwise known only from other species of Psychotria (e.g. see sect. "Eu-
machia DC."). Brachybotryne and its N-oxide derivative can occur as atropisomers which is discussed in

Table 4 Species of Palicourea accumulating polypyrroloindoline alkaloids

| Accepted species        | Reported under* | References                                          |
|-------------------------|-----------------|-----------------------------------------------------|
| Palicourea alpina       |                 | Woo-Ming and Stuart (1975)                           |
| Palicourea colorata     | = Psychotria colorata | Verotta et al. (1998, 1999)                        |
| Palicourea coriacea     |                 | da Silva et al. (2008); do Nascimento et al. (2006); Kato et al. (2017) |
| Palicourea domingensis  |                 | Ripperger (1982)                                    |
| Palicourea glomerulata  | = Psychotria glomerulata | Solis et al. (1997)                                |
| Palicourea hoffmannseggiana |             | Naves (2014)                                        |
| Palicourea muscosa      | = Psychotria muscosa | Jamison et al. (2017); Verotta et al. (1999)       |
| Palicourea ovalis       |                 | Garcia et al. (1997)                                |
| Palicourea semirasa     | = Palicourea fendleri | Nakano and Martín (1976)                           |
| Palicourea sessilis     |                 | Klein-Júnior et al. (2017)                          |

*Synonyms: = heterotypic synonyms, re homotypic synonyms

Fig. 7 Polypyrroloindoline alkaloids found in Palicourea species. Oligomers aligned to the central chimonanthine core.
Polypyroloindoline alkaloids—Polypyroloindoline alkaloids, the typical chemical complement of the genus *Eumachia* (see sect. "Eumachia DC."), are also found in a number of species of *Psychotria* (see sect. "Polypyroloindoline alkaloids") and *Palicourea* (see Table 4). The monomer alline was isolated from *Palicourea sessilis* (Klein-Júnior et al. 2017). The dimers (−)-chimonanthine and/or (−)-calycanthine are rather widespread and occur in *Palicourea alpina* (Sw.) DC. (Woo-Ming and Stuart 1975), *Palicourea colorata* (Willd. ex Roem. & Schult.) Delprete & J.H. Kirkbr. (Verotta et al. 1998, 1999), *Palicourea coriacea* (Cham.) K. Schum. (da Silva et al. 2008; do Nascimento et al. 2006), *Palicourea domingensis* (Jacq.) DC. (Ripperger 1982), *Palicourea glomerulata* (Donn. Sm.) Borhidi (Solis et al. 1997), *Palicourea hoffmannseggiana* (Naves 2014), *Palicourea muscosa* (Jacq.) Delprete & J.H. Kirkbr. (Verotta et al. 1999), *Palicourea ovalis* Standl. (Garcia et al. 1997) and in *Palicourea semirasa* Standl. (Nakano and Martín 1976; as *Palicourea fendleri* Standl.). Other dimers are found in *Palicourea glomerulata* (Solis et al. 1997) and *Palicourea muscosa* (Verotta et al. 1999).

Oligomers are less common and are only known from *Palicourea muscosa* (a trimer and a tetramer; Jamison et al. 2017; Verotta et al. 1999) and *Palicourea colorata* (trimers to pentamers; Verotta et al. 1998, 1999). *Palicourea colorata* is used by the Amazonian Caboclos for its potent analgesic activity, and experimental data suggests that its alkaloids indeed affect the brain opioid system (Amador et al. 1996, 2000; Elisabetsky et al. 1995). Structures of polypyroloindoline alkaloids isolated from *Palicourea* species are shown in Fig. 7.

### Table 5 Species of *Palicourea* accumulating harmala-type β-carboline alkaloids

| Accepted species         | Reported under                        | References                  |
|--------------------------|---------------------------------------|-----------------------------|
| *Palicourea alpina*      |                                       | Stuart and Woo-Ming (1974)   |
| *Palicourea deflexa*     |                                       | Bertelli et al. (2017)       |
| *Palicourea hoffmannseggiana* | = *Psychotria barbiflora* | de Oliveira et al. (2013); Naves (2014) |
| *Palicourea marcgravii*  |                                       | Kemmerling (1996)            |
| *Palicourea suerrensis*  | = *Psychotria suerrensis*             | Murillo and Castro (1998)    |
| *Palicourea winkleri*    |                                       | Berger et al. (2017)         |
| *Palicourea comb. ined*  | *Psychotria nemorosa*                 | Calixto et al. (2017)        |

*aSynonymy: = heterotypic synonym, ≡ homotypic synonym; comb. ined.: combinatio inedita, nomenclatural combination under *Palicourea* not yet published*
Table 6  Species of *Palicourea* accumulating tryptamine-secologanin type monoterpenoidoalkaloids, I. Strictosidine and related glucosides

| Accepted species | Reported under* | References |
|------------------|-----------------|------------|
| *Palicourea acuminata* | | Berger et al. (2012, 2017) |
| *Palicourea adusta* | | Valverde et al. (1999) |
| *Palicourea alpina* | | do Nascimento et al. (2006, 2008) |
| *Palicourea axillaris* | *Cephaelis axillaris* | Martín et al. (1994) |
| *Palicourea chiriquensis* | *Psychotria chiriquensis* | Berger (2012) |
| *Palicourea coriacea* | | do Nascimento et al. (2006, 2008) |
| *Palicourea crocea* | | Berger et al. (2015) |
| *Palicourea croceoides* | | Berger et al. (2015) |
| *Palicourea cyanococca* | | Berger et al. (2017) |
| *Palicourea deflexa* | *Psychotria deflexa* | Bertelli et al. (2015) |
| *Palicourea dichroa* | *Cephaelis dichroa* | Solis et al. (1993) |
| *Palicourea didymocarpus* | *Psychotria bahiensis* | Paul et al. (2003) |
| *Palicourea elata* | | Berger et al. (2012) |
| *Palicourea garciae* | | Berger et al. (2017) |
| *Palicourea hoffmannseggiana* | *Psychotria barbiflora* | de Oliveira et al. (2013) |
| *Palicourea manillaris* | *Psychotria myriantha* | Farias et al. (2012), Simões-Pires et al. (2006) |
| *Palicourea marcgravii* | | Morita et al. (1989) |
| *Palicourea minutiflora* | | Moura et al. (2020a, b) |
| *Palicourea padifolia* | | Berger et al. (2015) |
| *Palicourea prunifolia* | *Psychotria prunifolia* | Faria et al. (2010), Kato et al. (2012) |
| *Palicourea sessilis* | | Klein-Júnior et al. (2017) |
| *Palicourea suerrensis* | | Berger et al. (2017) |
| *Palicourea tsakiana* | | Berger et al. (2017) |
| *Palicourea winkleri* | | Berger et al. (2017) |
| *Palicourea* comb. ined | *Psychotria laciniata* | dos Santos et al. (2013a, b) |
| | *Psychotria laciniata* (as *Psychotria stenocalyx*) | Queiroz et al. (2017) |
| *Palicourea* comb. ined | *Psychotria nemorosa* | Calixto et al. (2017) |
| *Palicourea* comb. ined | *Psychotria nuda* | de Carvalho Junior et al. (2019) |
| *Palicourea* comb. ined | *Psychotria suterella* | de Carvalho Junior et al. (2021), dos Santos et al. (2013a, b), van de Santos et al. (2001) |

*Synonymy or misidentification:*–misidentification, = heterotypic synonym, = homotypic synonym; combined.: combinatio inedita, nomenclatural combination under *Palicourea* not yet published.
Alkaloids bearing a tricyclic pyrido(3,4-b)indole skeleton are termed β-carbolines, and these show different biosynthetic origins. The present section deals with ‘simple’ β-carbolines that are devoid of the fused terpenoid ring system found in MIA related to strictosidine (see sect. “Monoterpene-indole alkaloids”). Depending on the saturation of ring C, the group is divided in β-carboline, dihydro-β-carboline and tetrahydro-β-carboline alkaloids (Allen and Holmstedt 1980). Most simple β-carbolines are C1-methylated and belong to the so-called harmala alkaloid group named after their first known source,
Peganum harmala L. (Nitrariaceae). Biosynthetic considerations are found in Berger et al. (2021). Harmala alkaloids act as reversible monoamine oxidase (MAO) inhibitors targeting the MAO-A isoform and are therefore of pharmacological interest in the treatment of neurodegenerative diseases (Wang et al. 2010).

Likewise, harmala alkaloid-containing species are of great ethnobotanical and ethnopharmacological importance in the preparation of ayahuasca, a traditional hallucinogenic brew used by indigenous people of the Amazon basin and adjacent areas of South America. Banisteriopsis caapi (Spruce ex Griseb.) C.V. Morton (Malpighiaceae) contains harmala alkaloids, and they provide MAO inhibition required for an oral activity of the hallucinogenic principle N,N-dimethyltryptamine (DMT) derived from the second ingredient, Psychotria viridis Ruiz & Pav. (Callaway et al. 2005; Rivier and Lindgren 1972).

Within the genus Palicourea, harman was isolated from Palicourea alpina (Stuart and Woo-Ming 1974), Palicourea hoffmannseggiana (de Oliveira et al. 2013, as Psychotria barbiflora DC.; Naves 2014) and Palicourea suerrensis (Donn. Sm.) Borhidi (Murillo and Castro 1998). Harman-3-carboxylic acid was detected in Palicourea deflexa (DC.) Borhidi (Bertelli et al. 2017) and another derivative, tetrahydronorharman-1-one, was recently isolated from Palicourea winkleri Borhidi (Berger et al. 2017). Finally, 2-methyl tetrahydro-β-carboline (i.e. N-methyl

Table 7 Species of Palicourea accumulating tryptamine-secologanin type monoterpenoidole alkaloids, II. Strictosamide and related glucosides featuring a pentacyclic core

| Accepted species | Reported undera | References |
|------------------|-----------------|------------|
| Palicourea acuminata |  | Berger et al. (2012, 2017) |
| Palicourea dichroa | = Cephaëlis dichroa | Solis et al. (1993) |
| Palicourea mamillaris | = Psychotria myriantha | Farias et al. (2012); Simões-Pires et al. (2006) |
| Palicourea minutiflora |  | Moura et al. (2020a, b) |
| Palicourea prunifolia | = Psychotria prunifolia | Faria et al. (2010); Kato et al. (2012) |
| Palicourea didymocarpos | = Psychotria baliensis | Paul et al. (2003) |
| Palicourea winkleri |  | Berger et al. (2017) |
| Palicourea comb. ined | = Psychotria laciniata | dos Santos et al. (2013a, b) |
| Palicourea comb. ined | = Psychotria laciniata (as Psychotria stenocalyx) | Queiroz et al. (2017) |
| Palicourea comb. ined | = Psychotria leioarpa | Henriques et al. (2004), Lopes, (1998) |
| Palicourea comb. ined | = Psychotria nuda | de Carvalho Junior et al. (2019); Farias et al. (2008) |
| Palicourea comb. ined | = Psychotria suterella | dos Santos et al. (2013a, b), van de Santos et al. (2001) |

aSynonyms or misidentifications: – misidentifications, = heterotypic synonyms, = homotypic synonyms

Fig. 10 Tryptamine-secologanin type monoterpenoidole alkaloids isolated from Palicourea species, II. Strictosamide and related pentacyclic glucosides

© Springer
1,2,3,4-tetrahydro-β-carboline), an alkaloid that lacks the C1-methylation distinctive for harmala alkaloids was isolated from *Palicourea hoffmannseggiana* (Naves 2014), *Palicourea marcgravii* (Kemmerling 1996) and *Psychotria nemorosa* (Calixto et al. 2017).

Species of *Palicourea* accumulating β-carboline alkaloids are enumerated in Table 5 and the respective structures are shown in Fig. 8.

However, due to the presence of the azepane moiety, stachyoside is assigned here and it is drawn based on the illustration of the other structures. (b) Aglycones: Correantines. Numbering, exemplarily shown for correantoside, according to Achenbach et al. (1995)
Table 8 Species of *Palicourea* accumulating tryptamine-secologanin type monoterpene-indole alkaloids, III. Strictosidine- and strictosamide-derived aglycones

| Accepted species | Reported under | References |
|------------------|----------------|------------|
| *Palicourea acuminata* |  | Berger et al. (2012) |
| *Palicourea axillaris* | *Cephaelis axillaris* | Martín et al. (1994) |
| *Palicourea cyanococca* |  | Berger et al. (2017) |
| *Palicourea dichroa* | *Cephaelis dichroa* | Solis et al. (1993) |
| *Palicourea prunifolia* | *Psychotria prunifolia* | Faria et al. (2010), Kato et al. (2012) |
| *Palicourea rigida* |  | Vencato et al. (2006) |
| *Palicourea didymocarpos* | – *Psychotria bahiensis* | Paul et al. (2003) |
| *Palicourea* comb. ined | *Psychotria laciniata* | dos Santos et al. (2013a, b) |
| *Palicourea* comb. ined | *Psychotria suterella* | de Santos et al. (2001); dos Santos et al. (2013a, b) |

*a*Synonyms or misidentifications: – misidentifications, Ⅲ homotypic synonyms

Fig. 12 Tryptamine-secologanin type monoterpene-indole alkaloids isolated from *Palicourea* species, IV. Strictosidine- and strictosamide-derived aglycones. Numbering, exemplarily shown for lagamboside, according to Berger et al. (2012)
Monoterpene-indole alkaloids

The basic biosynthetic steps towards MIA are well known and the key role of strictosidine synthase has already been addressed above. This enzyme catalyses the stereospecific PSR between the amine function of tryptamine and the aldehyde function of secologanin. The resulting tetrahydro-β-carboline core represents

Fig. 13 Tryptamine-secologanin type monoterpene-indole alkaloids isolated from *Palicourea* species. V: Alkaloids from *Palicourea luxurians* (Rusby) Borhidi. (a) Javaniside, a spirocyclic oxindole alkaloid; (b) Alstrosterine-type alkaloids. Alstrosterine A was also isolated from *Chassalia curviflora* (Wall.) Thwaites, see sect. "*Chassalia Comm. ex Poir.*". Numbering of javaniside according to Ma & Hecht (2004), numbering of alstrosterine A is according to Cai et al. (2011)

Fig. 14 Tryptamine-loganin type monoterpene-indole alkaloids isolated from *Palicourea* species. Numbering according to Kerber et al. (2001), but other numbering schemes are also used (Berger et al. 2015, see supplementary figure S1)
the basic structure of all tryptamine-iridoid alkaloids. Among these, compounds possessing a secologanin moiety ("tryptamine-secologanin alkaloids") and compounds with a loganin moiety ("tryptamine-loganin alkaloids") may be differentiated (see below). The cores of tryptamine-iridoid alkaloids may be subjected to various modifications, and corresponding biosynthetic considerations are found in Berger et al. (2021).

**Tryptamine-secologanin type MIA**

**Strictosidine and related glucosides**

Accumulation of strictosidine and 23 related glucosides is reported from 28 species of *Palicourea* (see Table 6). Interestingly, most of these strictosidine-derived alkaloids retain the glucose moiety, which is remarkable because a certain level of chemical diversity is created even by omitting the deglucosylation step, otherwise considered the gateway to MIA diversity (Barleben et al. 2007; O’Connor and Maresh 2006). In many species, derivatives with tetrahydro-β-carboline (e.g. strictosidine) and β-carboline cores (e.g. lyaloside) co-occur.

Most alkaloids show only minor modifications leaving the basic strictosidine skeleton unchanged. Corresponding structures are shown in Fig. 9. However, some species (appendix, Table 11) accumulate alkaloid glucosides with structural modifications such as ring cleavage or additional ring formations. Examples include ophiorines A and B, first reported from the genus *Ophiorrhiza* (Aimi et al. 1985). These compounds possess a unique N-4–C-17 linkage creating an additional heterocycle, but they retain their glucose moiety and the carboxyl group from the iridoid function. According to their (positively charged) quaternary ammonium cation and negatively charged carboxyl group, these are classified as betaine type tryptamine-iridoid alkaloids. Within *Palicourea*, ophiorines are only known from *Palicourea suerrensis* (Berger et al. 2017).

**Strictosamide and related glucosides**

Strictosamide features a pentacyclic core and a lactam ring resulting from a condensation of the secondary amine and the carboxyl group derived from secologanin (see Berger et al. 2021). Strictosamide is found in 11 species of *Palicourea* (see Table 7) such as in *Palicourea winkleri*, where it occurs together with the recently described deoxostrictosamide (Berger et al. 2017). By contrast the stereoisomer vincosamide appears to be of restricted occurrence and was isolated even more recently from *Palicourea minutiflora* (Müll. Arg.) C.M. Taylor (Moura et al. 2020a, b). In addition the related N-β-D-glucopyranosyl vincosamide was reported from *Psychotria leiocarpa* Cham. & Schltdl. (Henriques et al. 2004). The respective structures are shown in Fig. 10.

**Correantosides and correantines**

Correantosides and the related correantines are a group of unusual MIA featuring an azepane moiety, which is derived by an intramolecular cyclization
between N-1 and the iridoid framework. Whilst correantosides are glucosides and retain the exocyclic ethylene group from secologanin, correantines are aglycones showing a different mode of ring formation and resulting positions of functional groups. Berger et al. (2021) postulated a probable biosynthesis. Correantines and correantosides appear to be of restricted distribution within Palicourea, they are only known from Palicourea correae (Dwyer & M.V. Hayden) Borhidi (Achenbach et al. 1995) and Psychotria stachyoides Benth. (Pimenta et al. 2010a, b, 2011). The respective structures are shown in Fig. 11.

Strictosidine- and strictosamide-derived aglycones

Agycones of strictosidine and strictosamide are infrequently encountered in Palicourea, and appear to be restricted to a few species (Table 8), in which they are usually accompanied by related glucosides (appendix, Table 11). The cleavage of the glucose moiety by a dedicated strictosidine β-glucosidase (SGD; Barleben et al. 2007) leads to a spontaneous ring opening and creates a reactive dialdehyde intermediate, which ultimately converts to modified carbon skeletons with open sidechains or new ring formations. Berger et al. (2021) postulated a probable biosynthesis. Some of these aglycones show complex structural features and many are of great pharmacological importance (O’Connor and Maresh 2006). Within the genus Palicourea, comparably simple structures of strictosidine-derived alkaloid aglycones are found and these are shown in Fig. 12.

Javaniside

Javaniside was recently isolated from Palicourea luxurians (Rusby) Borhidi, and represents the only spirocyclic oxindole alkaloid so far reported from the genus Palicourea (Kornpointner et al. 2020). Alkaloids with a spiro structure i.e. cycles fused at a central carbon, are well-known from species of the genus Uncaria (Rubiaceae) and probably contribute to its bioactivity (e.g. Muhammad et al. 2001; Wang et al. 2011). The structure of javaniside is shown in Fig. 13a and a biosynthetic scheme is found in Berger et al. (2021).

Alrostostines

Within Rubiaceae, alrostostine-type MIA were previously isolated from a single species of Chassalia and Rudgea (Schinnerl et al. 2012), and they are discussed in section "Chassalia Comm. ex Poir.”. Alrostostine A, dehydro-rudgeifoline and iso-alrostostine A were rather recently reported also from Palicourea luxurians (Kornpointner et al. 2020). That record represents the first and only occurrence in the large genus Palicourea (Fig. 13b).

Tryptamine-loganin type MIA

Contrary to the above-mentioned secologanin-derived MIA, a structurally related group features a loganin instead of a secologanin moiety. Structures of the respective alkaloids known from Palicourea species are shown in Fig. 14 and listed in Table 9. So far, these alkaloids have been reported from four species, Palicourea brachypoda (Müll. Arg.) L.B. Sm. & Downs (Both et al. 2002, as Psychotria umbellata
Vell.; Kerber et al. 2008, 2014, as Psychotria umbellata Thonn.), *Palicourea crocea* (Sw.) Roem. & Schult. (Berger et al. 2015; Düsmann et al. 2004; Narine and Maxwell 2009), *Palicourea fastigiata* Kunth (Berger et al. 2015) and *Psychotria brachyceras* Müll. Arg. (Kerber et al. 2001). Based on morphology the species have been classified in three different sections in the last complete monograph of the Brazilian *Psychotria* alliance (Müller Argoviensis 1881) and are also considered unrelated here (Berger, pers. obs.). Although phylogenetic data is necessary to clarify their relationships, this indicates that the change from tryptamine-secologanin to tryptamine-loganin alkaloids could have occurred several times. Loganin and secologanin are biosynthetically related and Berger et al. (2021) proposed a biosynthetic scheme for tryptamine-loganin alkaloids.

**Rudgea Salisb.**

The neotropical genus *Rudgea* (Palicoureeae) includes more than 150 species of shrubs and small to occasionally larger trees found from Mexico and the Lesser Antilles south to northern Argentina. The circumscription of the genus has always been rather stable and unproblematic when compared to that of other lineages of the tribe: *Rudgea* is diagnosed by persistent or fragmenting, entire, round, truncate to acute stipules with marginal glands or medial groups of glandular appendages, which are usually early caducous; terminal, and often whitish inflorescences, bright white, small to rather large, fragrant corollas, some of which possess conspicuous appendages on the lobes; comparably large, white, orange/red or black spongy to fleshy drupes, and dorsally smooth to ridged planoconvex, and ventrally flat but deeply furrowed pyrenes with 2 marginal and 1–3 abaxial preformed germination slits. Although *Rudgea* and *Notopleura* are very different morphologically, they show a well-supported sister-group relationship (Bruniera 2015; Razafimandimbison et al. 2014; Zappi 2003; see Fig. 1).

To date, three species of *Rudgea* have been phytochemically studied. Alkaloids were found only in *Rudgea cornifolia* (Kunth) Standl. which yielded rudgeifoline, an astrostine-type alkaloid (Fig. 15; Schinnerl et al. 2012). Similar alkaloids are also known from single species of *Chassalia*, *Geophila* and *Palicourea* (see above). The other two species deviate by accumulating triterpenes and quinones (de Cacia et al. 2007; Lopes et al. 1999; Young et al. 1998).

**Psychotrieae**

*Psychotria* L.

*Psychotria* is a pantropical genus that includes at least 1,600 species and is among the largest genera of flowering plants. The genus comprises of seven lineages with different distribution ranges including the ‘Afro-Asian-WIOR-neotropical *Psychotria* clade’, the ‘Afro-neotropical *Psychotria* clade’ or the ‘Pacific *Psychotria* clade’. *Psychotria* is paraphyletic in respect to the myrmecophytic Hydnophytinae nested within the latter subgroup. The recent transfer of most species of *Psychotria* subg. *Heteropsychotria* to *Palicourea* renders *Psychotria* a monophyletic group if the Hydnophytinae are formally included in *Psychotria*, as suggested by Razafimandimbison et al. (2014). In its current circumscription *Psychotria* is largely diagnosed by the following characters: A reddish-brown, grayish to blackish dried colour; interpetiolar, triangular and caducous stipules leaving a stipular scar with ferruginous hairs when shed; flowers adapted to insect pollination and characterized by small size, straight tubes and white, cream or greenish corollas; red or rarely white drupaceous fruits; seeds with an alcohol-soluble red seed coat pigment and pyrenes without preformed germination slits. However, numerous exceptions such as different fruit or flower colours occur in part of the range of the genus (e.g. Lachenaud 2019; Taylor 1996, 2020; Taylor et al. 2020).

Without taking two decades of taxonomic progress in the generic classification of Palicoureeae and Psychotrieae into account (see sections "Taxonomy of Palicoureeae and Psychotrieae" and "Palicourea Aubl."), recent phytochemical reviews have regarded various classes of IA and MIA as characterising the genus *Psychotria* (Calixto et al. 2016; de Carvalho Junior et al. 2017; Martins and Nunez 2015; Yang et al. 2016). The here-presented dataset applies an updated generic classification and challenges the previous assumption of *Psychotria* as an alkaloid-rich genus. Furthermore, it calls for a revised chemosystematic view based upon the currently accepted taxonomic concepts. The present review highlights
that all reports of MIA and most reports of other alkaloid groups from *Psychotria* pertain to species now assigned to *Carapichea*, *Eumachia* and *Palicourea*, leaving only few species with alkaloids (see Table 10): A single species (2.1% of all studied *Psychotria*) contains simple tryptamine analogues and five species (10.6%) accumulate polypyrroloindoline alkaloids, whereas the remaining 41 studied species (87.2%) are devoid of alkaloids (Table 10; appendix Table 11).

Published phytochemical data is currently available for 47 species of *Psychotria* corresponding to only 2.9% of its known diversity. Hence, the state of phytochemical research is extremely limited, and even more, these studies are unevenly distributed over the range of the genus. For example, only four species of the Continental African flora with ca. 240+ species (Lachenaud 2019) were studied and all of them are devoid of alkaloids: *Psychotria brandneriana* (L. Linden) Robbr., *devoid of alkaloids: tannins are reported from* *Psycho*

For 47 species of *Psychotria* (Table 11). Polypyrroloindoline alkaloids were found in the ethnobotanically important *Psychotria viridis*. Preliminary HPLC–UV/VIS analyses of 17 species from the morphologically and phylogenetically diverse Costa Rican flora (e.g. Berger and Schinnerl 2019; Taylor 2014) consistently showed a lack of alkaloids. Instead, accumulation of condensed tannins prevails which is also supported by an exceptionally high total phenolic content ranging from 277–454 mg gallic acid equivalents (GAE)/g of dry extract measured by the Folin–Ciocalteu reagent method (Berger 2012; Berger et al., unpublished data). Together with data from other regions (appendix, Table 11), this suggests that condensed tannins characterize the genus, which renders *Psychotria* the largest genus characterized by the accumulation of tannins. Furthermore, traces of asperuloside were detected in developing leaves of a few species (Berger 2012; Berger et al., unpublished data).

Simple indole alkaloids

*Tryptamine analogues*—The ethnobotanically important and well-studied *Psychotria viridis* is the only species of the genus known to contain simple tryptamine analogues. It yields the well-known hallucinogenic principle *N,N*-dimethyltryptamine (DMT) and the related *N*-methyltryptamine together with the *β*-carboline alkaloid 2-methyl tetrahydro-β-carboline (e.g. Callaway et al. 2005; Rivier and Lindgren 1972; Soares et al. 2017; see also the corresponding compound classes under sect. *"Palicourea Aubl."*). Reports on DMT content in other species such as *Psychotria carthagenensis* have so far proven erroneous and may have been based on misidentification of surveyed plants (Leal and Elisabetsky 1996; Lopes et al. 2000).

Polypyrroloindoline alkaloids—About half of the species of *Psychotria* subjected to phytochemical investigation occur in the Asian and Pacific region. 19 of these are devoid of alkaloids, instead accumulating various iridoids, polyphenols, terpenoids and other groups of specialized metabolites (see appendix, Table 11). Polypyrroloindoline alkaloids were reported from the remaining five species (Table 10), and first isolated from *Psychotria milnei* (A. Gray) K. Schum. (Adjibadé et al. 1990; Libot et al. 1987, 1988; Saad et al. 1995; as *Calycodendron milnei* (A. Gray) A.C. Sm.). Based on an expanded calyx, the species...
endemic to Fiji and Vanuatu was initially placed in the genera *Calycosia* and *Calycodendron*, but later transferred to *Psychotria*. DNA phylogenetic data has shown that it belongs to the Pacific clade which includes some of the more derived or morphologically aberrant species such as the epiphytic tuberous myrmecophytic Hydnophytinae (Barrabé et al. 2014) (Fig. 16). Other species with similar alkaloids include *Psychotria calocarpa* Kurz (Zhou et al. 2010), *Psychotria henryi* H. Lév. (Liu et al. 2013, 2014; some with unusual C3α′–N1 linkage), *Psychotria malayana* Jack. (Hadi and Bremner 2001; Hadi et al. 2014; but the species has sometimes been confused with species of *Eumachia*, see Taylor et al. 2017: 316) and *Psychotria pilifera* Hutch. (Li et al. 2011b). All polypyrroloindoline alkaloids reported from the genus *Psychotria* are shown in Fig. 17 (see Sects. "*Eumachia* DC." and "*Palicourea Aubl." for genera of the Palicoureeae accumulating these IA).

### β-Carbolines

Two β-carboline alkaloids were reported from the genus *Psychotria*, see sect. "β-Carbolines" under the genus *Palicourea* for some information on that class of alkaloids. GC–MS indicated the presence of 2-methyl tetrahydro-β-carboline in *Psychotria viridis* (Rivier and Lindgren 1972) and 3-methyl tetrahydro-γ-carboline in *Psychotria malayana* (Hadi et al. 2014). The structure of the latter was determined from GC–MS data and has not further been proven. It is unlikely that this structure resulted directly from a Pictet-Spengler reaction. It is probably a rearrangement product of chimonanthine or calycanthine, which was also described by the same authors from *P. malayana*. Finally, 2-methyl tetrahydro-β-carboline was also isolated from *Psychotria pilifera* (Liu et al. 2016, but see below) and corresponding structures are shown in Fig. 18.

Monoterpeno-indole alkaloids from *Psychotria pilifera*?

To date a single study has reported the isolation of MIA from the genus *Psychotria*. Together with four polypyrroloindoline IA, Liu et al. (2016) described the occurrence of MIA with highly derived skeletons from *Psychotria pilifera* collected in Yunnan Province, China (see supplementary Fig. S2). The occurrence of such alkaloids largely confined to the family Apocynaceae is unparalleled in genus, as well as in the entire Psychotrieae and Palicoureeae rendering the taxonomic entity of the studied plant material doubtful. Instead the reported chemical complement fits to a number of Apocynaceae, which could be confused with Rubiaceae, especially when sterile specimens or bulk material are collected for isolation. For example, most structural groups and even individual MIA reported for *Psychotria pilifera* have been isolated from *Tabernaemontana cymosa* Jacq. and are also present in other species of the genus (Achenbach et al. 1997). Hence, an adulteration of material of *Psychotria pilifera* with a species of Apocynaceae is suggested, and this explanation appears probable given the large amount (8 kg dry mass) collected from this rather rare and slender understory shrub (Chen and Taylor 2011). A second phytochemical study on *Psychotria pilifera* (Li et al. 2011b) reported the occurrence of only polypyrroloindoline IA, likewise supporting such an assumption. Hence, these compounds are therefore tentatively excluded from the genus *Psychotria* pending further study.

Curiously, the same species also afforded N-methylcarbazole (i.e. 9-methylcarbazole) (see supplementary Fig. S3; Liu et al. 2016), a tricyclic carbazole and a potent procarcinogenic component of tobacco smoke particulate matter, diesel fuel, domestic and industrial wastewater, and other sources of pollutant emissions (e.g. da Cunha et al. 2016). Carbazoles are characterized by an indole moiety annulated with a benzene ring, but originate from the anthranilic acid pathway via a 3-prenylquinolon and a 2-prenylindole to 3-methylcarbazole. They are therefore not derived from the amino acid tryptophan as suggested by the indole moiety. Within plants naturally occurring carbazoles are largely restricted to the Rutaceae family.

![Fig. 16 Alkaloids isolated from Psychotria species, I. Tryptamine analogues](image-url)
and feature a methyl group or an oxidized C₁-substituent at C-3 (Schmidt et al. 2012). N-methylcarbazole was never before isolated from plants, and differs from known plant-derived carbazoles by the lack of the C₁-substituent at C-3. Therefore, its report from *Psychotria pilifera* is doubtful and is here referred to environmental pollution or contaminated solvents used during the extraction and/or isolation process.

**Fig. 17** Alkaloids isolated from *Psychotria* species, II. Polypyrroloindoline alkaloid dimers to octamers. Note the unusual C–N-linkage in some of the dimers. Oligomers aligned to the central chimonanthine core

**Fig. 18** Alkaloids isolated from *Psychotria* species, III. A β-carboline and a γ-carboline alkaloid
Conclusion

Numerous phytochemical studies have been published on species originally ascribed to the genus *Psychotria* (Psychotrieae). However, recent phylogenetic and morphological data has challenged the traditional circumscription of the genus, which led to the recognition of various segregates within the new tribe Palicoureeae. Based on these revised taxonomic concepts, the phytochemistry of Palicoureeae and Psychotrieae is reviewed here, and accumulation patterns are delineated for most of the genera of the alliance. The present review highlights that alkaloid occurrence in *Psychotria* is rather limited and excludes all monoterpene indole alkaloids from the genus. Furthermore, it shows that most reports on alkaloids pertain to species of *Palicourea* and that all genera included in the tribe Palicoureeae feature chemically distinct alkaloid patterns, which may be of ecological relevance such as in plant defence against herbivores.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11101-021-09769-x) contains supplementary material, which is available to authorized users.

Acknowledgements We wish to thank the anonymous reviewers for their numerous useful comments that have greatly improved the present article.

Table 11 Compilation of published alkaloids and other compound groups from species of Palicoureeae and Psychotrieae based upon a revised generic classification

| Accepted species | Alkaloids | Compounds and/or compound groups | References (synonyms) |
|------------------|----------|----------------------------------|-----------------------|
| **PALICOUREEAE** |          |                                  |                       |
| **Carapichea**   |          |                                  |                       |
| *Carapichea affinis* | TIQA     | - Cephaeline, emetine, ipecoside, 6-O-methyl ipecoside, 6-O-methyl trans-cephaeloside | Bernhard et al. (2011) |
| TIQA             | - 7-O-Methyl alangine, ipecoside, 6-O-methyl ipecoside, 3'O'-O-demethyl borucoside, 6-O-methyl trans-cephaeloside | Kornpointner et al. (2018) |
| **Carapichea ipecacuanha** | TIQA | - Emetine, emetamine, protoemetine, 6-O-methyl psychotrine | Battersby et al. (1959), Battersby and Harper (1959, both as “Ipecacuanha root”) |
| TIQA             | - Emetine, cephaeline, emetamine, psychotrine, 6-O-methyl psychotrine, isoemetine | Hatfield et al. (1981, as Ceph. ipecacuanha) |
| TIQA             | - Emetine, cephaeline, emetamine, psychotrine, 6-O-methyl psychotrine, protoemetine | Wiegrebe et al. (1984, as Ceph. acuminata, Psy. granadensis sensu auct. non Benth., Psy. ipecacuanha) |
| TIQA             | - Ipecoside, neoipecoside, 7-O-methyl neoipecoside | Itoh et al. (1989, as Ceph. ipecacuanha) |
Table 11 continued

| Accepted species | Alkaloids | Compounds and/or compound groups | References (synonyms) |
|------------------|-----------|---------------------------------|----------------------|
| Carapichea klugii | TIQA      | Cephaeline, isocephaeline, 7'-O-demethyl isocapheeline, klugine, 7-O-methyl ipecoside | Muhammad et al. (2003, as Psy. klugii) |
| Chassalia        |           |                                 |                      |
| Chassalia capitata | n.s. ¹   | - Others: flavonoids            | Soobrattee et al. (2005) |
| Chassalia coriacea | n.s. ¹  | - Others: flavonoids            | Soobrattee et al. (2005) |
| Chassalia curviflora | MIA     | - Alstrostone A                 | Schinnerl et al. (2012) |
| Chassalia grandifolia | n.d     | - Others: coumarins, polyphenols | Wang and Zhou (1999) |
| Chassalia lanceolata | n.s. ¹ | - Others: flavonoids            | Soobrattee et al. (2005) |
| Chassalia petrinensis | n.s. ¹ | - Others: flavonoids            | Soobrattee et al. (2005) |
| Eumachia         |           |                                 |                      |
| Eumachia cymuligera | PIA     | - Hodgkinsine, quadrigemine B   | Brand et al. (2012)  |
| Eumachia depauperata | PIA    | - Calycosidine, N-8''-formyl calycosidine, N-8''-methyl-N''-1'-demethyl iso-calycosidine, hodgkinsine | Nascimento et al. (2015b, as Marg. carrascoana) |
| Eumachia forsteriana | PIA     | - (--)Calycanthine, iso-calycanthine, meso-chimonanthine | Adjibadé et al. (1985, 1986, 1989, 1992, all as Psy. forsteriana) |
| Eumachia frutescens | PIA     | - Hodgkinsine                   | Anet et al. (1961, as Hod. frutescens); Fridrichsons et al. (1967, 1974, as Hod. frutescens) |
| Eumachia leptothyrsra | PIA     | - Hodgkinsine                   | Parry et al. (1978, as Hod. frutescens) |
| Eumachia lyciiflora | PIA    | - Psychotridine                 | Hart et al. (1974, as Psy. beccarioides) |
| Eumachia oleoides | PIA      | - Hodgkinsine, quadrigemine C, psychotridine, isopsychotridine A, isopsychotridine B | Libot et al. (1987, as Psy. oleoides); see also Jamison et al. (2017) |
| Accepted species | Alkaloids | Compounds and/or compound groups | References (synonyms) |
|------------------|-----------|----------------------------------|----------------------|
| PIA              | - Hodgkinsine, psycholeine, quadrigemine C | Guérirre-Vogelein et al. (1992); Rasolonjanahary et al. (1995, both as Psy. oleoides) |
| PIA              | - Hodgkinsine, quadrigemine C, psychotridine, isopsychotridine B, quadrigemine I, oleoidine, caledonine | Jannic et al. (1999, as Psy. oleoides); see also Jamison et al. (2017) |
| *Eumachia straminea* | n.d | - Others: coumarins, flavonoids, triterpenes | Fu et al. (2015, as Psy. straminea) |
| *Eumachia rostrata* | PIA | - (−)-Calycanthine, (+)-chimonanthine, calycosidine, hodgkinsine, quadrigemine B | Lajis et al. (1993); Mahmoud et al. (1993, both as Psy. rostrata) |
| *Eumachia rostrata* | PIA | - Psychotrimine, psychopentamine | Takayama et al. (2004, as Psy. rostrata) |
| *Geophila* | MIA | - Alstrostines | Berger et al., unpublished |
| *Geophila macropoda* | n.d | - Others: coumarins, essential oils, polyphenols, triterpenes | Luo et al. (2011, as Geo. herbacea) |
| *Geophila uniflora* | n.d | - Others: essential oils | Rao et al. (2017, misidentified as Geo. repens) |
| *Geophila uniflora* | n.d | - Others: diterpenoids | Dash et al. (2019, misidentified as Geo. repens) |
| *Notopleura camponutans* | n.d | - Others: quinones | Jacobs et al. (2008); Solís et al. (1995, both as Psy. camponutans) |
| *Notopleura polyphlebia* | n.d | - Others: megastigmanes, flavonoids, quinones | Berger (2012); Berger et al. (2016) |
| *Notopleura uliginosa* | n.d | - Others: megastigmanes, quinones | Kostyan (2017) |
| *Palicourea acuminata* | MIA | - Bahienoside B, 5α-carboxystrictosidine, desoxycordifoline, lagamboside, lyaloside, strictosamide; others: coumarins | Berger (2012); Berger et al. (2012, 2017) |
| *Palicourea adusta* | MIA | - Lyaloside, (E)-O-(6′)-(4′″-hydroxy-3′″-methoxy)-cinnamoyl lyaloside, (E)-O-(6′)-(4′″-hydroxy-3′″,5″-dimethoxy)-cinnamoyl lyaloside | Valverde et al. (1999) |
| *Palicourea alpina* | βCA, MIA | - Harman, palinine | Stuart and Woo-Ming (1974) |
| *Palicourea axillaris* | MIA | - Calycanthine | Woo-Ming and Stuart (1975) |
| *Palicourea axillaris* | n.d | - Others: megastigmanes | Stuart and Woo-Ming (1975) |
| *Palicourea brachypoda* | MIA | - Psychollatine, umbellatine | Both et al. (2002); Kerber et al. (2008, as Psy. umbellata Vell.) |
| *Palicourea chiriquensis* | MIA | - Psychollatine, 3,4-dehydro-18,19-β-epoxy psychollatine, δ-1-((R)-2-hydroxypropyl)] psychollatine, δ-1-((S)-2-hydroxypropyl)] psychollatine | Kerber et al. (2014, as Psy. umbellata Thonn.) |
| *Palicourea colorata* | MIA | - 5α-Carboxystrictosidine, lyaloside; others: iridoids | Berger (2012, as Psy. chiriquensis) |
| *Palicourea colorata* | MIA | - (−)-Calycanthine, *iso*-calycanthine, (+)-chimonanthine, PML 100 (= 8-8a, 8′-8′a | Verotta et al. (1998, as Psy. colorata) |
Table 11 continued

| Accepted species         | Alkaloids                                      | Compounds and/or compound groups                                                                 | References (synonyms)                      |
|--------------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------|-------------------------------------------|
| Palicourea coriacea      | MIA, PIA                                       | - Calycanthine, strictosidinic acid, 3-epi-strictosidinic acid, strictosidinic ketone; others: triterpenes | do Nascimento et al. (2006)                 |
|                          | MIA                                            | - 4′-O-3′-Sucrose-strictosidinic acid                                                             | do Nascimento et al. (2008)                |
|                          | PIA                                            | - Calycanthine; others: polyphenols, quinones, triterpenes                                        | da Silva et al. (2008)                     |
| Palicourea correae       | MIA                                            | - Calycanthine                                                                                    | Kato et al. (2017)                        |
|                          | MIA                                            | - 10-Hydroxy correantoside, correantin A, correantin B, correantin C, 20-epi-correantin B, correantoside, isodolichantoside; others: megastigmanes, tetraterpenes | Achenbach et al. (1995, as Psy. correae)    |
| Palicourea croceae       | MIA                                            | - Croceaine A, croceaine B, Others: flavonoids                                                  | Düsmann et al. (2004)                     |
|                          | PIA                                            | - Croceaine A, psychollatine, 3,4-dehydropseudocolchidin N²-oxide (= 3,4-dihydro-1-(1-β-D-glucopyranosyloxy-1,4a,5,7a-tetrahydro-4-methoxy-carbonyl)cyclopenta[c]pyran-7-yl)-β-carboline-N²-oxide) | Narine and Maxwell (2009)                 |
| Palicourea crocea        | MIA, n.s                                        | - Strictosidine, strictosidinic acid                                                             | Berger et al. (2015)                      |
|                          | MIA                                            | - Others: flavonoids                                                                             | Berger et al. (2016)                      |
| Palicourea croceoides    | n.s                                            | - Harman-3-carboxylic acid, strictosidinic acid                                                  | Berger et al. (2015)                      |
| Palicourea cyanococca    | MIA                                            | - Bahienside B, 5α-carboxystrictosid, desoxycordifoline, lagamboside, lyaloside                  | Berger (2012, as Psy. cyanococca), Berger et al. (2017) |
| Palicourea deflexa       | βCA, MIA                                       | - Harman-3-carboxylic acid, strictosidinic acid                                                  | Bertelli et al. (2015, 2017, both as Psy. deflexa) |
| Palicourea demissa       | n.d                                            | - Others: coumarins, polyphenols, triterpenes                                                    | El-Seedi (1999)                           |
| Palicourea dichroa       | MIA                                            | - Others: coumarins, flavonoids, triterpenes                                                      | Sosa Moreno (2011)                        |
| Palicourea domingensis   | PIA                                            | - Chimonanthine                                                                                  | Ripperger (1982)                          |
| Palicourea elata         | MIA                                            | - Strictosidine                                                                                  | Berger (2012, as Psy. elata)               |
|                          | n.s                                            | - Others: chlorogenic acids                                                                     | Berger et al. (2016)                      |
| Palicourea eurycarpa     | n.s                                            | - Others: essential oils                                                                         | Setzzer et al. (2006)                     |
| Palicourea fastigiata    | MIA                                            | - Brachycerine                                                                                  | Berger et al. (2015)                      |
| Palicourea garciae       | MIA                                            | - Palicoside                                                                                    | Berger et al. (2017)                      |
| Palicourea glomerulata   | PIA                                            | - Glomerulatine A, glomerulatine B, glomerulatine C                                             | Solis et al. (1997, as Ceph. dichroa)      |
| Palicourea gracilenta    | TA                                             | - Bufotenin, brachybotryne, N-oxo brachybotryne                                                | Ribeiro et al. (2016, as Psy. brachybotrya) |
| Palicourea hoffmannseggiana | βCA, MIA, PIA                           | - Harman, strictosidinic acid                                                                   | de Oliveira et al. (2013, as Psy. barbiflora) |
|                          | TA, βCA, MIA, PIA                             | - N-Methyltryptamine, harman, 2-methyl tetrahydro-β-carboline, (+)-chimonanthine, strictosidinic acid; others: coumarins, polyphenols | Naves (2014)                              |
| Accepted species          | Alkaloids | Compounds and/or compound groups                                                                 | References (synonyms)                                                                 |
|--------------------------|-----------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| *Palicourea luxurians*   | MIA       | - Alstrostine A, dehydro-rudgeifoline, iso-alstrostine A, 5α-carboxystrictosidine, javaniside; others: iridoids | Kornpointner et al. (2020)                                                            |
| *Palicourea longiflora*  | n.d       | - Others: polyphenols                                                                           | Coelho et al. (2007)                                                                   |
| *Palicourea mamillaris*  | MIA       | - Myrianthosine, strictosidinic acid                                                             | Simões-Pires et al. (2006, as *Psy. myriantha*)                                         |
|                          | MIA       | - Strictosidinic acid                                                                           | Farias et al. (2012, as *Psy. myriantha*)                                              |
| *Palicourea marcgravii*  | MIA       | - Palicoside                                                                                     | Morita et al. (1989)                                                                   |
|                          | PA, βCA   | - N-Methyltyramine, 2-methyl tetrahydro-β-carboline                                               | Kemmerling (1996)                                                                      |
| *Palicourea minutiflora* | MIA       | - Strictosidinic acid, vincosamide; others: iridoids, polyphenols, triterpenes                   | Moura et al. (2020a, 2020b)                                                           |
| *Palicourea mortoniana*  | n.d       | - Others: flavonoids, chlorogenic acids                                                          | Berger et al. (2016, as *Psy. mortoniana*)                                             |
| *Palicourea muscosa*     | PIA       | - (−)-Calycanthine, (±)-chimonanthine, mesochimonanthine, PML 100 (= 8-8a, 8′-8′a tetrahydro iso-calycanthine 3α(R), 3′α(R)), PML 300, hodgkinsine | Verotta et al. (1999, as *Psy. muscosa*)                                               |
|                          | PIA       | - Hodgkinsine, quadrigemine H                                                                    | Jamison et al. (2017, as *Psy. muscosa*)                                               |
|                          | PIA       | - Calycanthine                                                                                   | Garcia et al. (1997)                                                                  |
| *Palicourea ovalis*      | MIA       | - Lyaloside, (E)-O-(6′)-(4′′-hydroxy-3′′,5′′-dimethoxy)-cinnamoyl lyaloside, strictosidine        | Berger et al. (2015)                                                                  |
| *Palicourea prunifolia*  | MIA       | - Strictosamide, prunifoleine, 14-oxoprunifoleine                                                | Faria et al. (2010, as *Psy. prunifolia*)                                              |
|                          | MIA       | - Strictosamide, 10-hydroxy isodeppeaninol, 10-hydroxy antirhine, 10-hydroxy antirhine N-oxide   | Kato et al. (2012, as *Psy. prunifolia*)                                               |
|                          | MIA       | - Prunifoleine, 10-hydroxy antirhine, 10-hydroxy isodeppeaninol                                  | Kato et al. (2017, as *Psy. prunifolia*)                                               |
| *Palicourea racemosa*    | n.d       | - Others: flavonoids                                                                            | Berger (2012); Berger et al. (2016)                                                    |
| *Palicourea rigida*      | n.d       | - Others: triterpenes                                                                           | Bolzani et al. (1992)                                                                 |
|                          | n.d       | - Others: iridoids                                                                              | Lopes et al. (2004)                                                                    |
|                          | MIA       | - Vallesiachotamine                                                                              | Vencato et al. (2006)                                                                   |
|                          | n.d       | - Others: flavonoids                                                                            | da Rosa et al. (2010)                                                                   |
|                          | n.d       | - Others: iridoids                                                                              | de Freitas Morel et al. (2011)                                                         |
|                          | n.d       | - Others: iridoids                                                                              | da Silva et al. (2013)                                                                  |
|                          | n.d       | - Others: diterpenes, triterpenes, iridoids                                                      | Alves et al. (2016)                                                                    |
|                          | n.d       | - Others: iridoids                                                                              | Valdevite et al. (2016)                                                                 |
|                          | n.d       | - Others: coumarins                                                                             | Alves et al. (2017)                                                                    |
|                          | n.d       | - Others: flavonoids                                                                            | Pinheiro et al. (2018)                                                                  |
| *Palicourea semirasa*    | PIA       | - Calycanthine, chimonanthine                                                                    | Nakano and Martín (1976, as *Pal. fendleri*)                                           |
| *Palicourea sessilis*    | n.d       | - Others: coumarins, triterpenes                                                                  | Moreno et al. (2014, as *Psy. vellosiana*)                                             |
|                          | TA, MIA   | - Alline, N-methyltryptamine, 4-N-methyl lyaloside, 4-N-methyl-3,4-dehydro strictosidine, isodolichantoside, 4α-hydroxy | Klein-Júnior et al. (2017)                                                             |
| Accepted species       | Alkaloids       | Compounds and/or compound groups                                      | References (synonyms)                      |
|-----------------------|-----------------|------------------------------------------------------------------------|--------------------------------------------|
| **isodolichantoside**, 4\(\beta\)-hydroxy isodolichantoside, 5-oxodolichantoside | **n.d**          | - **Others**: hydroxycinnamic acid amides, flavonoids, polyphenols     | Samulski et al. (2020)                     |
| **Palicourea spectabilis** | **n.d**          | - **Others**: diterpenes, coumarines, flavonoids                       | Benevides et al. (2005, as *Psy. spectabilis*) |
| **Palicourea didymocarpos** | **MIA**         | - Bahienside A, bahienside B, 5\(\alpha\)-carboxystrictosidine, angustine, strictosamide, (\(E\))-vallesiachotamine, (\(Z\))-vallesiachotamine | Paul et al. (2003, misidentified as *Psy. bahiensis*) |
| **Palicourea suerrensis** | **\(\beta\)CA** | - Harman                                                                | Murillo and Castro (1998, as *Psy. suerrensis*) |
| **Palicourea tsakiana** | **MIA**         | - Lyaloside, lyalosidic acid, strictosidine, strictosidinic acid, ophiorine A, ophiorine B; **others**: coumarines | Berger (2012, as *Psy. suerrensis*); Berger et al. (2017) |
| **Palicourea winkleri** | **\(\beta\)CA, MIA** | - Tetrahydronorharman-1-one, lyalosidic acid, strictosamide, deoxostrictosamide, strictosidinic acid | Berger et al. (2017) |
| **Psychotria brachyceras** | **MIA**        | - Brachycerine                                                           | Kerber et al. (2001)                       |
| **Psychotria laciniata** | **MIA**        | - Lyaloside, (\(E\))-O-(6\('\))-\(4''\)-hydroxy-3\('\),5\('\)-dimethoxy)-cinnamoyl lyaloside, strictosamide, (\(E\))-vallesiachotamine, (\(Z\))-vallesiachotamine (= isovallesiachotamine) | dos Santos et al. (2013a)                  |
|                        | **MIA**        | - Angustine, vallesiachotamine lactone, (\(E\))-vallesiachotamine, (\(Z\))-vallesiachotamine, pauridianthoside | dos Santos et al. (2013b)                  |
|                        | **MIA**        | - Lyaloside, (\(E\))-O-(6\('\))-\(4''\)-hydroxy-3\('\),5\('\)-dimethoxy)-cinnamoyl lyaloside, pauridianthoside, strictosamide, vallesiachotamine lactone, (\(E\))-vallesiachotamine, (\(Z\))-vallesiachotamine (= isovallesiachotamine) | Queiroz et al. (2017, as *Psy. stenocalyx*) |
| **Psychotria leiocarpa** | **n.s**        | - **Others**: iridoids                                                  | Lopes et al. (2004)                        |
|                        | **MIA**        | - Strictosamide                                                         | Lopes (1998)                               |
|                        | **MIA**        | - \(N,\beta\)-o-Glucopyranosyl vincosamide                           | Henriques et al. (2004)                    |
|                        | **MIA**        | - \(N,\beta\)-o-Glucopyranosyl vincosamide                           | Matsuura and Fett-Neto (2013)              |
|                        | **n.s**        | - **Others**: essential oils                                           | Andrade et al. (2010)                      |
| **Psychotria nemorosa** | **PA, TA, \(\beta\)CA, MIA** | - Hordenine, \(N\)-formyltryptamine, 2-methyl tetrahydro-\(\beta\)-carboline, strictosidine; **others**: fatty acids, iridoids, polyphenols, triterpenes | Calixto et al. (2017)                      |
| **Psychotria nuda** | **MIA**        | - Strictosamide                                                         | Farias et al. (2008)                       |
|                        | **TA, MIA**    | - \(N,N,N\)-Trimethyltryptamine, strictosidine, 5\(\alpha\)-carboxystrictosidine, strictosamide, lyaloside; **others**: coumarines, iridoids, polyphenols, triterpenes | de Carvalho Junior et al. (2019)           |
| **Psychotria stachyoides** | **MIA** | - Stachyoside, nor-methyl-23-oxo-correantoside | Pimenta et al. (2010a)                     |
|                        | **MIA**        | - Correantosine E, correantosine F                                      | Pimenta et al. (2010b)                     |
|                        | **MIA**        | - \(N\)-Demethylcorreantoside; **others**: coumarines, quinones, triterpenes | Pimenta et al. (2011)                      |
| **Psychotria suterella** | **MIA**        | - Lyaloside, strictosamide, naucletine                                   | van de Santos et al. (2001)                |
Table 11 continued

| Accepted species       | Alkaloids                                      | Compounds and/or compound groups                                           | References (synonyms)                     |
|------------------------|------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------|
| MIA                    | - Lyaloside, (E)-O-(6’)-(4”-hydroxy-3”,$S’’$-dimethoxy)-cinnamoyl lyaloside, strictosamide, (E)-vallesiachotamine, (Z)-vallesiachotamine (= isovallesiachotamine) | dos Santos et al. (2013a)                                                            |
| MIA                    | - Lyalosidic acid, strictosidinic acid; others: iridoids, triterpenes           | de Carvalho Junior et al. (2021)                                             |
| Rudgea                 |                                                |                                                                              |                                           |
| Rudgea cornifolia      | MIA                                            | - Rudgeifoline                                                               | Schinnerl et al. (2012)                  |
| Rudgea jasminoides     | n.d                                            | - Others: triterpenes                                                       | Lopes et al. (1999)                      |
| Rudgea jasminoides     | n.d                                            | - Others: quinones                                                           | de Cacia et al. (2007)                   |
| Rudgea viburnoides     | n.d                                            | - Others: triterpenes                                                       | Young et al. (1998)                      |
| PSYCHOTRIEAE           |                                                |                                                                              |                                           |
| Psychotria s. str      |                                                |                                                                              |                                           |
| Hydnophyrum formicarum | n.d                                            | - Others: flavonoids, polyphenols, triterpenes                               | Rédei et al. (2005)                      |
| Hydnophyrum formicarum | n.d                                            | - Others: flavonoids, polyphenols, triterpenes                               | Hasmah et al. (2008)                     |
| Hydnophyrum formicarum | n.d                                            | - Others: flavonoids, polyphenols, triterpenes                               | Prachayasittikul et al. (2008, 2012)     |
| Hydnophyrum formicarum | n.d                                            | - Others: polyphenols, triterpenes                                          | Abdullah et al. (2017a, 2017b)           |
| Myrmecodia pendens     | n.d                                            | - Others: flavonoids, polyphenols                                          | Engida et al. (2013, 2015)               |
| Myrmecodia pendens     | n.d                                            | - Others: flavonoids, diterpenoids, triterpenoids                           | Alibasyah et al. (2017); Gartika et al. (2018); Kurnia et al. (2019); Satari et al. (2019) |
| Myrmecodia tuberosa    | n.d                                            | - Others: iridoids                                                          | Hanh et al. (2016)                       |
| Psychotria adenophylla | n.d                                            | - Others: triterpenes                                                       | Dan and Dan (1986)                      |
| Psychotria adenophylla | n.d                                            | - Others: polyphenols                                                       | Berger (2012)                            |
| Psychotria asiatica    | n.d                                            | - Others: quinones, sesquiterpenes                                         | Hayashi et al. (1987, as Psy. rubra)     |
| Psychotria asiatica    | n.s                                            | - Others: iridoids                                                          | Inouye et al. (1988, as Psy. rubra)      |
| Psychotria asiatica    | n.d                                            | - Others: aliphatic compounds, triterpenes, amides                          | Giang et al. (2007, as Psy. reevesii)    |
| Psychotria brandneriana| n.d                                            | - Others: flavonoids, iridoids                                             | Lu et al. (2014a, as Psy. rubra)         |
| Psychotria calocarpa   | PIA                                            | - Psychotriasine                                                            | Zhou et al. (2010)                       |
| Psychotria capensis     | n.d                                            | - Others: triterpenes, tetramerpenes                                       | Kafua et al. (2009)                      |
| Psychotria capensis     | n.d                                            | - Others: polyphenols                                                       | Berger (2012)                            |
| Psychotria carthagenensis| n.d                                      | - Others: triterpenes                                                       | Leal and Elisabetsky (1996), Lopes et al. (2000); see also Rivier and Lindgren (1972) |
| Psychotria chagrensis   | n.d                                            | - Others: polyphenols                                                       | Berger (2012)                            |
| Psychotria chagrensis   | n.d                                            | - Others: polyphenols                                                       | Berger (2012)                            |
| Psychotria fractistipula| n.d                                           | - Others: triterpenes                                                       | de Oliveira (2015)                       |
| Psychotria gitingensis  | n.d                                            | - Others: megastigmans                                                     | Tan et al. (2012)                        |
| Psychotria graciiflora | n.d                                            | - Others: iridoids, polyphenols                                            | Berger (2012)                            |
| Psychotria grandis      | n.d                                            | - Others: iridoids, polyphenols                                            | Berger (2012)                            |
| Psychotria hainanensis | n.d                                            | - Others: aliphatic compounds, flavonoids, triterpenes                     | Li et al. (2011a)                        |
| Psychotria hawaiensis   | n.d                                            | - Others: iridoids, polyphenols                                            | Berger (2012)                            |
| Accepted species                  | Alkaloids | Compounds and/or compound groups                                                                 | References (synonyms)                                                                 |
|----------------------------------|-----------|----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| *Psychotria henryi*              | PIA       | “Compound 1”, “compound 2”                                                                           | Liu et al. (2013)                                                                     |
|                                  | PIA       | Psychohenin                                                                                        | Liu et al. (2014)                                                                     |
| *Psychotria hexandra*            | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria horizontalis*        | n.d       | *Others*: iridoids, polyphenols                                                                     | Berger (2012)                                                                         |
| *Psychotria ligustrifolia*       | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria limonensis*          | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria laezoniensis*        | n.d       | *Others*: flavonoids, iridoids, megastigmanes, sugars                                                 | Ramil et al. (2020)                                                                   |
| *Psychotria malayensis*          | PIA       | Chimonanthine, hodgkinsine                                                                          | Hadi and Brenner (2001)                                                               |
|                                  | PIA, βCA  | (+)-Chimonanthine, (−)-chimonanthine, meso-chimonanthine, calycanthine, hodgkinsine, 2-methyl tetrahydro-γ-carboline; others: pyrazine | Hadi et al. (2014)                                                                    |
| *Psychotria manillensis*         | n.s       | *Others*: iridoids                                                                                  | Inouye et al. (1988)                                                                  |
| *Psychotria marginata*           | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria mariniana*           | n.d       | *Others*: iridoids, triterpenes                                                                      | Gonzalez and Dieck (1996)                                                             |
| *Psychotria micrantha*           | n.d       | *Others*: iridoids, polyphenols                                                                      | Berger (2012)                                                                         |
| *Psychotria milnei*              | PIA       | Calycosidine, hodgkinsine                                                                            | Libot et al. (1987, as *Cal. milnei*)                                                 |
|                                  | PIA       | Vatine, vatine A, vatamidine                                                                          | Adjibadé et al. (1990, as *Cal. milnei*)                                              |
|                                  | PIA       | Hodgkinsine, quadrigemine H, psychotridine C, isopsychotridine E, vatine, vatine A, vatamine, vatamidine | Saad et al. (1995, as *Cal. milnei*)                                                  |
| *Psychotria nervosa*             | n.d       | *Others*: flavonoids, polyphenols                                                                     | Berger (2012); Berger et al. (2016)                                                   |
| *Psychotria orophila*            | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria orosiana*            | n.d       | *Others*: iridoids, polyphenols                                                                      | Berger (2012)                                                                         |
| *Psychotria parvifolia*          | n.d       | *Others*: polyphenols                                                                               | Berger (2012)                                                                         |
| *Psychotria pilifera*            | PIA       | Psychotripine                                                                                       | Li et al. (2011b)                                                                     |
| some compounds probably originating from an adulteration by an Apocynaceae | MIA       | Psychotriasine, quadrigemine I, calycanthine, iso-calycanthine, 2-methyl tetrahydro-β-carboline; others: N-methyl-carbazole | Liu et al. (2016)                                                                     |
| *Psychotria psychotriifolia*     | n.d       | *Others*: iridoids, polyphenols                                                                      | Berger (2012)                                                                         |
| *Psychotria pisonioides*         | n.d       | *Others*: polyphenols                                                                               | Berger (2012, misidentified as *Psy. convergens*)                                     |
| *Psychotria prainii*             | n.d       | *Others*: carbamates, iridoids                                                                        | Tran et al. (2019)                                                                   |
|                                  | n.d       | *Others*: coumarins, flavonoids, polyphenols, megastigmanes, triterpenes                              | Yang et al. (2018)                                                                   |
| *Psychotria punctata*            | n.s       | *Others*: polyphenols                                                                               | Berger (2012, as *P. kirkii*); Schindler et al. (2021)                                |
|                                  | n.s. 3    | *Others*: polyamines                                                                                | Van Elst et al. (2013) (as *Psy. kirkii*)                                             |
Table 11 continued

| Accepted species               | Alkaloids | Compounds and/or compound groups | References (synonyms) |
|--------------------------------|-----------|----------------------------------|-----------------------|
| *Psychotria serpens*           | n.s. ³    | - Others: aminocyclitols          | Sieber et al. (2015)  |
|                                | n.s.      | - Others: iridoids               | Inouye et al. (1988)  |
|                                | n.d.      | - Others: triterpenes            | Lee et al. (1988)     |
|                                | n.d.      | - Others: polyphenols            | Berger (2012)         |
|                                | n.d.      | - Others: flavonoids             | Lin et al. (2015)     |
|                                | n.d.      | - Others: flavonoids, triterpenes| Zhou et al. (2018)    |
| *Psychotria subsessilis*        | n.d.      | - Others: iridoids, polyphenols  | Berger (2012, as *P. quinqueradiata*) |
| *Psychotria sylvivaga*         | n.d.      | - Others: polyphenols            | Berger (2012)         |
| *Psychotria tenuifolia*        | n.d.      | - Others: polyphenols            | Berger (2012)         |
| *Psychotria viridiflora*       | n.s. ³    | - Others: polyamines             | Van Elst et al. (2013) |
| *Psychotria viridis*           | IA, βCA   | - N-Methyltryptamine, *N,N*-dimethyltryptamine, 2-methyl tetrahydro-β-carboline | Rivier and Lindgren (1972) |
|                                | IA        | - *N,N*-Dimethyltryptamine       | Blackledge and Taylor (2003) |
|                                | IA        | - *N,N*-Dimethyltryptamine       | Callaway et al. (2005) |
|                                | n.s.      | - Others: polyphenols            | Berger (2012)         |
|                                | IA        | - *N-Methyltryptamine, *N,N*-dimethyltryptamine; *others*: triterpenes, hydrocarbons, fatty acids, triglycerides | Soares et al. (2017) |
| *Psychotria yunnanensis*       | n.d.      | - Others: lignans, monoterpenes, megastigmanes, polyphenols, sesquiterpenes | Lu et al. (2014b, 2014c) |
| *Psychotria zeylanica*         | n.d.      | - Others: iridoids, polyphenols  | Berger (2012)         |
| *Psychotria* sp.               | n.d.      | - Others: polyphenols, sphingolipids, triterpenes | Ye et al. (2014); Zhang et al. (2010, 2012, 2013) |
| *Psychotria* sp. ⁵              | n.d.      | - Others: megastigmanes          | Tan et al. (2014, misidentified as *Psy. cadigensis*) |
| identification unclear ⁶       | n.d.      | - Others: triterpenes            | Sandra et al. 2018 (misidentified as *Pal. croceoides*) |

All individual alkaloids are listed and their corresponding alkaloid groups are noted. For further detected compounds (“*others*”) only the respective structural and/or biosynthetic groups are mentioned. Most studies were reported from names now considered homo- or heterotypic synonyms, and these names are given in brackets after the corresponding references. Note that phytochemical studies are often tailored to certain compound groups and do not necessarily reflect the full phytochemical complement of a studied species. PA: “protoalkaloids”; TIQA: tetrahydroisoquinoline alkaloids; TA: tryptamine analogues; PIA: polypyrroloindoline alkaloids; βCA: β-carboline alkaloids; MIA: monoterpene-indole alkaloids; n.s.: no alkaloids studied; n.d.: no alkaloids detected

¹The study was limited to the detection and quantification of flavonoids
²A nomenclatural combination transferring the species to the genus it belongs according to morphological and/or molecular data is not yet available (comb. ined.)
³The studies were limited to detecting polyamines and aminocyclitols
⁴Probably confused with a species of *Eumachia*, see comments in Taylor et al. (2017: 316)
⁵*Psychotria cadigensis*, now thought to be extinct, was a narrow endemic to Mt. Cadig, Luzon Island (Philippines; Sohmer and Davis, 2007). The report of this species from Mindoro Island is likely based on a misidentification
⁶Sandra et al. (2018) report the isolation of a triterpene from Nigerian material of *‘Palicourea croceoides’*, but the genus is endemic to the Neotropics. No voucher specimen was cited and the authors did not respond to numerous requests. Although they indeed include a photograph of *Palicourea croceoides*, it cannot serve as voucher on the identity of the species because it was actually taken on the Caribbean Island of Dominica in 2006 and copy-pasted without indication of source. Cal.: *Calycodendron*; Ceph.: *Cephaelis*; Geo.: *Geophila*; Hod.: *Hodgkinsonia*; Marg.: *Margaritopsis*; Pal.: *Palicourea*; Psy: *Psychotria*
References

Abdullah NS, Ahmad WYW, Sabri NA (2017a) The chemical constituents from young tubers of Hydnophytum formicarum. Malaysian J Anal Sci 21(2):291–297. https://doi.org/10.17576/mjas-2017-2102-03

Abdullah NS, Ahmad WYW, Sabri NA (2017b) New compounds from Hydnophytum formicarum young tubers. Malaysian J Anal Sci 21(4):778–783. https://doi.org/10.17576/mjas-2017-2104-03

Achenbach H, Lottes M, Waibel R, Karikas GA, Correa MD, Gupta MP (1995) Alkaloids and other compounds from Psychotria correae. Phytochemistry 38(6):1537–1545. https://doi.org/10.1016/0031-9422(94)00823-C

Achenbach H, Benirschke M, Torrenegra R (1997) Alkaloids and other compounds from seeds of Tabernaemontana cymosa. Phytochemistry 45(2):325–335. https://doi.org/10.1016/S0031-9422(96)00645-0

Adjibade Y, Kuballa B, Cabalion P, Anton R (1986) A new alkaloid from Psychotria forsteriana. Planta Med 52(6):523. https://doi.org/10.1055/s-2007-96305

Adjibade Y, Kuballa B, Cabalion P, Anton R (1989) Preliminary chemical study of the alkaloids from the fruits of Psychotria forsteriana. Planta Med 55(1):115. https://doi.org/10.1055/s-2006-961898

Adjibade Y, Saad H, Sévenet T, Kuballa B, Quirion JC, Anton R (1990) New polypodine alkaloids from Calycodendron milnei. Planta Med 56(2):212–215. https://doi.org/10.1055/s-2006-960927

Adjibade Y, Weniger B, Quirion JC, Kuballa B, Cabalion P, Anton R (1986) A new alkaloid from Psychotria forsteriana. Planta Med 52(6):523. https://doi.org/10.1055/s-2007-969305

Advani SP, Heinemann UF, Hentschel H, Schacke H (1975) Hybridization studies in the Psychotria species group. Beitr Biol Pflanzen 27:67–79. https://doi.org/10.1016/0005-2742(75)90008-4

Allemand A, Sadava D (2001) The molecular basis of life: the origin of eukaryotic cells. Evolution 55(10):2300–2306. https://doi.org/10.1111/j.0014-3820.2001.tb00152.x

Allen JR, Holmstedt BR (1980) The simple β-carboline alkaloids. Phytochemistry 19(8):1573–1582. https://doi.org/10.1016/S0031-9422(08)87373-5

Alves VG, da Rosa EA, de Arruda LLM, Rocha BA, Bersani Amado CA, Santin SMO, Pomini AM, da Silva CC (2016) Acute toxicity, antiedematogenic activity, and chemical constituents of Psychotria rigida Kunth. Z Naturforsch C: Biosci 71(3–4):39–43. https://doi.org/10.1515/znc-2015-0036

Alves VG, Schuquel ITA, Ferreira HD, Santin SMO, da Silva CC (2017) Coumarins from roots of Palicourea rigida. Chem Nat Compd 53(6):1157–1159. https://doi.org/10.1007/s10000-017-2224-8

Amador TA, Elisabetsky E, de Souza DO (1996) Effects of Psychotria colorata alkaloids in brain opioid system. Neur Res 21(1):97–102. https://doi.org/10.1007/BF02527677

Amador TA, Verotta L, Nunes DS, Elisabetsky E (2000) Antinociceptive profile of hodgkinsine. Planta Med 66(8):770–772. https://doi.org/10.1055/s-2000-9604

Andersson L (2002) Re-establishment of Carapichea (Rubiacae, Psychotrieae). Kew Bull 57(2):363–374. https://doi.org/10.2307/4111112

Andrade JMM, Biegelmeier R, Xavier CAG, Bordignon SAL, Moreno PRH, Zuanazzi JAS, Henriques AT, Apel MA (2010) Essential oil constituents of Psychotria leioarpa. Chem Nat Compd 46(4):649–650. https://doi.org/10.1007/s10071-010-9702-6

Anet EFLJ, Hughes GK, Ritchie E (1961) Hodgkinsine, the alkaloid of Hodgksonia frutescens F. Muell Austr J Chem 14(1):173–174. https://doi.org/10.1017/CH9610173

Aniszewski T (2015) Alkaloids: Chemistry, Biology, Ecology, and Applications, 2nd edn. Elsevier, Amsterdam

Barleben L, Panjikar S, Ruppert M, Koepke J, Stöckigt J (2007) Molecular architecture of strictosidine glucosidase: the gateway to the biosynthesis of the monoterpenoid indole alkaloid family. Plant Cell 19(9):2886–2897. https://doi.org/10.1105/tpc.106.045682

Barrabê L, Davis AP (2013) (2027) Proposal to conserve the name Margaritopsis against Eumachia (Rubiacae). Taxon 62(5):1069–1070

Barrabê L, Buerki S, Mouly A, Davis AP, Munzinger J, Maggia L, D, Satari MH (2017) The effectiveness of flavonoids and and evaluation of in vivo toxicity of emetine derivatives. Mol Pharmaco 26(43):5299–5302. https://doi.org/10.1065/mjas-2017-2104-03

Battersby AR, Harper BJT (1959) 346. Ipecacuanha alkaloids. Part II. The structure of protoemetine and a partial synthesis of (–)-emetine. J Chem Soc 1959:1748–1753.https://doi.org/10.1039/JR9590001748

Battersby AR, Harper BJ (1959) 347. Ipecacuanha alkaloids. Part I. Fractionation studies and the thesis of (–)-emetine. J Chem Soc 1959:1744–1748.https://doi.org/10.1039/JR9590001744

Benevides PJ, Young MCM, da Silva BV (2005) Biological Activities of Constituents from Psychotria spectabilis. Pharm Biol 42(8):565–569. https://doi.org/10.1080/13880200490901780

Berger A (2017) Two new combinations, lectotypifications and a new name for Costa Rican Palicourea s.l. PhytoKeys 80:53–63. https://doi.org/10.3897/phytokeys.80.13330
Berger A, Fasshuber H, Schinnerl J, Robien W, Brecker L, Valant-Vetschera K (2011) Iridoids as chemical markers of false ipecac (Ronabae emetica), a previously confused medicinal plant. J Ethnopharmacol 138(3):756–761. https://doi.org/10.1016/j.jep.2011.10.024

Berger A, Fasshuber H, Schinnerl J, Brecker L, Greger H (2012) Various types of tryptamine-iridoid alkaloids from Palicourea acuminata (=Psychotria acuminata Rubiaceae). Phytochemistry Lett 5(3):558–562. https://doi.org/10.1016/j.phych.2012.05.013

Berger A, Kostyan MK, Klose SI, Gastergge M, Lorbeer E, Brecker L, Schinnerl J (2015) Logandin and secologandin derived tryptamine–iridoid alkaloids from Palicourea crocea and P. padifolia (Rubiaceae). Phytochemistry 116:162–169. https://doi.org/10.1016/j.phytochem.2015.05.013

Berger A, Preinfalk A, Windberger M, Fasshuber HK, Gastegger M, Klose I, Robien W, Felsing S, Brecker L, Valant-Vetschera K (2016) New reports on flavonoids, benzoic- and chlorogenic acids as rare features in the Psychotria alliance (Rubiaceae). Biochem Syst Ecol 66:145–153. https://doi.org/10.1016/j.bse.2016.02.027

Berger A, Tanghadi E, Brecker L, Schinnerl J, Valant-Vetschera K (2017) Chemodiversity of tryptamine-derived alkaloids in six Costa Rican Palicourea species (Rubiaceae–Palicoureeae). Phytochemistry 143:124–131. https://doi.org/10.1016/j.phytochem.2017.07.016

Berger A, Schinnerl J (2019) Taxonomical and phytochemical diversity of Costa Rica Palicoureeae and Psychotrieae (Rubiaceae). Acta Zootax Austria 156:231–248. https://www.zobodat.at/pdf/VZBG_156_0231-0248.pdf

Berger A, Valant-Vetschera K, Brecker L (2021) Alkaloid diversification in the genus Palicourea (Rubiaceae: Palicoureeae) viewed from a (retro-)biosynthetic perspective. Phytochem Rev. https://doi.org/10.1007/s11101-021-09768-y

Berger A (2012) Distribution and systematic significance of selected secondary metabolites within Psychotrieae/Palicoureeae (Rubiaceae). Diploma thesis, University of Vienna. https://doi.org/10.25365/thesis.24493

Berger A (2018a) Rediscovery of Chamisso’s type specimens of Central American Palicourea, part I: The entomophilous species. Ann. Natushist. Mus. Wien, Ser. B 120:59–140. http://www.jstor.org/stable/26335282

Bernhard M, Fasshuber H, Robien W, Brecker L, Greger H (2011) Dopamine-iridoid alkaloids in Carapichea affinis (=Psychotria boreocana) confirm close relationship to the vomiting root Ipecac. Biochem Syst Ecol 39(3):232–235. https://doi.org/10.1016/j.bse.2011.03.006

Bertelli PR, Biegelmeier R, Rico EP, Klein-Junior LC, Toson NSB, Minetto L, Bordignon SAL, Gasper AL, Moura S, de Oliveira DL, Henriques AT (2017) Toxicological profile and acetylcholinesterase inhibitory potential of Palicourea deflexa, a source of β-caroline alkaloids. Comp Biochem Physiol Part C 201:44–50. https://doi.org/10.1016/j.cbpc.2017.09.003

Bertelli PR, Rico EP, Grünspan LD, Biegelmeyer R, Klein-Junior LC, Vander Heyden Y, Gasper AL, Bordignon SAL, Oliveira DL, Henriques AT (2015) Application of zebrafish embryos toxicity test to evaluate the alkaloid fraction of Psychotria deflexa. Planta Med 81(16):PM_160. https://doi.org/10.1055/s-0035-1565537

Blackledge RD, Taylor CM (2003) Psychotria viridis -A botanical source of dimethyltryptamine (DMT). Microgram 1(1–2):18–22

Bolzani VS, Trevisan LMY, Young MCM (1992) Triterpenes of Palicourea rigida H.B.K. Rev Latinoam Quim 23(1):20–21

Borhidi AL (2011) Transfer of the Mexican species of Psychotria subgen. Heteropsychotria to Palicourea based on morphological and molecular evidences. Acta Bot Hung 53(3–4):241–250. https://doi.org/10.1556/abot.53.2011.3-4.4

Borhidi AL (2017) La circunscripción de Palicourea subgen. Heteropsychotria (Rubiaceae, Palicoureeae). Acta Bot Hung 59(1–2):25–61. https://doi.org/10.1556/034.59.2017.1-2.4

Both FL, Kerber VA, Henriques AT, Elisabetsky E (2002) Analogic properties of umbellatine from Psychotria umbellata. Pharm Biol 40(5):336–341. https://doi.org/10.1076/phbi.40.5.336.8453

Brand G, Henriques AT, Passos GDS, Baldoqui DC, de Oliveira Santin SM, da Costa WF, Sarragiotto MH (2012) Pyrroolidinoindoline alkaloids from Margaritopsis cymuligera (Mull. Arg.) C.M. Taylor (Rubiaceae). Biochem Syst Ecol 45:155–157. https://doi.org/10.1016/j.bse.2012.07.009

Bruniera CP (2015) Sistemática e taxonomia de Rudrea Salisb. (Palicoureeae, Rubiaceae). Doctoral Thesis, Universidade de São Paulo. https://doi.org/10.11606/T.41.2015.tde-28072015-145432

Cai X-H, Bao M-F, Zhang Y, Zeng C-X, Liu Y-P, Luo X-D (2011) A new type of monoterpene indole alkaloid precursor from Alstonia rostrata. Org Lett 13(14):3568–3571. https://doi.org/10.1021/ol200996a

Calixto NO, Pinto MEF, Ramalho SD, Burger M, Bobey AF, Young MCM, Bolzani VS, Pinto AC (2016) The genus Psychotria: Phytochemistry, chemotaxonomy, ethnopharmacology and biological properties. J Braz Chem Soc 27(8):1355–1378. https://doi.org/10.5935/0103-5053.20160149

Calixto NO, Cordeiro MS, Gionzi TBS, Oliveira GG, Lopes NP, Fernandes PD, Pinto AC, Rezende CM (2017) Chemical constituents of Psychotria nemorosa Gardner and antinociceptive activity. J Braz Chem Soc 28(5):707–723. https://doi.org/10.21577/0103-5053.20160219

Callaway JC, Brito GS, Neves ES (2005) Phytochemical analyses of Banisteriopsis caapi and Psychotria viridis. J Psych Drugs 37(2):145–150. https://doi.org/10.1080/02791072.2005.10399795

Canham SM, Hafensteiner BD, Lebsack AD, May-Dracka TL, Nam S, Stearns BA, Overman LE (2015) Stereocontrolled enantioselective total synthesis of the [2+2] quadrugemine alkaloids. Tetrahedron 71(37):6424–6436. https://doi.org/10.1016/j.tet.2015.02.080

Chen T, Taylor CM (2011) Psychotria. In: Yang QE, Landrein S, Osborne J, Borosova R (eds) Flora of China, vol 19.
Coelho EG, Amaral ACF, Ferreira JLP, dos Santos AG, Pinheiro MLB, de Silva AJR (2007) Calcium oxalate crystals and methyl salicylate as toxic principles of the fresh leaves from Palicourea longiflora, an endemic species in the Amazonas state. Toxicin 49(3):407–409. https://doi.org/10.1016/j.toxicin.2006.10.003

Cook D, Lee ST, Taylor CM, Gardiner DR (2014) Detection of toxic monofluoroacetate in Palicourea species. Toxicin 80:9–16. https://doi.org/10.1016/j.toxicin.2013.12.003

Cordell GA, Quinn-Beattie ML, Farnsworth NR (2001) The potential of alkaloids in drug discovery. Phytother Res 15(3):183–205. https://doi.org/10.1002/ptr.890

da Cunha ALMC, Sá A, Mello SC, Vásquez-Castro YE, Luna AS, Aucelio RQ (2016) Determination of nitrogen-containing polycyclic aromatic compounds in diesel and gas oil by reverse-phase high performance liquid chromatography using introduction of sample as detergentless microemulsion. Fuel 176:119–129. https://doi.org/10.1016/j.fuel.2016.02.035

de Carvalho Junior AR, Oliveira Ferreira R, de Souza Passos M, da Silva Boeno SI, de Lima Glória das Virgens L, Ventura TLB, Calixto SD, Lassouskaia E, de Carvalho MG, Braz-Filho R, Cucino Vieira J (2019) Antimycobacterial and nitric oxide production inhibitory activities of triterpenes and alkaloids from Psychotria nuda (Cham. & Schltdl.) Wawra. Molecules 24(6):1026. https://doi.org/10.3390/molecules24061026

de Carvalho Junior AR, Ferreira RO, de Souza Passos M, Vieira MGC, de Lima Glória das Virgens L, Calixto SD, Ventura TLBV, Lassouskaia E, de Carvalho MG, Braz-Filho R, Vieira IJC (2021) Chemical composition, antimycobacterial and anti-inflammatory activities of iridoids and triterpenoids from Psychotria suterella (Rubiaceae). Pharmacosan Mag 17(74):355–359. https://doi.org/10.4103/pm.pm_93_ 2

de Freitas Morell LJ, Baratto DM, Pereira PS, Contini SHT, Mommm HG, Bertoni BW, de Castro S (2011) Loganin production in Palicourea rigida HBK (Rubiaceae) from populations native to Brazilian Cerrado. J Med Plants Res 5(12):2559–2565. https://doi.org/10.5897/JMPR.9000856

de Sousa Queiroz C, de Carvalho Batista FR, de Oliveira LO (2011) Evolution of the 5.8 S nrDNA gene and internal transcribed spacers in Carapichea specucauha (Rubiaceae) within a phylogenetic context. Mol Phylogenetics Evol 59(2):293–302. https://doi.org/10.1016/j.ympev.2011.01.013

da Rosa EA, Silva BC, Silva FM, Tanaka C, Peralta RM, de Oliveira C, Kato L, Ferreira HD, da Silva CC (2010) Flavo- noids and antioxidant activity in Palicourea rigida Kunth Rubiaceae. Rev Bras Farmacogn 20(4):484–488. https://doi.org/10.1590/S0102-695X2010000400004

da Silva VC, de Carvalho MG, Alves AN (2008) Chemical constituents from leaves of Palicourea coriacea (Rubiaceae). J Nat Med 62(3):356–357. https://doi.org/10.1007/s11418-008-0227-2

da Silva MDS, Pereira AMS, de Freitas Morell LJ, de Castro FS, Bertoni BW (2013) Association of loganin contents with the genetic characterization of natural populations of Palicourea rigida Kunth determined by AFLP molecular markers. Biochem Syst Ecol 51:189–194. https://doi.org/10.1016/j.bse.2013.08.032

Dan S, Dan SS (1986) Phytochemical study of Adansonia digitata, Coccoloba excoriata Psychotria Adenophylla and Schileichera Oleosa. Fitoterapia 57(6):445–446

Dash UC, Kanhar S, Dixit A, Dandapat J, Sahoo AK (2019) Isolation, identification, and quantification of pentylocumene from Geophila repens: A new class of cholinesterase inhibitor for Alzheimer’s disease. Bioorg Chem 88:102947. https://doi.org/10.1016/j.bioorg.2019.102947

de Cacia OM, Negri G, Salatino A, Braga MR (2007) Detection of anthraquinones and identification of 1,4-naphthohydroquinone in cell suspension cultures of Rudgea jasminoides (Rubiaceae). Rev Bras Biol 30(1):167–172. https://doi.org/10.1590/S0100-84042007000100017

de Carvalho Junior AR, Vieira IJC, de Carvalho MG, Braz-Filho R, Lima MAS, Ferreira RO, Maria JE, de Oliveira DB (2017) 13C-NMR Spectral data of alkaloids isolated from Psychotria species (Rubiaceae). Molecules 22(1):103. https://doi.org/10.3390/molecules22010103

de Oliveira AM, Lemos RPL, Conserva LM (2013) β-Carboline alkaloids from Psychotria barbiflora DC. (Rubiaceae). Biochem Syst Ecol 50:339–341. https://doi.org/10.1016/j.bse.2013.04.015

de L Carvalho FK, Cook D, Lee ST, Taylor CM, Oliveira JBS, Riet-Correa F (2016) Determination of toxicity in rabbits and corresponding detection of monofluoroacetate in four Palicourea (Rubiaceae) species from the Amazonas state, Brazil. Toxicin 109:42–44. https://doi.org/10.1016/j.toxicin.2015.11.009

Delprete PG, Kirkbride Jr. JH (2015) New combinations in Eumachia (Rubiaceae) for species occurring on the Guiana Shield. J Bot Res Inst Texas 9(1):75–79. https://www.jstor.org/stable/24621246

Delprete PG, Kirkbride Jr. JH (2016) New combinations and new names in Palicourea (Rubiaceae) for species of Psychotria subgenus Heteropsychotria occurring in the Guianas. J Bot Res Inst Texas 10(2):409–442. https://www.jstor.org/stable/44855880

Delprete PG, Lachenaud O (2018) Conspectus of Palicourea section Potaroenses (Rubiaceae), with a new species from French Guiana and a new combination. Plant Ecol Evol 151(1):119–129. https://doi.org/10.5091/plecevo.2018.1356

do Nascimento CA, Gomes MS, Liao LM, de Oliveira C, Kato L, da Silva CC, Tanaka C (2006) Alkaloids from Palicourea coriacea (Cham.) K. Schum. Z Naturforsch B: Chem Sci 61(11):1443–1446. https://doi.org/10.1515/znb-2006-1120

do Nascimento CA, Liao LM, Kato L, da Silva CC, Tanaka CM, Schuquel IT, de Oliveira CM (2008) Δ tetrahydro β-carbol ine trisaccharide from Palicourea coriacea (Cham.) K. Schum. Carbohydr Res 343(6):1104–1107. https://doi.org/10.1016/j.carres.2008.01.032

dos Santos PC, Simões-Pires CA, Nrusio A, Soldi TC, Kato L, de Oliveira CMA, de Faria EO, Marcourt L, Gottfried C, Currapt P-A, Henriques AT (2013a) Indole alkaloids of Psychotria as multifunctional cholinesterases and mono- amine oxidases inhibitors. Phytochemistry 86:8–20. https://doi.org/10.1016/j.phytochem.2012.11.015
Kato L, Takeda Y, Nishimura H, Kanomi A, Okuda T, Puff C (1988) Chemotaxonomic studies of rubiaceous plants containing indoid glycosides. Phytochemistry 27(8):2591–2598. 
https://doi.org/10.1016/S0031-9422(88)80730-4

Itoh A, Tanahashi T, Nagakura N (1989) Neopicoside and 7-methylneopicoside, new unusually-cyclized tetracydroisoquinoline-monoterpenic glucosides from *Cephaelis ipecacuanha*. Phytochemistry 28(2):383–387. 
https://doi.org/10.1016/S0031-9422(00)97080-8

Itoh A, Ikuta Y, Baba Y, Tanahashi T, Nagakura N (1999) Ipecac alkaloids from *Cephaelis acuminata*. Phytochemistry 52(6):1169–1176. 
https://doi.org/10.1016/S0031-9422(99)00361-1

Itoh A, Ikuta Y, Baba Y, Tanahashi T, Nagakura N (2002) Tetrahydroisoquinoline-monoterpenic glucosides from *Cephaelis acuminata*. Phytochemistry 59(1):91–97. 
https://doi.org/10.1016/S0031-9422(01)00418-6

Jannic V, Guérritte F, Laprévote O, Serani L, Martin MT, Sévenet T, Potier P (1999) Pyrrolidinoindoline alkaloids from *Psychotria oleoides* and *Psychotria lyciiflora*. J Nat Prod 62(6):838–843. 
https://doi.org/10.1021/jn9803277

Kemmerling W (1996) Toxicity of *Palicourea marcgravii*: combined effects of fluoroacetate, N-methyltyramine and 2-methyltetrahydro-β-carboline. Z Naturforsch, C: Biosci 51(1–2):59–64. 
https://doi.org/10.1515/znc-1996-1-211

Kerry MC, Gregiariini T, Paranomos JT, Schwabach J, Farias F, Fett JP, Fett-Neto AG, Zuanazzi JA, Quirion JC, Elizabetsky E, Henriques AT (2001) Brachycerine, a novel monoterpenic indole alkaloid from *Psychotria brachycera*. J Nat Prod 64(5):677–679. 
https://doi.org/10.1021/np000590e

Koehbach J, Attah AF, Berger A, Hellinger R, Kutchan TM, Carpenter EJ, Rolf M, Sonibare MA, Moody JO, Wong GK, Dessein S, Greger H, Gruber CW (2013) Cytolide discovery in Gentianales revisited—identification and characterization of cyclic cystine-knot peptides and their phylogenetic distribution in Rubiaceae plants. Biopolymers 100(5):438–452. 
https://doi.org/10.1002/bip.22238

Kornpointner C, Berger A, Fischer IM, Popl L, Groher C, Valant-Vetschera K, Brecker K, Schinnerl J (2018) Revisiting Costa Rican *Carapichea affinis* (Rubiaceae: Palicoureae): A source of bioactive dopamine-iridoid alkaloids. Phytochemistry Lett 26:164–169. 
https://doi.org/10.1016/j.phytol.2018.05.004

Kornpointner C, Berger A, Traxler F, Habziadia I, Massar M, Matek J, Brecker L, Schinnerl J (2020) Alkaloid and iridoid glucosides from *Palicourea luxurians* (Rubiaceae: Palicoureae) indicate tryptamine and tryptophan iridoid alkaloid formation apart the strictosidine pathway. Phytochemistry 173:112296. 
https://doi.org/10.1016/j.phytochem.2020.112296

Kostyan MK (2017) Comparative analysis of secondary metabolites in selected Notopleura species, Master Thesis, University of Vienna, Vienna, Austria. 
https://doi.org/10.2174/1570163815666180828113920
Morita H, Ichihara Y, Takey K, Watanabe K, Ikotawa H, Motidome M (1989) A new indole alkaloid glycoside from the leaves of *Palicourea marcuavii*. Planta Med 55(3):288–289. https://doi.org/10.1055/s-1997-30000

Moura VM de, Ribeiro MAS, Corrêa JGS, Peixoto MA, Souza GK, Bonfim-Mendonça PS, Svizdinszki TIE, Pominii AM, Meurer EC, Santin SMO (2020b) Minutifloroside, a new bis-iridoid glucoside with antifungal and antioxidant activities and other constituents from *Palicourea minutiflora*. J Braz Chem Soc 31(3):505–511. https://doi.org/10.21577/0103-5053.20190209

Muhammad I, Khan IA, Fischer NH, Fronczek FR (2001) Two steroidal isomerides pentacyclic oxindole alkaloids from *Uncaria tomentosa*: uncarine C and uncarine E. Acta Crystallogr C 57(4):480–482. https://doi.org/10.1107/S0108270199010032

Muhammad I, Dunbar DC, Khan SI, Tekwani BL, Bedir E, Takamatu S, Ferreira D, Walker LA (2003) Antiparasitic alkaloids from *Psychotria klugii*. J Nat Prod 66(7):962–967. https://doi.org/10.1021/np030086k

Müller Argoviensis J (1881) *Psychotria Tribus I Retiniphyllae-Tribus VI Psychotrieae*. In: von Martius CFP, Eichler Lipsiae, pp 1–470. https://www.biodiversitylibrary.org/item/9666

Murillo R, Castro V (1998) Isolation of the alkaloid harmane from *Psychotria suerrensis*. Ing Sci Quim 18(2):61–62

Nagakura N, Itoh A, Tanahashi T (1993) Four tetrahydroisoquinoline-monoterpene glucosides from *Cephaelis ipecacuanha*. Phytochemistry 32(3):761–765. https://doi.org/10.1016/0031-1823(93)80167-7

Nakano T, Martin A (1976) Studies on the alkaloids of *Pali- courea fendleri*. Planta Med 30(2):186–188. https://doi.org/10.1055/s-0028-1097715

Narine LL, Maxwell AR (2009) Monoterpenoid indole alkaloids from *Palicourea crocea*. Phytochem Lett 2(1):34–36. https://doi.org/10.1016/j.phytol.2008.10.007

Nascimento RRG, Monteiro JA, Pimenta ATA, Trevisan MTS, Braz-Filho R, de Souza EB, Silveira ER, Lima MAS (2015a) Novos flavonoides de *Margaritopsis caramuscoa* com atividade antioxidante. Quim Nov 38(1):60–65. https://doi.org/10.5935/0100-4042.20140289

Nascimento RRG, Pimenta ATA, de Lima NP, Junior JRC, Costa-Lotufo LV, Ferreira EG, Tinoco LW, Braz-Filho R, Silveira ER, Lima MAS (2015b) New alkaloids from *Margaritopsis caramuscoa* (Rubiaceae). J Braz Chem Soc 26(6):1152–1159. https://doi.org/10.5935/0103-5053.20150079

Naves RF (2014) Estudo fitoquímico das folhas de *Psychotria hoffmannseggianna* Roem. & Schult. (Rubiaceae). Master Thesis, Universidade Federal de Goiás, Goiás, Brazil, pp 1–212. http://repositorio.bc.ufg.br/handle/tede/tede/3612

Nepokroeff M, Bremer B, Sytsma KJ (1999) Reorganization of the genus *Psychotria* and tribe Psychotrieae (Rubiaceae) inferred from ITS and rbcL sequence data. Syst Bot 24(1):5–27. https://doi.org/10.2307/2419383

Nomura T, Quesada AL, Kutchai TM (2008) New β-D-glucosidas de terpenoid-isoquinoline alkaloid biosynthesis in *Psychotria ipecacuacaunha*. J Biol Chem 283(50):34650–34659. https://doi.org/10.1074/jbc.M806953200

Nomura T, Kutchai TM (2010a) Three new O-methyltransferases are sufficient for all O-methylation reactions of ipecac alkaloid biosynthesis in root culture of *Psychotria ipecacuacaunha*. J Biol Chem 285(10):7722–7738. https://doi.org/10.1074/jbc.M109.086157

Nomura T, Kutchai TM (2010b) Is a metabolic enzyme complex involved in the efficient and accurate control of Ipecac alkaloid biosynthesis in *Psychotria ipecacuacaunha*? Plant Signal Behav 5(7):875–877. https://doi.org/10.4161/psb.5.7.11901

O’Connor SE, Maresh JJ (2006) Chemistry and biology of monoterpene indole alkaloid biosynthesis. Nat Prod Rep 23(4):532–547. https://doi.org/10.1039/B512615K

de Oliveira CF (2015) Morfoanatomia, caracterização fitoquímica e avaliação das atividades biológicas de *Psychotria fractistipula* L.B. SM, Klein & Delprcte (Rubiaceae). Dissertação, Universidade Federal do Paraná, Curitiba. https://hdl.handle.net/1884/37389

Parry KP, Smith GF (1978) Quadrigemines-A and -B, two minor alkaloids of *Hodgkinsonia frutescens* F. Mull. J Chem Soc, Perkin Trans 1(12):1671–1682. https://doi.org/10.1039/P19780001671

Paul JHA, Maxwell AR, Reynolds WF (2003) Novel bis-(monoterpenoid) indole alkaloids from *Psychotria bahiensis*. J Nat Prod 66(6):752–754. https://doi.org/10.1021/np020554a

Pimenta ATÁ, Braz-Filho R, Delprcte PG, de Souza EB, Silveira ER, Lima MAS (2010a) Structure elucidation and NMR assignments of two unusual monoterpene indole alkaloids from *Psychotria stachyoides*. Magn Res Chem 48(9):734–737. https://doi.org/10.1002/mrc.2656

Pimenta ATÁ, Braz-Filho R, Delprcte PG, de Souza EB, Silveira ER, Lima MAS (2010b) Unusual monoterpene indole alkaloids from *Psychotria stachyoides* Benth. Biochem Syst Ecol 38(4):846–849. https://doi.org/10.1016/j.bse.2010.07.013

Pimenta ATÁ, Uchôa DE, Braz-Filho R, Silveira ER, Lima MAS (2011) Alkaloid and other chemical constituents from *Psychotria stachyoides* Benth. J Braz Chem Soc 22(11):2216–2219. https://doi.org/10.1590/S0103-50532011001100027

Pinheiro RP, Moraes MA, Santos BCS, Fabri RL, Del-Vechio-Vieira G, Yamamoto CH, Araújo ALSM, Araújo ALA, Sousa OV (2018) Identification of compounds from *Psychotria rigida* leaves with topical anti-inflammatory potential using experimental models. Inflammopharmacology 26(4):1005–1016. https://doi.org/10.1007/s10787-017-0415-3

Porto DD, Henrique AT, Fett-Neto AG (2009) Bioactive alkaloids from South American *Psychotria* and related
species. Open Bioact Comp J 2:29–36. https://doi.org/10.2174/1874847300902010029

Prachayasittikul S, Buraparungsang P, Vorachartcheewan A, Isaranurka-Na-Ayudhya C, Ruchirawat S, Prachayasittikul V (2008) Antimicrobial and antioxidative activities of bioactive constituents from Hydnophyton formicarum Jack. Molecules 13(4):904–921. https://doi.org/10.3390/molecules13040904

Prachayasittikul S, Pingaw R, Yamkamon V, Vorachartcheewan A, Wanwimolruks R, Ruchirawat S, Prachayasittikul V (2012) Chemical constituents and antioxidant activity of Hydnophyton formicarum Jack. Int J Pharmacoil 8(5):440–444. https://doi.org/10.3923/ijp.2012.440.444

Queiroz GS, Luz ABG, dos Santos Nascimento MVP, Thomasi SS, Ferreira AG, Dalmarco EM, Brighente IMC (2017) Phytochemical study and anti-inflammatory effect of Psychotria stenocalyx (Rubiaceae). J App Pharm Sci 7(04):168–173. https://doi.org/10.7332/JAPS.2017.70425

Ramil RJ, Ramil MDI, Konno T, Murata T, Kobayashi K, Buyankhishig B, Agrpus SC, Sasaki K (2020) A new hexenoic acid glycoside with cytotoxic activity from the leaves of Psychotria luzoniensis. Nat Prod Res. https://doi.org/10.1080/14786419.2020.1765345

Rao H, Lai P, Gao Y (2017) Chemical composition, antibacterial activity, and synergistic effects with conventional antibiotics and nitric oxide production inhibitory activity of essential oil from Geophila repens (L.) I.M. Johnst. Molecules 22(9):1561 https://doi.org/10.3390/molecules22091561

Rasolomahanary R, Sévénet T, Guéritte-Voegelein F, Kordon C (1995) Psycholine, a natural alkaloid extracted from Psychotria oleoides, acts as a weak antagonist of somatostatin. Eur J Pharmacol 285(1):19–23. https://doi.org/10.1016/0014-2999(95)00345-L

Razafimandimbison SG, Taylor CM, Wikström N, Pailler T, Khodabandeh A, Bremer B (2014) Phylogeny and generic limits in the sister tribes Psychotrieae and Palicoureeae (Rubiaceae): Evolution of schizocarps in the origins of bacterial leaf nodules of the Malagasy species. Am J Bot 101(7):1102–1126. https://doi.org/10.3732/ajb.1400076

Rédei D, Abdullah H, Hawariah A, Forgo P, Molnár J, Hohmann J (2005) Constituents and antiproliferative activity of the Malaysian plant Hydnophyton formicarium. Poster: 53rd Annual Congress of the Society for Medicinal Plant Research, Florence, Italy. https://doi.org/10.13140/RG.2.2.32172.49288

Ribeiro MAS, Gomes CMB, Formaggio ASN, Pereira ZV, Melo UZ, Basseto EA, da Costa WF, Baldoqui DC, Sarragiotto MH (2016) Structural characterization of dimeric indole alkaloids from Psychotria brachybotrya by NMR spectroscopy and theoretical calculations. Tetrahedron Lett 57(12):1331–1334. https://doi.org/10.1016/j.tetlet.2016.02.040

Ripperger H (1982) Chimonanthin aus Palicourea domingensis. Pharmazie 37(12):867

River L, Lindgren JE (1972) Ayahuasca, the South American hallucinogenic drink: An ethnomedical and chemical investigation. Econ Bot 26(2):101–129

Robbrecht E (1975) Hymenocolea, a new genus of Psychotriaceae (Rubiaceae) from tropical Africa. Bull Jard Bot Nat Belg 45:273–300. https://doi.org/10.2307/3667482

Robbrecht E, Manef JF, (2006) The major evolutionary lineages of the coffee family (Rubiaceae, angiosperms). Combined analysis (nDNA and cpDNA) to infer the position of Coptosapelta and Luculia, and supergroup construction based on rbcl, rps16, trnl-trnfA and atpB-rbcL data. A new classification in two subfamilies, Cinchonioideae and Rubioideae. Syst Geogr Pl 76(1):85–145. https://www.jstor.org/stable/20649700

Roth A, Kuballa B, Cabalion P, Anton R (1985) Preliminary study of the alkaloids of Psychotria forsteriana. Planta Med 51(3):289. https://doi.org/10.1055/s-2007-969941

Roth A, Kuballa B, Bounthanh C, Cabalion P, Sévenet T, Beck JP, Anton R (1986) Cytotoxic activity of polyindolone alkaloids of Psychotria forsteriana (Rubiaceae). Planta Med 52(06):450–453. https://doi.org/10.1055/s-2007-969251

Saad HEA, El-Sharkawy SH, Shier WT (1995) Biological activities of pyrrolidinoindoline alkaloids from Calycodendron milnei. Planta Med 61(4):313–316. https://doi.org/10.1055/s-2006-958090

Samulski GB, Gontijo DC, Moreira NC, Brandão GC, de Oliveira AB (2020) Deregulation of Psychotria sessilis ethanol extracts by UPLC-DAD-ESI-MS/MS discloses the presence of hydroxycinnamic acid amides and the absence of monoterpenoid indole alkaloids. Biochem Syst Ecol 92:104114. https://doi.org/10.1016/j.bse.2020.104114

Sandra UI, Ishmael AV, Cokey I, Sani G, Godfrey N, Edet EE (2018) Chromatographic assay, antimicrobial analysis and structural elucidation of bioactive compounds of Palicourea croceoides leaves extract. J Am Biol Chem 5(2):6–14

Satari MH, Situmeang B, Yudha IP, Kurnia D (2019) Antibacterial diterpenoid against pathogenic oral bacteria of Streptococcus mutans ATCC 25175 isolated from Sarang Semut (Myrmecodia pendans). Jurnal Kimia Valensi 5(2):218–223 https://doi.org/10.15408/jkv.v5i2.8864

Schindler F, Fragner L, Herpell JB, Berger A, Brenner M, Tischer S, Bellaire A, Schönenberger J, Li W, Sun X, Schinnerl J, Brecker L, Weckwerth W (2021) Dissecting metabolism of leaf nodules in Ardisia crenata and Psychotria punctata. Front Mol Biosci 8:683671. https://doi.org/10.3389/fmolb.2021.683671

Schinnerl J, Orlowska EA, Lorbeer E, Berger A, Brecker L (2012) Alstrosterines in Rubiaceae: Alstrosterine A from Chassalia curviflora var. ophioxyloides and a novel derivative, rudgeifoline from Ardisia crenata. Phytochemistry 73(3):586–590. https://doi.org/10.1016/j.phytochemistry.2012.05.019

Schindler F, Fragner L, Herpell JB, Berger A, Brenner M, Tischler S, Bellaire A, Schönengerber J, Li W, Sun X, Schinnerl J, Brecker L, Weckwerth W (2021) Dissecting metabolism of leaf nodules in Ardisia crenata and Psychotria punctata. Front Mol Biosci 8:683671. https://doi.org/10.3389/fmolb.2021.683671

Schinnerl J, Orlowska EA, Lorbeer E, Berger A, Brecker L (2012) Alstrosterines in Rubiaceae: Alstrosterine A from Chassalia curviflora var. ophioxyloides and a novel derivative, rudgeifoline from Ardisia crenata. Phytochemistry 73(3):586–590. https://doi.org/10.1016/j.phytochemistry.2012.05.019

Schmidt AW, Reddy KR, Knöller HJ (2012) Occurrence, biogenesis, and synthesis of biologically active carbazole alkaloids. Chem Rev 112(6):3193–3328. https://doi.org/10.1021/cr200447s

Setzer WN, Noletto JA, Haber WA (2006) Chemical composition of the floral essential oil of Psychotria eurycarpa from Monteverde, Costa Rica. J Essent Oil Bear Plants 9(1):28–31. https://doi.org/10.1080/0972060X.2006.10643466

Shamma M (1972) Emetine and related alkaloids. In: Organic Chemistry 25: The isoquinoline alkaloids. Academic Press, New York, pp 426–457. https://doi.org/10.1016/B978-0-12-638250-1.50027-7
Sieber S, Carlier A, Neuburger M, Grabenweger G, Eberl L, Gademann K (2015) Isolation and total synthesis of kirkamide, an amionic cyclitol from an obligate leaf nodule symbiont. Angew Chem 127(27):8079–8081. https://doi.org/10.1002/ange.201502696

Silva KTD, Smith GN, Warren KEH (1971) Stereochemistry of strictosidine. Chem Commun 16:905–907. https://doi.org/10.1039/C29710000905

Simões-Pires CA, Farias FM, Marston A, Queiroz EF, Silva KTD, Smith GN, Warren KEH (1971) Stereochemistry of Phytochem Rev (2022) 21:941–986

Takayama H, Mori I, Kitajima M, Aimi N, Lajis NH (2004) New type of trimeric and pentameric indole alkaloids from Psychotria rostrata. Org Lett 6(17):2945–2948. https://doi.org/10.1021/ol0408971x

Tan MA, Eusebio JA, Alejandro GJD (2012) Chemotaxonomic implications of the absence of alkaloids in Psychotria gittingensis. Biochem Syst Ecol 45:20–22. https://doi.org/10.1016/j.bse.2012.07.016

Tan MA, Panghulan GFM, Uy MM, Takayama H (2014) Chemical constituents from Psychotria cadigensis and their chemotaxonomic relevance. Am J Essent Oil Nat Prod 1(4):18–19

Taylor CM (1996) Overview of the Psychotrieae (Rubiaceae) in the Neotropics. Opera Bot Belg 7:261–270

Taylor CM (2001) Overview of the neotropical genus Notopleura (Rubiaceae: Psychotrieae), with the description of some new species. Ann Missouri Bot Gard 88(3):478–515. https://doi.org/10.2307/3298587

Taylor CM (2019a) Rubiacearum Americanarum Magna Hama Pars XLIV: Review of the Palicourea pilosa group, with some new species and a new subspecies (Palicoureeae). Novon 27(2):102–130. https://doi.org/10.3417/2018316

Taylor CM (2019b) Rubiacearum Americanarum Magna Hama Pars XLV: More new species and taxonomic changes in Palicourea (Rubiaceae, Palicoureeae) and Psychotria subg. Heteropsychotria. Novon 27(3):165–195. https://doi.org/10.3417/2019387

Taylor CM (2020) Overview of Psychotria in Madagascar (Rubiaceae, Psychotrieae), and of Bremekamp’s foundational study of this group. Candollea 75(1):51–70. https://doi.org/10.15553/c2020v751a5

Taylor CM, Gereau RE (2013) The genus Carapichea (Rubiaceae, Psychotrieae). Ann Missouri Bot Gard 99(1):100–127. https://www.jstor.org/stable/42703711

Taylor CM, Schmidt GRE (2020) Some distinctive new species of Psychotria from Madagascar (Rubiaceae, Psychotrieae). Candollea 75(2):159–182. https://doi.org/10.15553/c2020v752a1

Taylor CM, Lorence DH, Gereau RE (2010) Rubiacearum Americanarum Magna Hama Pars XXV: the nocturnally flowering Psychotria domingensis-Coussarea hondensis group plus three other Mesoamerican Psychotria species transfer to Palicourea. Novon 20(4):481–492. https://doi.org/10.3417/2009124

Taylor CM, Hollowell VC (2016) Rubiacearum Americanarum Magna Hama Pars XXXV: The new group Palicourea sect. Nonatelia, with five new species (Palicoureeae). Novon 25(1):69–110. https://doi.org/10.3417/2015012

Taylor CM, Razafimandimbison SG, Barabé L, Jardim JG, Barbosa MRV (2017) Eumachia expanded, a pantropical genus distinct from Psychotria (Rubiaceae, Palicoureeae). Candollea 72(2):289–318. https://doi.org/10.15553/c2017v722a6

Taylor CM (2005) Margaritopsis (Rubiaceae, Psychotrieae) in the Neotropics. Syst Geogr Pl 75(2):161–177. http://www.jstor.org/stable/3668574

Taylor CM (2014) Rubiaceae. In: Hammel BE, Grayum MH, Herrera C, Zamora N (eds) Manual de Plantas de Costa Rica. Vol. VII. Monogr Syst Bot Missouri Bot Gard 129:464–779

Taylor CM (2015a) Rubiacearum Americanarum Magna Hama XXXIII: The new group Palicourea sect. Didymocarpeae with four new species and two new subspecies (Palicoureeae). Novon 23(4):452–478. https://doi.org/10.3417/2012003
Taylor CM (2015b) Rubiacearum Americanarum Magna Hama Pars XXXIV: The new group Palicourea sect. Trichephalium with eight new species and a new subspecies (Palicoureae). Novon 24(1):55–95. https://doi.org/10.3417/2015001

Taylor CM (2017) Rubiacearum Americanarum Magna Hama XXXVII: The new group Palicourea sect. Chocooanae of the Chocó biogeographic region, with two new species (Palicoureae). Novon 25(3):322–342. https://doi.org/10.3417/2016002

Taylor CM (2018) Rubiacearum Americanarum Magna Hama Pars XXXVIII: A new circumscription of Palicourea sect. Bracteiflorae, an Andean radiation with several new species (Palicoureae). Novon 26(1):66–138. https://doi.org/10.3417/2017036

Tran PH, LeVD, Do TH, Nguyen TL, Nguyen PT, Nguyen TT, Nguyen TD (2019) Anti-inflammatory constituents from Psychotria prainii H. Lév Nat Prod Res 33(5):695–700. https://doi.org/10.1016/S0305-1978(01)00059-X

Uzor PF (2016) Recent developments on potential new applications of emetine as anti-cancer agent. EXCLI Journal 15:323–328. https://doi.org/10.17179/excli2016-280

Valdevite M, Bertoni BW, Contini SHT, de Castro FS, Pereira AMS (2016) Accumulation of loganin by genotypes of Palicourea rigida and related differential gene expression as determined by cDNA-SRAP. Plant Cell, Tissue Organ Cult 125(3):445–456. https://doi.org/10.1007/s11240-016-0959-8

Valverde J, Tamayo G, Hesse M (1999) β-Carboline monoterpenoid glucosides from Palicourea adusta. Phytochemistry 52(8):1485–1489. https://doi.org/10.1016/S0031-9422(99)00215-0

van de Santos L, Fett-Neto AG, Kerber VA, Elisabetsky E, Verotta L, Pilati T, Tato` M, Elisabetsky E, Amador TA, Nunes DS, Vencato I, da Silva FM, de Oliveira CMA, Kato L, Tanaka Y, Zhou H, He H-P, Wang Y-H, Hao X-J (2010) A new dimeric saponin with eight new species and a new subspecies (Palicoureae). Novon 24(1):55–95. https://doi.org/10.3417/2017036

Van Elst D, Nuyens S, Van Wyk B, Verstraete B, Dessein S, Wiegrebe W, Kramer WJ, Shamma M (1984) The emetine alkaloid extracts of Amazon Psychotria calocarpa. Helv Chim Acta 67:15–19. https://doi.org/10.1002/hlca.19840670102

Van Elst D, Nuyens S, Van Wyk B, Verstraete B, Dessein S, Prinsen E (2013) Distribution of the cardiotoxin pavetamine in the coffee family (Rubiaceae) and its significance for gousiakete, a fatal poisoning of ruminants. Plant Physiol Biochem 67:15–19. https://doi.org/10.1016/j.plaphy.2013.02.022

Vencato I, da Silva FM, de Oliveira CMA, Kato L, Tanaka CMA, da Silva CC, Sabino JR (2006) Vallesiachotamine Acta Crystallogr E 62:o429–o431. https://doi.org/10.1107/S1600536805041553

Verotta L, Pilati T, Tatô M, Elisabetsky E, Amador TA, Nunes DS (1998) Pyrrolidinoindoline alkaloids from Psychotria colorata. J Nat Prod 61(3):392–396. https://doi.org/10.1021/np9701642

Verotta L, Peterlongo F, Elisabetsky E, Amador TA, Nunes DS (1999) High-performance liquid chromatography-diode array detection-tandem mass spectrometry analyses of the alkaloid extracts of Amazon Psychotria species. J Chromatogr A 841(2):165–176. https://doi.org/10.1016/S0021-9673(99)00029-8

Wang Y, Zhou J (1999) Chemical constituents of curvedflower chasalis bark (Chasalis curviflora). Zhongcaoyao 30(9):644–645

Wang YH, Samoylenko V, Tekwani BL, Khan IA, Miller LS, Chaurasiya ND, Rahman MM, Tripathi LM, Khan SI, Joshi VC, Wigger FT (2010) Composition, standardization and chemical profiling of Banisteriopsis caapi, a plant for the treatment of neurodegenerative disorders relevant to Parkinson’s disease. J Ethnopharmacol 128(3):662–671. https://doi.org/10.1016/j.jep.2010.02.013

Wang K, Zhou Y-Y, Li M-M, Li Y-S, Peng L-Y, Cheng X, Li Y, Wang Y-P, Zhao Q-S (2011) Macrophyllion and macrophyllines A and B, oxindole alkaloids from Uncaria macrophylla. J Nat Prod 74(1):12–15. https://doi.org/10.1021/np1004938

Woo-Ming RB, Stuart KL (1975) Calycanthone from Palicourea fulva. Phytochemistry 14(11):2529. https://doi.org/10.1016/0031-9422(75)80394-3

Yang H, Zhang H, Yang C, Chen Y (2016) Chemical constituents of plants from the genus Psychotria. Chem Biodivers 13(7):807–820. https://doi.org/10.1002/cbdv.201500259

Yang HM, Zhang HM, Zhang YK, Liao PN, Chen YG (2018) Compounds from the twigs and leaves of Psychotria prainii. Chem Nat Compd 54(1):178–180. https://doi.org/10.1007/s10600-018-2289-z

Ye H-C, Zheng X-H, Wang Y-M, Peng G-T, Su X-J, Lei L-F, Zhang C-X (2014) Saponins from the stem of Psychotria sp. Zhongshan Daxue Xuebao 53(1):93–97

Young MCM, Araújo AR, da Silva CA, Lopes MN, Trevisan LMV (1998) Triterpenes and saponins from Rudgea viburnioides. J Nat Prod 61(7):936–938. https://doi.org/10.1021/np9704617

Zappi DC (2003) Revision of Rudgea (Rubiaceae) in southeastern and southern Brazil. Kew Bull. 58(3):513–596. https://doi.org/10.2307/4111145

Zhang C-X, He X-X, Guan S-Y, Zhong Y, Lin C-Z, Xiong T-Q, Zhu C-C (2012) New spingolidip lipid psychotramide A-D from the stem of Psychotria sp. Nat Prod Res 26(20):1864–1868. https://doi.org/10.1080/14786419.2011.617747

Zhang C-X, Zhang D-M, Chen M-F, Guan S-Y, Yao J-H, He X-X, Lei L-F, Zhong Y, Wang Z-F, Ye W-C (2013) Antiproliferative triterpenoid saponins from the stem of Psychotria sp. Planta Med 79(11):978–986. https://doi.org/10.1055/s-0032-1328650

Zhang C-X, Peng G-T, He X-X, Lin C-Z, Xiong T-Q, Deng J-W, Zhao Z-X, Zhu C-C (2010) Chemical constituents of Psychotria sp. (I). Zhongshan Daxue Xuebao 49(4):22–25

Zhou H, He H-P, Wang Y-H, Hao X-J (2010) A new dimeric alkaloid from the leaf of Psychotria calocarpa. Helv Chim Acta 93(8):1650–1652. https://doi.org/10.1002/hch.a.20090439

Zhou BD, Zhang XL, Niu HY, Guan CY, Liu YP, Fu YH (2018) Chemical constituents from stems and leaves of Psychotria serpens. Zhongguo Zhong Yao Za Zhi 43(24):4878–4883. https://doi.org/10.10554.cnki.cjcm20180912.003

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.