Aspidosperma Species as Sources of Antimalarials. Part III. A Review of Traditional Use and Antimalarial Activity*

Abstract

Several plant species belonging to the genus Aspidosperma are traditionally used in Brazil and other Meso- and South American countries for the treatment of malaria and fevers. These traditional uses were motivation for this review. A literature survey completed for this review has identified scientific bibliographical references to the use of 24 Aspidosperma species to treat malaria/fevers and to 19 species that have had their extracts and/or alkaloids evaluated, with good results, for in vitro and/or in vivo antimalarial activity. Indole alkaloids are typical constituents of Aspidosperma species. However, only 20 out of more than 200 known indole alkaloids isolated from this genus have been assayed for antimalarial activity. These data support the potential of Aspidosperma species as sources of antimalarials and the importance of research aimed at validating their use in the treatment of human malaria.

Introduction

Natural products and malaria
Malaria remains one of the most prevalent infectious diseases worldwide and is, therefore, a global health problem despite substantial efforts to control the disease over the past few decades. Approximately 3.3 billion people are at risk, and 250 million cases each year were reported in the period 2006–2008, primarily in Africa [1]. In the Americas, malaria transmission occurs in 21 countries. P. vivax caused 77% of all cases reported in 2008, but P. falciparum was responsible for almost 100% of all cases in Haiti and the Dominican Republic [1]. Brazil reported the highest number of malaria cases (603 532) in the region in 2005, primarily in the Brazilian Legal Amazon Region, where 10–15% of the population is at risk. Brazil was among the 30 highest-burden countries for malaria [2]. However, a decrease of approximately 25% in the number of reported cases has been recorded since 2006 [3,4].

Historically, plants have had a remarkable role in therapeutics and were the principal source of drugs until the 19th century. Quinine, isolated in 1820, from Cinchona species (Rubiaceae), was the first antimalarial drug introduced in chemotherapy and remained the only clinical weapon until the 1940s, when chloroquine, a synthetic 4-aminoquinoline, became available. Efficient and inexpensive, chloroquine was widely used until the 1960s, when resistance to the drug by P. falciparum became widespread in the malaria-endemic countries, causing a strong increase in mortality rates. The antimalarial drugs in current use are artemisinin, the active compound from Artemisia annua L. (Asteraceae), a traditional plant used for millennia in China, and its semisynthetic derivatives artemether, arteunate, and arteether [5].

Artemisinins are currently the most effective drugs for antimalarial chemotherapy and have been globally adopted for the treatment of P. falciparum malaria. The most recently introduced antimalarial drug is atovaquone, a synthetic naphthoquinone based on lapachol. Lapachol, a prenylnaphthoquinone, was first isolated from Tabebuia impetiginosa (Mart. ex DC.) Standl. (synon. T. avellanedae Lor. ex Griseb.), a South American representative of the Bignoniaceae [6].

The emergence of P. falciparum strains resistant to artemisinin and its derivatives would cause a resurgence of human malaria to high levels in many

* For Part I see [48], for Part II see [36], Part of RCP Doctorate Thesis at PPGCF, UFMG, Belo Horizonte, MG, Brazil.

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countries. For this reason, R&D on new antimalarial drugs is urgent. Plants continue to represent a valuable source of drugs. A review of all small molecules that have been approved as pharmaceutical agents within the 25-year period from 1/1981 to 6/2006 has demonstrated that approximately 50% of these molecules originated from natural products [7]. Investigations that begin by screening plants used in traditional medicines are particularly valuable. In the past decade, a substantial number of publications have focused on the screening of either extracts or natural products for antimalarial activity [8]. However, as we have noted previously, very few highly active antimalarial natural products have been evaluated for cytotoxicity and in vivo assays. This lack of previous study limits the potential of these products as bases for the development of new antimalarial drugs [5,9]. The relevance of these results should not, however, be underestimated. Active naturally occurring antimalarial compounds might be useful as bases for semisynthetic derivatives, as agents for direct use if their structures are too complex for an economically and/or technologically viable total synthesis, or as templates for the total synthesis of structurally related compounds [5]. Moreover, bioactive natural products from medicinal plants might be useful as biological markers in the development of efficient and safe phytomedicines [5,9], a new approach of growing interest that would provide malaria-endemic countries with good-quality herbal medicines of low cost, that would be locally and sustainably produced [8]. High-tech methods are available to standardize phytoremediation [10, 11], and new molecular biological assays can serve to screen extracts and plant constituents as well as to evaluate their pharmacological profiles, elucidate the synergistic effects of the constituents of an extract and, thus, gain a better understanding of the various mechanisms underlying their pharmacological effects [11–14].

Several Aspidosperma species have a history of medicinal uses, including the treatment of human malaria and/or fevers in Brazil as well as in other Meso- and South American countries [15–19]. The present review reports the results of a literature survey on Aspidosperma species traditionally used to treat malaria and/or fevers as well as data on those previously evaluated for antimalarial activity.

Traditional use in treating malaria

Data obtained by searching for Aspidosperma species with reported traditional uses as antimalarials and/or febrifuges as well as those species that have been experimentally evaluated for antimalarial activity are shown in Table 1. The table includes the accepted taxonomic nomenclature, synonyms, and occurrence, according to Koch and collaborators [20], LEFB [24], Lorenzi (1992) [15], TROPICOS® Specimen Data Base [25], and The Plant List [26]. The reported uses for treating malaria/fevers are based on the scientific literature. Medicinal uses described on commercial Internet sites, as well as uses other than for malaria and/or fevers, have not been included. Reported antimalarial activity may refer to in vitro assays with different Plasmodium species, in vivo assays in different animals with different Plasmodium species, or clinical assays in humans. Details of these findings are shown in Table 2.

Our literature survey has identified 24 Aspidosperma species (Table 1) used to treat malaria/fevers, representing approximately 50% of the representatives of this taxon [24]. In addition to these 24 species, Table 1 includes two other species, A. cylindrocarpon and A. macrocarpon, for which no reports have been found on their use to treat malaria/fever but that have been evaluated for antimalarial activity [27,28].

The "Dicionário das plantas úteis do Brasil e das exóticas cultivadas" (Dictionary of useful plants from Brazil and of the exotics cultivated), by Pio-Corrêa (1874–1934) [17], was our first source of information on the antimalarial use of plants belonging to the genus Aspidosperma. More than 50 Aspidosperma species are listed within this six-volume collection, with taxonomic data and vernacular names. Most of the applications described there are as sources of timber, whereas only three species, A. discolor, A. polynoeuron, and A. gomezianum, are identified as plants used to treat malaria and/or fevers.

The botanical names shown for the 26 Aspidosperma species in Table 1 are those originally reported in the literature. However, it should be emphasized that these are not the presently accepted names in certain cases. This is the situation for A. marcegnivulum Woodson (A. marcegnivulum), which is not presently an accepted name [24] but a synonym of A. excelsum Benth. together with A. nitidum Benth. ex Müll. Arg., according to Koch and collaborators [20] and LEFB [24], but is described as a synonym for A. excelsum only by the The Plant List [26]. In the same source [26], however, A. nitidum Benth. ex Müll. Arg. is an accepted name, with A. acutatum Ducke as a synonym. Another contradiction is found for A. album (Vahl) Benoist ex Pichon and A. desmatanum Benth. ex Müll. Arg., cited as accepted names for distinct species [20,24,26], whereas the second species represents a synonym for the first one [25]. Furthermore, A. parvifolium A. DC. is the accepted name of a species that has A. tambopatense A.H. Gentry and A. vargasii A. DC. as synonyms [20,24], whereas the latter synonym is also cited as a distinct species [25,26]. A similar situation is observed for A. tomentosum Mart., an accepted name having A. gomezianum A. DC. as a synonym [25,26], although both of them are also reported as distinct species [20,26]. These observations show that several controversies remain in the taxonomy of Aspidosperma species.

Phytochemistry and antimalarial activity

Chemically, Aspidosperma species are characterized by the presence of alkaloids and have yielded more than 200 indole alkaloids. The phytochemical investigation of several Brazilian Aspidosperma species, primarily in the period between 1960 and...
Table 1  Literature survey on *Aspidosperma* species, their traditional use to treat malaria and/or fevers, and reported antimalarial activity.

<table>
<thead>
<tr>
<th><em>Aspidosperma</em> species</th>
<th>Local names in Brazil References: [15, 17, 20, 24]</th>
<th>Occurrence References: [15, 17, 20, 24–26]</th>
<th>Reported use to treat malaria/fever</th>
<th>Reported antimalarial activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. auriculatum</em> Markgr. [20, 26]</td>
<td>Carapanaúba Carapanaúba-amarela</td>
<td>Brazil: Endemic (PA)</td>
<td>Yes [64]</td>
<td>No</td>
</tr>
<tr>
<td><em>A. cylindrocarpon</em> Müll. Arg. Syn. <em>A. brevifolia</em> Rusby [20, 26]</td>
<td>Peroba-iquíra, Peroba de Lagoa Santa, Peroba de Minas, Peroba rosa</td>
<td>Bolivia, Paraguai Peru, Brazil: Amazônia, Cerrado, Atlantic Rainforest</td>
<td>No</td>
<td>Yes See Table 2</td>
</tr>
<tr>
<td><em>A. discolor</em> A. DC. Accepted name Syn. <em>A. francisci</em> A. DC. [20, 26]</td>
<td>Cabo-de-machado, Quina, Carapanaúba-amarela, Pau-pereira, Peroba-de-rego, Peroba</td>
<td>Bolivia, French Guiana, Guyana, Peru, Suriname, Venezuela, Brazil: Amazonia, Caatinga, Cerrado, Atlantic Forest</td>
<td>Yes [17]</td>
<td>No</td>
</tr>
<tr>
<td><em>A. gomezeianum</em> A. DC. Accepted name [20, 24] Non-cons., syn. of <em>A. tomentosum</em> Mart. [25]</td>
<td>Peroba-amarela, Pequiá-de-pedra, Pau-cetim, Guatambu, Ipê-peroba</td>
<td>Brazil: NE (Bahia), SE/Minas Gerais, Espirito Santo, Rio de Janeiro</td>
<td>Yes [17, 28]</td>
<td>No</td>
</tr>
<tr>
<td><em>A. microcarpus</em> Benth. Accepted name Syn. <em>A. macrocarpus</em> Benth., <em>A. mexicanus</em> Dubey ex Huber ex Ducke, <em>A. guayusa</em> Müll. Arg. (+ 13 other syn.) [20, 26]</td>
<td>Carapanaúba, Carapanaúba-preta</td>
<td>Bolivia, Colômbia, French Guiana, Guyana, Ecuador, Panamá, Peru, Suriname, Venezuela</td>
<td>Yes [71]</td>
<td>Yes See Table 2</td>
</tr>
<tr>
<td><em>A. oblongum</em> A. DC. Accepted name Syn. <em>A. khulhonnii</em> Markgr. [26]</td>
<td>Carapanaúba, Carapanaúba-amarela</td>
<td>French Guiana, Guyana, Suriname, Venezuela, Brazil: Pará, Amazonas, Maranhão, Goiás</td>
<td>Yes [73]</td>
<td>Yes See Table 2</td>
</tr>
<tr>
<td><em>A. parvifolium</em> A. DC. Accepted name Syn. <em>A. ingratum</em> K. Schum., <em>A. vargasii</em> A. DC., <em>A. tambopatense</em> A. H. Gentry [20, 25, 26]</td>
<td>Pau-Pereira, Peru, Guatambú, Guatambú-marfim Amaralé</td>
<td>Argentina, Bolivia, Guyana, Paraguay, Peru, Venezuela, Brazil: Amazonia, Caatinga, Cerrado, Atlantic Rainforest</td>
<td>Yes [74]</td>
<td>Yes See Table 2</td>
</tr>
</tbody>
</table>

continued
A. pyrifolium Mart.  
Accepted name  
Syn. A. bicolor Mart. (+ several others) [26]  
Pereiro-do-sertão, Pereiro-preto, Pau-de-coam, Pequía-da-restinga  
Argentina, Bolivia, Paraguay, Brazil: Caatinga, Cerrado  
Yes  
Yes  
See Table 2

A. quebracho blanco Schidtl.  
Accepted name  
Syn. A. quebracho Griseb (+ several others) [26]  
Quebracho-branco (Brazil), Quebracho-blanco (Argentina)  
Argentina, Bolivia, Paraguay, Uruguay, Brazil: Mato Grosso  
Yes  
Yes  
See Table 2

A. ramiforum Müll. Arg.  
Accepted name  
Syn. Geissospermum ramiforum (Müll. Arg.) Miers [26]  
Pau-pereira, Peroba, Guatambuí-amarelo  
Bolivia, Brazil: Amazonia Cerrado, Atlantic Rainforest  
Yes  
Yes  
See Table 2

A. rigidum Rusby  
Accepted name  
Syn. A. acrenum Markg. (+ several others) [20, 26]  
Carapanaúba, Aracaranga  
Bolivia, Colombia, Costa Rica, Ecuador, Panamá, Peru, Venezuela [25], Brazil: Endemic (Amazonia, Cerrado) [24]  
Yes  
Yes  
See Table 2

A. sandwithii Markgr.  
Accepted name  
No synonyms [20, 26]  
Carapanaúba  
French Guiana, Guyana, Suriname, Brazil: Pará, Amazonas  
Yes  
No  
See Table 2

A. schultesii Woodson  
Accepted name  
No synonyms [20, 26]  
Maku  
French Guiana, Peru, Venezuela Brazil: Amazonas, Roraima, Mato Grosso  
Yes  
No  
See Table 2

A. spruceanum Benth. ex Müll. Arg.  
Accepted name  
Syn. A. ipapoanum Markgr., A. melanocalix Müll. Arg. (+ several others) [20, 26]  
Amargoso, Araracanga, Guatambu, Peroba, Quina da mata, Pequía marfim  
Bolivia, Colombia, Ecuador, French Guiana, Mexico, Panama, Peru, Venezuela, Brazil: Amazonia, Cerrado, Atlantic Rainforest  
Yes  
Yes  
See Table 2

A. tomentosum Mart  
Accepted name  
Syn. A. camporum Müll. Arg., A. dosycarpum A. DC. and others [20, 24, 26]  
Non-accepted name, syn. for A. gomezianum A. DC. fide Woodson, Jr. R.E., 1951 [25]  
Guatambú-do-cerrado, Pereiro-do-campo  
Bolivia, Paraguay, Brazil: Amazonia, Caatinga, Cerrado  
Yes  
No  
See Table 2

A. ulei Markg.  
Accepted name  
Syn. A. occidentale Markg. [20, 26]  
Pitã  
Guyana, Suriname, Venezuela, Brazil: Amazonia, Atlantic Forest  
Yes  
Yes  
See Table 2

A. vargiisi A. DC.  
Accepted name [25, 26]  
Non-accepted name, syn. for A. parvifolium A. DC. [20, 24]  
Amarelão  
Bolivia, Colombia, Guyana, Peru, Suriname, Venezuela  
Yes  
Yes  
See Table 2

1980, is highly valuable and can be appreciated in a 2007 review [29]. However, there are relatively few reports on the biological activities of these alkaloids [5, 30].

Of the 26 Aspidosperma species included in Table 1, 19 have had their crude extracts and/or alkaloidal extracts assayed for antimalarial activity. Detailed data are shown in Table 2. Evaluations were performed as early as 1932, and several experiments were conducted before the methodology for the P. falciparum erythrocyte culture became available [31]. These experiments include in vivo assays in ducklings infected with P. lophurae [32], in vitro assays with P. cathemerium [33], and clinical assays in humans [34, 35] (Table 2). Good activity (IC₅₀ < 10 μg/mL) has been reported for extracts from A. macrocarpon [28], A. megalo-
<table>
<thead>
<tr>
<th>Aspidosperma species</th>
<th>Country of collection</th>
<th>Part of the plant</th>
<th>Extracts</th>
<th>Compounds</th>
<th>Bioassay</th>
<th>Plasmodium species/strains</th>
<th>Results</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. cylindrocarpon</td>
<td>Brazil</td>
<td>Trunkwood</td>
<td>EtOH</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>W2: IC₅₀ = 44 µg/mL; 3D7: IC₅₀ = 39 µg/mL. Cytotoxicity Vero cells CC₅₀ &gt; 500 µg/mL. SI: W2 = 11.4; SI: 3D7 = 12.8</td>
<td></td>
<td>[27]</td>
</tr>
<tr>
<td>A. desmanthum</td>
<td>Brazil</td>
<td>Trunk bark</td>
<td>Aspidocarpine (2)</td>
<td></td>
<td>In vitro/P. falciparum K1</td>
<td>IC₅₀ = 0.019 µM (0.07 µg/mL)</td>
<td></td>
<td>[45]</td>
</tr>
<tr>
<td>A. excelsum</td>
<td>Peru (Remo caspi)</td>
<td>Trunk bark</td>
<td>EtOH</td>
<td>3D7</td>
<td>In vitro/P. falciparum</td>
<td>IC₅₀ = 42 µg/mL. SI human lymphocyte inhibition IC₅₀ &gt; 100 µg/mL</td>
<td></td>
<td>[39]</td>
</tr>
<tr>
<td>A. macrocarpon</td>
<td>Brazil</td>
<td>Root bark</td>
<td>EtOH</td>
<td>FcB1</td>
<td>In vitro/P. falciparum</td>
<td>FcB1: IC₅₀ = 4.9 µg/mL. Cytotoxicity MRC-5 CC₅₀ = 79.2 µg/mL. SI = 16.2</td>
<td></td>
<td>[28]</td>
</tr>
<tr>
<td>A. marcgravium</td>
<td>Guyane</td>
<td>Leaves</td>
<td>Tetrahydrousambaresine (175)</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>FcM29: 0.26 µg/mL (0.59 µM)</td>
<td></td>
<td>[32]</td>
</tr>
<tr>
<td>A. megalocarpon</td>
<td>Colombia</td>
<td>Trunk bark</td>
<td>MeOH</td>
<td>D2 and F32 strains</td>
<td>In vitro/P. falciparum</td>
<td>MeOH extract D2 strain: IC₅₀ = 8 µg/mL; F32 strain: IC₅₀ = 25 µg/mL. Cytotoxicity U-937 human promonocytic cells: CC₅₀ = 0.4 µg/mL. SI: Pf/D2 = 0.05; SI: Pf/F32 = 0.02</td>
<td></td>
<td>[36]</td>
</tr>
<tr>
<td>A. nitidum</td>
<td>Brazil</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>In vivo Duckling/P. lophurae</td>
<td>Inactive</td>
<td></td>
<td>[32, 80]</td>
</tr>
<tr>
<td>A. nitidum</td>
<td>Brazil</td>
<td>Trunk bark</td>
<td>H₂O extract</td>
<td></td>
<td>In vivo/P. berghei</td>
<td>Inactive</td>
<td></td>
<td>[44]</td>
</tr>
<tr>
<td>A. oblongum</td>
<td>Brazil</td>
<td>–</td>
<td>EtOH</td>
<td>W2 and D6</td>
<td>In vitro/P. falciparum</td>
<td>W2: IC₅₀ = 4742.5 ng/mL; D6: IC₅₀ = 847.4 ng/mL</td>
<td></td>
<td>[37]</td>
</tr>
<tr>
<td>A. olivaceum</td>
<td>Brazil</td>
<td>–</td>
<td>EtOH</td>
<td>Hexane-ACOEt</td>
<td>In vivo/P. berghei</td>
<td>Inactive</td>
<td></td>
<td>[67]</td>
</tr>
<tr>
<td>A. olivaceum</td>
<td>Brazil</td>
<td>Leaves, trunk wood, trunk bark</td>
<td>DCM and EtOH</td>
<td></td>
<td>In vivo/P. falciparum</td>
<td>W2: IC₅₀ = 5.0 to 7 µg/mL; 3D7: IC₅₀ = 5.0 to 25.5 µg/mL</td>
<td></td>
<td>[27]</td>
</tr>
<tr>
<td>A. olivaceum</td>
<td>Brazil</td>
<td>–</td>
<td>Olivicine (4)</td>
<td></td>
<td>In vivo/P. berghei</td>
<td>In vivo: active (50 mg/kg/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. parvifolium</td>
<td>Brazil</td>
<td>Trunk bark</td>
<td>EtOH extract, Uleine (3)</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>W2: IC₅₀ = 32.8 µg/mL; 3D7: IC₅₀ = 20.5 µg/mL. Uleine W2 and 3D7: IC₅₀ = 0.75 µg/mL (2.81 µM); 3D7: IC₅₀ = 11.90 µg/mL (32.69 µM)</td>
<td></td>
<td>[27]</td>
</tr>
<tr>
<td>A. polygonum</td>
<td>Brazil</td>
<td>Trunk bark</td>
<td>Total alkaloids</td>
<td></td>
<td>In vitro/P. cathemerum</td>
<td>Active</td>
<td></td>
<td>[33]</td>
</tr>
<tr>
<td>A. pyrifolium</td>
<td>Bolivia</td>
<td>Stem bark</td>
<td>ETOH-H₂O (7:3)</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>F32 strain FBIT</td>
<td>Inactive</td>
<td>[40, 81]</td>
</tr>
<tr>
<td>A. pyrifolium</td>
<td>Bolivia</td>
<td>Stem bark</td>
<td>Eight alkaloids</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>FcM29: IC₅₀ = 3.2 to 28.5 µM. Nigerian strain: IC₅₀ = 5.1 to 22.6 µM</td>
<td></td>
<td>[42]</td>
</tr>
<tr>
<td>A. quebracho-blanco</td>
<td>Argentina</td>
<td>Trunk bark</td>
<td>Total alkaloids</td>
<td>Human</td>
<td>Human</td>
<td>Active</td>
<td></td>
<td>[35, 80]</td>
</tr>
<tr>
<td>A. quebracho-blanco</td>
<td>Argentina</td>
<td>Trunk bark</td>
<td>EtOH</td>
<td>Human</td>
<td>Human</td>
<td>Inactive</td>
<td></td>
<td>[34, 80]</td>
</tr>
<tr>
<td>A. quebracho-blanco</td>
<td>Bolivia</td>
<td>Leaves, trunk bark</td>
<td>ETOH-H₂O (7:3)</td>
<td></td>
<td>In vitro/P. falciparum</td>
<td>F32 strain FBIT</td>
<td>Trunk bark extract F32: IC₅₀ = 3.9 µg/mL. FBIT: IC₅₀ = 1.22 mg/mL. Leaf extract: inactive</td>
<td></td>
</tr>
</tbody>
</table>

continued
of plant species for antimalarial screening. Negative results were described for in vivo assays of *A. nitidum* crude extracts [32, 44] (© Table 2). These results are surprising as *A. nitidum* is one of the most frequently cited *Aspidosperma* species of those used to treat malaria/fevers in Brazil. Therefore, this species deserves further investigation with a focus on the alkaloids.

Interestingly, a strong interest in *Aspidosperma* species has resumed in the past two decades, and several species whose phytochemistry was intensively investigated during 1960–1980 have been reexamined, leading to the isolation of several known indole alkaloids. Several of these alkaloids have been evaluated for various biological/pharmacological effects [30]. A total of 20 *Aspidosperma* alkaloids have been assayed for antimalarial activity and have been isolated by Brazilian researchers, one from *A. desmanthum* [45], one from *A. vargasii* [45], one from *A. parvifolium* [27, 46], five from *A. ulei* [47], and one from *A. olivaceum* [48]; additionally, a French-Bolivian group has evaluated 11 alkaloids from *A. megalocarpon* and *A. pyrifolium* [41].

**Table 2 Continued**

<table>
<thead>
<tr>
<th><em>Aspidosperma</em> species</th>
<th>Country of collection</th>
<th>Part of the plant</th>
<th>Extracts Compounds</th>
<th>Bioassay Plasmodium species/strains</th>
<th>Results</th>
<th>Citotoxicity murine macrophages:</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. ramiforum</em> Brazil</td>
<td>Leaves, trunk wood, trunk bark</td>
<td>DCM and EtOH</td>
<td><em>In vitro/P. falciparum</em> W2 and 3D7</td>
<td>IC50 = 19.7 to 36.5 µg/mL 3D7: IC50 = 1.0 to 48.0 µg/mL</td>
<td>[27]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. ramiforum</em> Brazil</td>
<td>– –</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><em>A. rigidum</em> Peru (Remo caspi)</td>
<td>Trunk bark</td>
<td>EtOH</td>
<td><em>In vitro/P. falciparum</em> 3D7</td>
<td>IC50 &lt; 10 µg/mL SI human lymphocyte inhibition 75%</td>
<td>[39]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. spruceanum</em> Brazil</td>
<td>Leaves, trunk wood, trunk bark</td>
<td>DCM and EtOH</td>
<td><em>In vitro/P. falciparum</em> W2 and 3D7</td>
<td>IC50 = &lt; 6.0 to 65.0 µg/mL 3D7: IC50 = &lt; 6.0 to 100 µg/mL</td>
<td>[27]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. tomentosum</em> Brazil</td>
<td>Leaves, trunk wood, seeds, fruits</td>
<td>EtOH</td>
<td><em>In vitro/P. falciparum</em> W2 and 3D7</td>
<td>IC50 = 20.5 to 26.5 µg/mL 3D7: IC50 = 3.0 to 38.5 µg/mL</td>
<td>[27]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. ulei</em> Brazil</td>
<td>Leaf, bark, trunk wood, root wood, root bark</td>
<td>Five alkaloids*</td>
<td><em>In vitro/P. falciparum</em> K1</td>
<td>K1: IC50 = 16.7 to &gt; 176.0 µM Citotoxicity NIH3T3 murine fibroblasts</td>
<td>[47]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. vargasii</em> Brazil</td>
<td>Trunk bark</td>
<td>Ellipticine (1)</td>
<td><em>In vitro/P. falciparum</em> K1</td>
<td>IC50 = 0.073 µM (0.018 µg/mL)</td>
<td>[45]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. vargasii</em> Brazil</td>
<td>Bark</td>
<td>Ellipticine (1)</td>
<td><em>In vitro/P. falciparum</em> 3D7 and K1</td>
<td>K1: IC50 = 0.81 µM 3D7: IC50 = 0.35 µM Citotoxicity murine macrophages: CC50 &gt; 4.1 × 102 µg/mL SI: K1 &gt; 5.0 × 104 3D7 &gt; 1.2 × 105</td>
<td>[48]</td>
<td></td>
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</table>

*Aspidosperminine (6), 10-methoxy-aspidosperminine (7), N-formil-aspidosperminine (8), vallesine (9), (+)- aspidospermine (10), demethoxyaspidosperminine (11), palosine (12), haplocine (13). * * 20-epi-dascarpine (3), 3,4,5,6-tetradehydro-B-yohimbine, 20(E)-nor-subincanadine E, 19E-hunteracine, 12-hydroxy-N-acetyl-21(N)-dehydroplumeran-18-oic acid*

Ellipticine (1) and aspidocarpine (2) (© Fig. 1) have been isolated from the trunk bark of *A. vargasii* and *A. desmanthum*, respectively. Both of these species have been collected at the Ducke Reserve in Manaus, Amazonas state, Brazil, and they have shown remarkable in vitro activity against the multidrug-resistant K1 strain of *P. falciparum* (IC50 = 73 nM and 19 nM, respectively) [45]. Ellipticine (1), a pyridocarbazol alkaloid, was originally isolated from *Ochrosia elliptica* (an Australian evergreen shrub) and occurs in other genera of the family Apocynaceae, such as *Aspidosperma* and *Bleekeria* [49–51]. Ellipticine (1) and several related synthetic derivatives are highly cytotoxic to human cancer cell lines, and elliptinium acetate (9-OH-NME, Celliptium®) is an antineoplastic agent currently used in the treatment of metastatic breast cancer [49–51]. Recently, ellipticine (1) and olivacine (5) (© Fig. 1) were assayed against *P. falciparum* strains K1 and 3D7. Olivacine disclosed lower in vitro antimalarial activity than ellipticine, and low cytoxicity for both agents was observed against murine macrophages. Ellipticine was also more active than olivacine in an evaluation of the effects in *P. berghei*-infected mice. Remarkably, 100% parasitemia suppression was observed at an oral dose of 50 mg/kg/day (four days), and no mortality or other signs of toxicity were reported [48]. Ellipticine (1) and its derivatives were described as the most active compounds, with IC50 values < 1 µg/mL (range 0.08 to 0.47 µg/mL), in a series of 184 randomly selected compounds belonging to several classes of natural products, either from plants or from marine organisms, or prepared as intermediates during the synthesis or semisynthesis of isolated products that were assayed against the *P. falciparum* FcM29 strain [52].

A total of 12 indole alkaloids were recently isolated from the EtOH extracts of various parts of *A. ulei* Markgr. Only five of these alkaloids were assayed for antimalarial activity against the multidrug-resistant K1 strain of *P. falciparum*. 20-Epi-dascarpidine (3) (© Fig. 1) showed moderate activity (IC50 4.5 µg/mL, 16.7 µM), whereas 3,4,5,6-tetrahydro-B-yohimbine, 19E-hunteracine, 20(E)-nor-subincanadine E, and 12-hydroxy-N-acetyl-21(N)-dehydroplumeran-18-oic acid were inactive. Two of the known alkaloids isolated, uleine and olivacine, have previously...
been shown to be active [46,48]. The compounds were evaluated against NIH3T3 murine fibroblasts and showed no cytotoxicity up to a concentration of 50 µg/mL [47].

Eleven known aspidospermane alkaloids (Fig. 2) were isolated from A. pyrifolium and A. megalocarpon, both collected in Bolivia [42,53] and both also occurring in Brazil [24–26]. Three of the active compounds, aspidospermine (6), 10-methoxy-aspidospermidine (7), and N-formyl-aspidospermine (8) (Fig. 2), were shown to be less cytotoxic to NIH 3 T3 cells (human fibroblasts), with calculated SI values of 22.7, 15.6, and 8.3, respectively [41]. The in vitro antimalarial activity of A. megalocarpon bark extract against D2 and F32 strains of P. falciparum has been reported; subsequently, a very low SI (< 1) was reported in relation to cytotoxicity assays in U-937 human promonocytic cells [36].

Uleine (4) (Fig. 1) was first isolated from A. ulei in 1959 [54,55]. It is frequently found in species, e.g., A. australis, A. dasycarpum, A. eburneum, A. excelsum, A. formosanum, A. gilbertii, A. gomezianum, A. multiflorum, A. nigricans, A. olivaceum, and A. parvifolium [29], as well as in other apocynaceous representatives such as Himathanthus lancifolius [56].

A recent phytochemical reinvestigation of A. parvifolium trunk bark afforded four known indole alkaloids, uleine (4) (Fig. 1), epi-uleine, apparicine, and N-demethyluleine [57]. A bioguided fractionation of the trunk bark alkaloidal fraction demonstrated the in vitro activity of uleine against chloroquine-resistant P. falciparum (W2), with an IC50 at the ng level, at least against the W2 clone (Table 2) [27,46]. The antimalarial activity of uleine (4), an aspidospermane indole alkaloid, may be related to the inhibition of heme polymerization to give hemozoin, as demonstrated by its in vivo effect in the food vacuole of chloroquine-resistant P. falciparum (W2 clone) monitored by confocal microscopy [46].

Uleine (4) (Fig. 1) has been evaluated for cytotoxicity against the NCI 60 cancer cell line panel and was inactive in all of them [58], reinforcing its high potential as a leading antimalarial compound.

In summary, crude extracts, alkaloidal extracts, and isolated alkaloids from 19 Aspidosperma species have been evaluated for antimalarial activity, and positive results have been observed for most of them. These results disclose the high potential of Aspidosperma species as sources of antimalarial alkaloids. A substantial literature search, approximately 1031 articles describes the antimalarial activity of plant extracts, but very few of these reports include the effect of pure constituents [14], a requirement for the development of new drugs. The development of new drugs is lengthy and extremely costly. However, if effective, safe, and locally produced phytomedicines are the goal, a more direct and less expensive route might certainly be pursued [5,59,60].

Conclusions

Our literature survey has identified 24 Aspidosperma species reported to be used to treat malaria/fevers. Of these, a total of 19 species have had extracts and/or isolated alkaloids evaluated for antimalarial activity by different assays, showing positive results. Only 20 of more than 200 known indole alkaloids from Aspidosperma species have been assayed for antimalarial activity, and variable levels of parasite inhibition have been observed. Among the assayed Aspidosperma alkaloids, uleine (4) (Fig. 1) appears the most promising as an antimalarial because it has shown good in vitro activity [27,46] and no cytotoxicity in several human cancer cell lines [58]. These findings have motivated a patent in Brazil [61]. However, recent results on the in vivo evaluation of ellipticine (1) (Fig. 1) appear to place this alkaloid in the leading position among natural antimalarials because it has, remarkably, shown 100% parasitemia suppression at an oral dose of 50 mg/kg/day and no signs of mortality or toxicity [48]. Our review also demonstrates a need for molecular genetic studies to facilitate the identification and the differentiation of Aspidosperma species and, therefore, to clarify the controversial question of synonyms. The high chemical diversity of alkaloids from Aspidosperma species and the small number of these alkaloids that have been as-
sayed for antimalarial activity coupled with the traditional use of several species of this taxon to treat malaria in Brazil as well as in other Meso- and South American countries make further investigations of the plants in this genus of great interest in the quest for natural antimalarial products. There is a need to isolate plant constituents to evaluate their pharmacological profile, to further pursue studies of synergistic effects, and to make these constituents available for use as markers in the standardization of extracts to be used in the development of effective, safe, and low-cost phytomedicines. These phytomedicines would then be available to Amazonian people, who inhabit the region where many of the *Aspidosperma* species occur and that have the highest incidence of malaria in Meso- and South America.

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**Conflict of Interest**

The authors declare that they do not have any conflict of interest in reference to the content of this article.

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Reviews


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