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Phenylpropanoids in species of plants of the *Duguetia* genus: A review

Fenilpropanoides em espécies de plantas do gênero *Duguetia*: Uma revisão

Fenilpropanoides en espécies vegetales del género *Duguetia*: Una revisión

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Abstract
The genus *Duguetia* encompasses 93 species, 63 of which are distributed in Brazil. However, only ten species had their chemical and biological profiles investigated so far. Although the alkaloids are the class of phytocompounds most studied, the interest in the phenylpropanoids is growing since distinct biological activities have been attributed to these derivatives lately. This review gathered studies describing the phytochemical distribution, methods of extraction, and biological activities of the phenylpropanoid from *Duguetia* species. It was evidenced that nonpolar solvents were able to provide the highest yield of 2,4,5-trimethoxystyrene, γ-asarone, and asaraldehyde which were mainly located at the ground stem barks. On the other hand, the α-asarone, elimicin, and (E)-methyl-isoeugenol were isolated from the polar extracts or the essential oils from the barks and leaves. The 2,4,5-trimethoxystyrene and asarone derivates were effective as crop protectors. The α- and γ-asarone, 2,4,5-trimethoxycinnamic acid, asaraldehyde, elemicin, and (E)-methyl-isoeugenol demonstrated anti-inflammatory, antidyslipidemic, antinociceptive, antibacterial, antidepressant, anxiolytic, insecticide, and larvicide activities. The *Duguetia* species can be a potential source of phenylpropanoids, therefore, future studies involving their extraction, identification, and application are still necessary and may culminate in the discovery of new drug candidates or natural agricultural defensives.
Keywords: *Duguetia*; Phenylpropanoids; Biological activity; Extraction.

Resumo
O gênero *Duguetia* abrange 93 espécies, das quais 63 estão distribuídas no Brasil. No entanto, apenas dez espécies tiveram seus perfis químicos e biológicos investigados até agora. Embora os alcaloides sejam a classe de fitocompostos mais estudada, o interesse pelos fenilpropanoides está crescendo, uma vez que atividades biológicas distintas têm sido atribuídas a esses derivados ultimamente. Esta revisão reuniu estudos descrevendo a distribuição fitoquímica, métodos de extração e atividades biológicas dos fenilpropanoides da espécie *Duguetia*. Foi evidenciado que os solventes não-polares foram capazes de fornecer o maior rendimento de 2,4,5 trimetoxiestireno, γ-asarona, e asaraldeído localizados, principalmentes, nas cascas do caule moído. Por outro lado, a α-asarona, elimicina e (E)-metil-isoeugenol foram isolados dos extratos polares ou dos óleos essenciais das cascas e folhas. Os derivados 2,4,5 trimetoxiestireno e asarona foram eficazes como protetores de cultivares. A α- e γ-asarona, ácido 2,4,5-trimetoxicinâmico, asaraldeído, elemicina e (E)-metil-isoeugenol demonstraram atividades antiinflamatória, antidislipidêmica, antinocceptiva, antibacteriana, antidepressivo, ansiolítica, inseticida e larvicida. Plantas do gênero *Duguetia* podem ser uma fonte potencial de fenilpropanoides portanto, estudos futuros envolvendo sua extração, identificação e aplicação ainda são necessários e podem culminar na descoberta de novos candidatos a medicamentos ou defensivos agrícolas
Palavras-chave: Duguetia; Fenilpropranóides; Atividade biológica; Extração.

Resumen
El género *Duguetia* compreende 93 especies, de las cuales 63 se distribuyen en Brasil. Sin embargo, hasta ahora solo se han investigado los perfiles químicos y biológicos de diez especies. Aunque los alcaloides son la classe de fitocompuestos más estudiada, el interés en los fenilpropanoides está creciendo, ya que últimamente se les han atribuído distintas actividades biológicas a estos derivados. Esta revisión reunió estudios que describen la distribuición fitoquímica, los métodos de extracción y las actividades biológicas del los fenilpropanoides de las especies *Duguetia*. Se evideció que los disolventes no polares fueron capaces de proporcionar el mayor rendimiento de 2,4,5-trimetoxiestireno, γ-asarona y asaraldehído ubicados principalmente en la corteza del tallo molido. Por otra parte, se aislaron α-asarona, elimicina y (E)-metil-isoeugenol a partir de extractos polares o aceites esenciales de corteza y hojas. Los derivados 2,4,5-trimetoxiestireno y asarona fueron efectivos como protetores de cultivares. A α- y γ-asarona, ácido 2,4,5-trimetoxicinámico, asaraldehído, elimicina y (E)-metil-isoeugenol demonstraron actividades antiinflamatorias, antidislipidémicas, antinociceptivas, antibacterianas, antidepressivas, ansiolíticas, insecticidas y larvicidas. Las plantas del género *Duguetia* pueden ser una fuente potencial de fenilpropanoides, por lo que aún son necessarios futuros estudios que involucren su extracción, identificación y aplicación y puedan culminar en el descubrimento de nuevos candidatos a fármacos o plaquicidas.
Palabras clave: *Duguetia*; Fenilpropranoides; Actividad biológica; Extracción.

1. Introduction

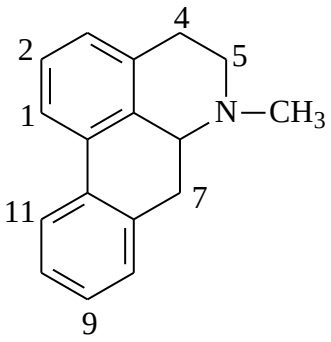
The *Annonaceae* are a family of dicotyledonous flowering plants from *Magnoliales* order. It is considered the Family with the largest taxon with 235 genera and 2,500 species (Chatrou et al., 2004; Simpson, 2010).

The genus *Duguetia* is the third largest genus of *Annonaceae* in the Neotropics, encompassing 93 species, 63 of which are distributed in Brazil, and 29 are endemic (Maas et al., 2003). These species are geographically distributed in North, Center-West, Southeast, and South of Brazil within the Amazon, Cerrado, Pantanal, Caatinga, and Atlantic Forest ecosystems. The individuals are further dispersed across Paraguay, Colombia, Suriname, Guianas, Bolivia, and Peru, although 4 species are exclusive from the West Coast of Africa (Almeida et al., 2010; Maas et al., 2003; Perez & Cassels, 2010).

Regarding the morphology, most of the *Duguetia* species consists of trees or shrubs recognized by the presence of star-like or peltate trichomes which differ from those of another genus of *Annonacea*e. The leaves are simple, entire, petiolate, and exstipulate presenting a distichous phyllotaxis. The inflorescences are bibracteated flourishing in the terminal ending of the bracts which are displayed in opposite sides of the stalk with the articulation of the upper bract located above the lower axis. In general, the inflorescences and leaves growth together and the former remain perennial even after the leaf's abscission. Yet, the flowers are actinomorphic, cyclic, trimerous, and bisexual while the fruits present varied diameters (1-15 cm) containing a basal ring-shaped structure composed of connate carpels known as collar (Maas et al., 2003; Mello-Silva et al., 2012; van Zuilen et al., 1995).

The most notorious phytochemical characteristic of the Neotropical species of Duguetia is the presence of alkaloids containing the isoquinoline skeleton, mainly, aporphinoids (Figure 1) or aporphinoid-related compounds frequently hydroxylated on C-7 and/or disubstituted on C-9 and C-11 such as the calcinine, spixianine, duguetin, and duguevalline (C. A Carollo et al., 2006; da Silva et al., 2007; de Souza et al., 2020; Debourges et al., 1987; Maas et al., 2003; Nardelli et al., 2021; Pérez et al., 2004; Perez & Cassels, 2010; Sousa et al., 2016; Valter et al., 2008). On the other hand, the 7-methoxy derivatives are more common in the African species (Perez & Cassels, 2010). The presence of non-aporphinoid alkaloids including berbinoids, aminoethylphenantrene subtypes, azaanthraquinones, and morphinandienones derivatives were also reported (Debourges et al., 1987; Maas et al., 2003; Perez & Cassels, 2010).

Figure 1. General chemical structure of aporphine.



Source: Drawn by the authors.

Other chemical constituents such as the lignans pachypolignan and bisnorlignan (Ngouonpe et al., 2019), β-sitosterol (C. A Carollo et al., 2006; T. C. B. Santos et al., 2019), phenylpropanoids (2,4,5-trimethoxiestyrene, asaraldehyde, asarone, and elimicin) (Alves et al., 2020; Alves et al., 2015; da Silva et al., 2007; de Sousa et al., 2020; Gonçalves et al., 2017; Koona & Bouda, 2004; Koona & Bouda, 2006; A. C. B. C. Rodrigues et al., 2015; Saldanha et al., 2019; T. C. B. Santos et al., 2019; Siqueira et al., 2001; Sousa et al., 2012; Z. W. Wang et al., 1988), monoterpenes (sabinene, β-phellandrene, and terpin-4-ol), sesquiterpenes (bicyclogermacren, germacren-D, ishwarane, (+)-spathulenol, β-bisabolene, elemicin, cyperene, and α-gurjunene) (Carollo et al., 2005; da Silva et al., 2007; Maia et al., 2006; A. C. B. C. Rodrigues et al., 2015; Saldanha et al., 2019; Valter et al., 2008), as well as glycosides of quercetin, kaempferol, and isorhamnetin flavonoids (Carollo et al., 2006; Pinho et al., 2016; Santos & Salatino, 2000) have been isolated from distinct parts or from the essential oils of Duguetia species (Almeida et al., 2010; Carollo et al., 2005; Maia et al., 2006; Rodrigues et al., 2015; Saldanha et al., 2019; Sousa et al., 2012; Sousa et al., 2016).

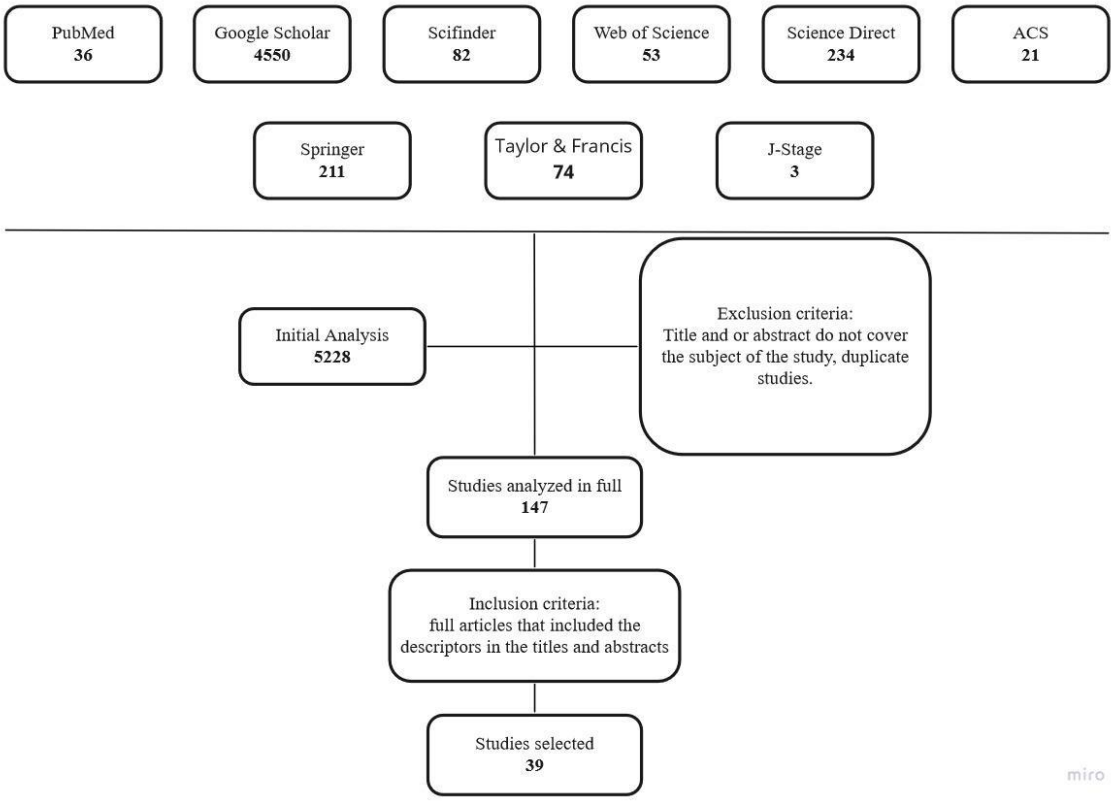
Until 2003, chemical constituents of only eight species of Duguetia had been characterized as described in an extensive review (Maas et al., 2003). According to the authors, the absence of more phytochemical information could be justified by the great homogeneity observed in their chemical composition and by the absence of significant biological activities. However, ethnopharmacology studies revealed the use of Duguetia species for the treatment of pediculosis (Correa, 1978; Silberbauer-Gottsberger, 1981), rheumatism (Perez & Cassels, 2010; V. E. G. Rodrigues & Carvalho, 2001), and malaria (Frausin et al., 2014; Pérez et al., 2004; Tsabang et al., 2012). Further investigations demonstrated their anti-inflammatory, healing, analgesic, antispasmodic, antimicrobial, antifungal, and larvicidal activities (Casagrande & Ferrari, 1970; de Souza et al., 2020; Fernandes et al., 2014; Muhammad et al., 2001; Pinho et al., 2016; A. M. S. Rodrigues et al., 2006; T. C. B. Santos et al., 2019; Sousa et al., 2012; Sousa et al., 2016). Standardized extracts and isolated compounds were also active against tumor cell lines (Castoldi et al., 2020; da Silva et al., 2009; Matos et al., 2006; Muhammad et al., 2001; A. C. B. C. Rodrigues et al., 2015), promastigote forms of Leishmania braziliensis (da Silva et al., 2009; Prates et al., 2020), and free radicals (Almeida, et al., 2011; Favareto et al., 2019).

Although, the majority of the biological activities initially investigated were attributed mainly to the alkaloids, additional attention has been devoted to the phenylpropanoid derivatives (Perez & Cassels, 2010). In an attempt to contribute with those dedicated to further investigate the phytochemical composition, the therapeutical, and the biological potential of these secondary metabolites from Duguetia genus, this review aimed for the first time to integrate the scientific data about the phenylpropanoids present in these species focusing on their extraction, identification, and biological activities.

2. Methodology

This review was conducted using the following databases: Google Scholar®, PubMed®, Scifinder®, Web of Science®, Science Direct®, ACS®, Springer®, Taylor-Francis®, and J-Stage®. We did not include temporal and language restrictions on the ethnopharmacological use, obtention of the extracts, isolation of the pure compound, and their biological activities. The search terms "*Duguetia*," or "*Duguetia* extract," or "*Duguetia* essential oil" or "*Duguetia* phenylpropanoids" or "*Duguetia* ethnopharmacology" or "Phenylpropanoids" were applied in order to refine the search. Potential full-texts of the eligible papers were identified and included according the title and abstract. Duplicate studies were excluded. The full texts of the selected papers from the year 1976 to 2021 were assessed and their relevant references were also checked for additional inclusion as presented in Figure 2. This search methodology was also conducted by others (Arora et al., 2013; Chellian et al., 2017; Geethangili & Ding, 2018). The papers selected for this review are presented in Table 1.

Figure 2. Flowchart of the review process.



Source: Authors.

Table 1. Distribution of the papers used in this review.

Topic	Selected references
Studies describing the extraction of the phenylpropanoids from *Duguetia* species	(Almeida et al., 2012; Almeida et al., 2007; Alves et al., 2020; Alves et al., 2015; da Silva et al., 2007; de Souza et al., 2020; Gonçalves et al., 2017; Gottlieb, Magalhães, Magalhães, Maia, & Marsaioli, 1978; Koona & Bouda, 2004; Koona & Bouda, 2006; Mathouet, Elomri, Lameiras, Daıch, & Vérité, 2007; Nahar & Sarker, 2006; A. C. B. C. Rodrigues et al., 2015; Saldanha et al., 2019; T. C. B. Santos et al., 2019; Siqueira et al., 2001; Sousa et al., 2012; Z. W. Wang et al., 1988; Waterman, 1976)
Studies demonstrating the insecticide and herbicide activities of the phenylpropanoids	(Alves et al., 2020; Alves, Machado, Campos, Oliveira, & Carvalho, 2016; Gonçalves et al., 2017; Koona & Bouda, 2004; Koona & Bouda, 2006; Liu, Zhou, Liu, & Du, 2013; Popławski et al., 2000; Ribeiro et al., 2016; Siqueira et al., 2001; Vidotto et al., 2013; Z. W. Wang et al., 1988)
Studies demonstrating the acaricide and larvicidal activity of the phenylpropanoids	(Alves et al., 2015; Bhardwaj et al., 2010; de Sousa et al., 2020; Pares et al., 2021; A. M. S. Rodrigues et al., 2006; Santana et al., 2015)
Studies demonstrating the anti-inflammatory and anti-nociceptive activities	(Saldanha et al., 2019; Saldanha et al., 2020; Saldanha et al., 2021; Sousa et al., 2008; Sousa et al., 2004)
Studies demonstrating the antitumoral, antimicrobial, antifungal, hypocholesterolemic, and axiolytic activities	(Almeida et al., 2010; Antunez-Solis et al., 2009; Castoldi et al., 2020; Fajemiroye et al., 2014; Fernandes et al., 2014; Pinho et al., 2016; A. C. B. C. Rodrigues et al., 2015; Sousa et al., 2012)
Studies used for the discussion	(Almeida, De Oliveira, et al., 2011; Bhardwaj et al., 2010; da Silva et al., 2009; dos Santos et al., 2018; Huang, Ho, & Kini, 1999; Ilijeva & Buchbauer, 2016; L. Korkina, Kostyuk, De Luca, & Pastore, 2011; Lee, Lee, Yun, & Hwang, 2004; Łozowicka & Kaczynski, 2013; Matos et al., 2006; Muhammad et al., 2001; Perez & Cassels, 2010; R. P. Rodrigues et al., 2020; Rossi et al., 2007; Silveira e Sá, Andrade, de Oliveira, & de Sousa, 2014; Sousa et al., 2016; Z. J. Wang et al., 2020)

Source: Authors.

3. Results and Discussion

3.1 Phenylpropanoids

Despite of being involved in flavonoid and lignin biosynthesis, the phenylpropanoids have adaptive and protective functions in plants including phytotoxic and insecticide activities (Ibrahim & Barron, 1989). Additional biological activities such as antimicrobial, anti-inflammatory, antioxidant, and antitumoral were also attributed to these secondary metabolites (Almeida, De Lima, et al., 2011; Favareto et al., 2019; Ilijeva & Buchbauer, 2016; L. Korkina et al., 2011; L. G. Korkina, 2007).

Chemically, the basic skeleton of the phenylpropanoids consists of an aromatic ring with a 3-carbons side chain as presented in table 1. The nature and position of the moieties linked to the benzene ring as well as the position of the double bond in the propyl side chain results in distinct biological activities (Deng & Shanfa, 2017).

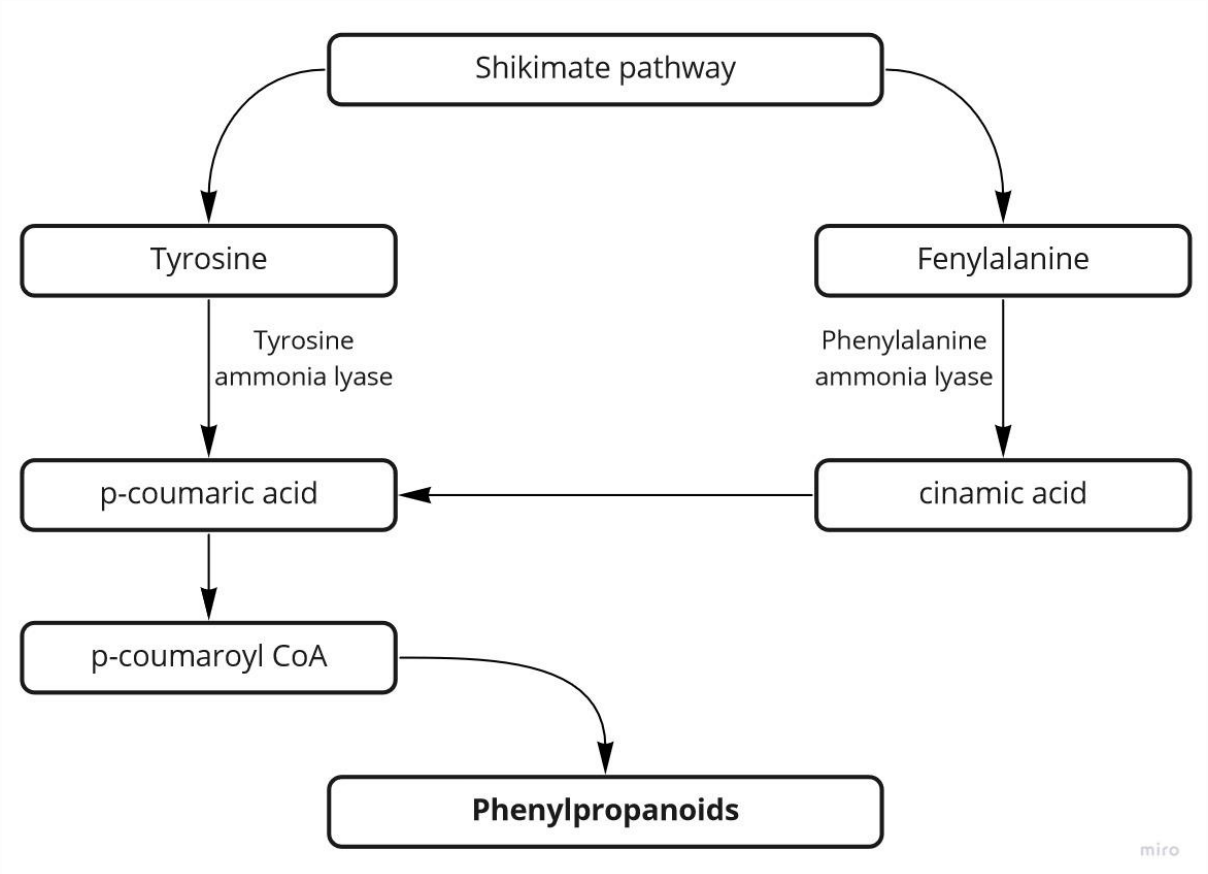
The phenylpropanoid pathway was precisely reviewed and discussed by others and it is beyond the scope of this study (Deng & Shanfa, 2017; Ibrahim & Barron, 1989; Singh et al., 2021; Vogt, 2010). Briefly, the initial biosynthesis reaction involves an enzymatic action of the phenylalanine ammonia-lyase or tyrosine ammonia-lyase on the amino acids L-phenylalanine or L-tyrosine, respectively (Ibrahim & Barron, 1989). These precursors are obtained through the shikimate pathway (Jensen, 1986). The biosynthesis of p-cumaroil-CoA is an important branching point that leads to the generation of

several phenylpropanoid compounds (Figure 2). The p-cumaroil-CoA may also suffer other specific ramifications to give rise flavonoids, stilbenes, monolignols, phenolic acids, and coumarins (Deng & Shanfa, 2017; Singh et al., 2021; Vogt, 2010)

3.2 Plant material, extraction, and yield

Ten specific phenylpropanoids were already isolated from Duguetia species. They were found in the stem barks, roots, fruits, and leaves of the Duguetia species (Table 1). Different approaches were initially applied to extract these secondary metabolites from the plant materials including alkaloid extraction procedures (Almeida et al., 2012), maceration with polar (ethanol, ethanol/water, and methanol) (Almeida et al., 2012; Almeida et al., 2007; Alves et al., 2020; Alves et al., 2015; Gonçalves et al., 2017; Santos et al., 2019; Siqueira et al., 2001; Wang et al., 1988) and non-polar (hexane, cyclohexane, dichloromethane, and petroleum ether) solvents (da Silva et al., 2007; de Sousa et al., 2020; Gottlieb et al., 1978; Koona & Bouda, 2004; Koona & Bouda, 2006; Mathouet et al., 2007; Nahar & Sarker, 2006; Waterman, 1976) solvents, as well as steam- or hydro-distillation to obtain the essential oils (da Silva et al., 2007; Rodrigues et al., 2015; Salazar, Salazar, Ulloa, Mendoza, & Chamoro, 1992; Sousa et al., 2012).

Figure 2. Schematic of phenylpropanoids phytochemical pathway.



Source: Adapted from Vogt, T. 2010 (Vogt, 2010).

Table 2. Phenylpropanoids found in *Duguetia* species.

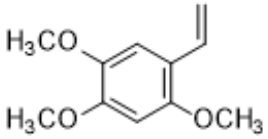
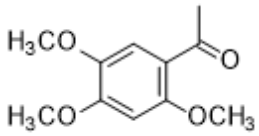
Compound	Chemical structure	Species	Extraction and plant material
2,4,5-trimethoxy-styrene		*Duguetia furfuracea*	- Essential oil obtained by steam-distillation of fresh barks from the underground stem during 5 h (Saldanha et al., 2019). - Essential oil obtained by hydro-distillation of fresh barks from the underground stem during 4 h (da Silva et al., 2007).
		Duguetia lanceolata	- Dichloromethane soluble fraction of a methanolic extract of dried stem barks (Alves et al., 2020; Alves et al., 2015). - Hexanic soluble fraction of an ethanolic extract of the leaves (dried powder) (Gonçalves et al., 2017).
		Duguetia pycnastera	- Hexanic extract of the dried ground barks (de Sousa et al., 2020).
		Duguetia panamensis	- Hexanic soluble fraction of an ethanolic extract of dried and pulverized barks (Z. W. Wang et al., 1988).
		Duguetia staudtii	- Hexanic extract of dried ground barks (Koona & Bouda, 2004; Koona & Bouda, 2006). - Soxhlet petroleum ether extract of dried ground root barks (Waterman, 1976).
		Duguetia eximia	- Hexanic extract of the trunk wood (Gottlieb et al., 1978).
2,4,5-trimethoxy-acetophenone		*Duguetia staudtii*	- Soxhlet dichloromethane extract of dried ground stem barks (Nahar & Sarker, 2006).

Table 2. Continued

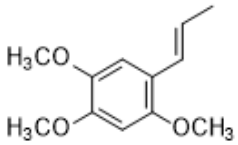
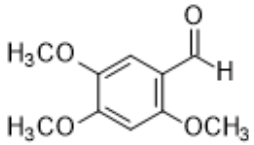
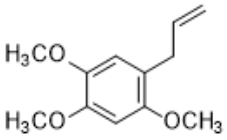
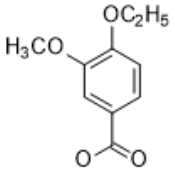
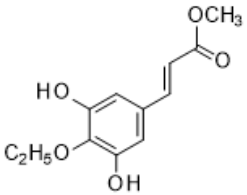
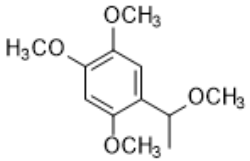
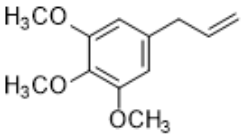
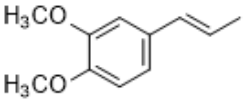
1,2,4-trimethoxy-5- [(E)-prop-1-enyl] benzene (α-asarone)		*Duguetia furfuracea*	- Essential oil (1.2%, *v.w*$^{-1}$) obtained by hydro-distillation (4 h) of fresh barks from the underground stem (da Silva et al., 2007). - Essential oil (0.5%, *v.w*$^{-1}$) obtained by steam-distillation (5 h) of fresh barks from the underground stem (Saldanha et al., 2019). - Hexane and dichloromethane soluble fractions of an hydroethanolic extract of dried and powdered roots (de Souza et al., 2020)
		Duguetia lanceolata	- Dichloromethane soluble fraction of the methanolic extract of dried stem barks (Alves et al., 2020; Alves et al., 2015). - Essential oils (0.5%, *v.w*$^{-1}$) obtained hydro-distillation during 2h and 4h of dried barks (Sousa et al., 2012).
2,4,5-trimethoxy-benzaldehyde (asaraldehyde)		*Duguetia furfuracea*	- Petroleum ether extract of the dried ground underground stem barks (da Silva et al., 2007). - Hexane soluble fraction of an hydroethanolic extract of dried and powdered roots (T. C. B. Santos et al., 2019).
		Duguetia glabriuscula	- Chloroform soluble fraction of an ethanolic extract of the stem barks (Siqueira et al., 2001).
		Duguetia staudtii	- Soxhlet dichloromethane extract of dried ground stem barks (Nahar & Sarker, 2006).
1,2,4-trimethoxy-5-prop-2-enyl benzene (γ-asarone)		*Duguetia pycnastera*	- Hexanic extract of the dried ground barks (de Souza et al., 2020).

Table 2. Continued

3-methoxy-4-ethoxy benzoic acid*		*Duguetia chrysocarpa*	-	Chloroform soluble fraction of an acidified (3% HCl) ethanolic extract of dried and pulverized fruits (Almeida et al., 2012).
methyl 3,5-dihydroxy-4-ethoxycinnamate*		*Duguetia gardneriana*	-	Ethyl ether soluble fraction of an acidified (3% HCl) ethanolic extract of dried and powdered stem barks (Almeida et al., 2007).
1,2,4-trimethoxy-5-(1-methoxy-ethyl)-benzene		*Duguetia confinis*	-	Dichloromethane extract of dried barks (Mathouet et al., 2007).
5-allyl-1,2,3-trimethoxybenzene (elemicin)		*Duguetia gardneriana*	-	Essential oil (0.13%, v.w^{-1}) obtained by hydro-distillation (3 h) of dried leaves (A. C. B. C. Rodrigues et al., 2015).
(E)-4-allyl-1,2 dimethoxybenzene ((E)-methyl-isoeugenol)		*Duguetia furfuracea*	-	Essential oil (1.2%, *v.*w^{-1}) obtained by hydro-distillation (4 h) of fresh barks from the underground stem (da Silva et al., 2007).

Source: Authors.

Among the phenylpropanoids derivatives, the 2,4,5-trimethoxystyrene was the most abundant compound (Waterman, 1976). According to the author, 500 g of ground root barks from D. staudtii were extracted by Soxhlet with petrol. The resultant extract was partially concentrated, filtrated, and re-crystallized with the same solvent to give 2.16 g of the phenylpropanoid (0.43%, w.w–1). Similar result (0.33%, w.w–1) was obtained using hexane to macerate the dried barks (600 g) from the same species during 6 hours (T. C. B. Santos et al., 2019). The maceration of the dried ground barks (635.8 g) of D. pycnastera with hexane (5 x 3 L) followed by silica gel column chromatography and further purification by conventional and preparative thin-layer chromatography (TLC), respectively, resulted in 693 mg of the 2,4,5-trimethoxystyrene (0.11%, w.w–1) and 206.8 mg of γ-asarone (0.03%, w.w–1) (de Souza et al., 2020). From the hexanic extract (6 g, 0.15%, w.w–1) of a trunk wood sample of D. eximia, it was obtained 11 mg of 2,4,5-trimethoxystyrene after silica gel chromatography and TLC procedures (Gottlieb et al., 1978). On the other hand, the methanolic extract of the dried stem barks of D. lanceolata (Alves et al., 2020) and the essential oil from the underground stem barks of D. furfuracea (da Silva et al., 2007) yielded 0.03 g of the compound per g of plant material. The 2,4,5-trimethoxystyrene was also reported to comprise 16.1% of the compounds eluted by GC/MS from essential oil resulted from fresh underground stem barks of D. furfuracea (T. C. B. Santos et al., 2019). Yet, the maceration of the leaves (1,059 g) of D. lanceolata with methanol (8 x 4 L, 24 h) followed by liquid-liquid partitioning of the extract with hexane provided only 0.008% (w.w–1) of the phenylpropanoid derivative (Gonçalves et al., 2017). Similarly, a chloroform soluble fraction of an ethanolic extract from the ground dried barks (58 g) of D. panamensis gave 24 mg (0.005%, w.w–1) of the compound (Z. W. Wang et al., 1988).

Regarding the asaraldehyde, the equivalent of 31.98 mg (0.021%, $w.w^{-1}$) was obtained after an exhaustive Soxhlet extraction with petroleum ether of the dried ground barks (155 g) of *D. furfuracea* (da Silva et al., 2007). Similarly, dried ground stem barks of *D. staudtii* (250 g) were Soxhlet-extracted with dichloromethane. The extract was further submitted to a solid-phase extraction (C18 cartridge) followed by a preparative reversed phase HPLC yielding 71.9 mg of asaraldehyde (0.03%, $w.w^{-1}$) and 39.2 mg of 2,4,5-trimethoxy-acetophenone (0.016%, $w.w^{-1}$) (Nahar & Sarker, 2006). In contrast, when a crude hydro-ethanolic extract (3 x 12 L, 7 days) of the dried powdered roots (3.04 kg) of *D. furfuracea* was subjected to silica gel column chromatography, 182.32 mg (0.006%, $w.w^{-1}$) of the phytocompound was obtained (T. C. B. Santos et al., 2019). This compound was also identified in the organic phase after the stem barks of *D. gabriuscula* had been subjected to maceration with ethanol 95% (40 ºC), followed by partition with methanol:water (9:1, v/v^{-1}) and chloroform, however, the authors did not report the yield (Siqueira et al., 2001).

The α-asarone was found in both essential oil and organic soluble fraction derived of polar extracts from the stem barks. After a CG/MS analysis of the essential oil from D. furfuracea, it was observed that this phenylpropanoid comprised 21.9% of total compounds (Saldanha et al., 2019). Further studies demonstrated that it was possible to isolate 160.2 mg of α-asarone corresponding to 4.45% (w.w–1) of the oil (da Silva et al., 2007). On the other hand, this compound represented only 1.9% of the composition of the essential oil from D. lanceolata. When a dichloromethane soluble fraction of a methanolic extract derived from the dried stem barks of D. lanceolata was investigated, two major peaks were observed after CG/MS analysis, which were referred as 2,4,5-trimethoxystyrene and α-asarone, respectively, but the authors were not able to quantify both compounds (Alves et al., 2015). The same group, however conducted additional purification studies of the extract and was able to obtain 452.2 mg of α-asarone from 1,059 g of dried stem barks of D. lanceolata (0.04%, w.w–1) (Alves et al., 2020).

Other phenylpropanoids derivatives were found in minor amount on distinct species of Duguetia. In this sense, 13 mg (0.001%, w.w–1) of 1,2,4-trimethoxy-5-(1-methoxy-ethyl)-benzene were obtained after the dried barks (968 g) of D. confinis had been successively extracted with dichloromethane (4 x 3L) and the resultant extract (17.14 g) chromatographed on silica

gel column (Mathouet et al., 2007). Among the compounds identified in the essential oil of the dried leaves of D. gardneriana the phenylpropanoid, elimicin comprised 8% of the total isolated compounds (A. C. B. C. Rodrigues et al., 2015). Whereas, 17.2 mg of (E)-methyl-isoeugenol, representing 0.48% of the eluted compounds were obtained from the essential oil of the underground stem barks of D. furfuracea (da Silva et al., 2007).

Although the compounds 3-methoxy-4-ethoxy benzoic acid and methyl 3,5-dihydroxy-4-ethoxycinnamate had been isolated from the ethanolic extracts derived from the dried fruits of D. *Duguetia chrysocarpa* (Almeida et al., 2012) and from the stem barks of *D. gardneriana* (Almeida et al., 2007), respectively, the authors were not able to inform the yield.

Therefore, according to the studies available so far it was possible to observe that the highest amounts of 2,4,5-trimethoxystyrene, γ-asarone, and asaraldehyde could be obtained from the ground stem barks when using organic solvents during the initial step of the extraction. On the other hand, the α-asarone, elimicin, and (E)-methyl-isoeugenol were isolated from the polar extracts or the essential oils.

3.3 Biological activities

Despite the biological activities of the phenylpropanoids had been systematically reviewed elsewhere (Ilijeva & Buchbauer, 2016; L. Korkina et al., 2011; Silveira e Sá et al., 2014), this current work was focused specifically in those derivatives obtained from the Duguetia species. In fact, the studies are complementary and reinforce the importance of this class of secondary metabolites as potential source of new drug candidates or prototypes for further chemical modifications

3.3.1 Insecticide and herbicide activities

The activities of a diet supplemented with dichloromethane soluble fractions derived from methanolic crude extracts of distinct parts of D. lanceolata against the caterpillars of the crop pest Spodoptera frugiperda were investigated (Alves et al., 2016). Only the fraction from the bark showed insecticidal activity with median values of lethal time and lethal concentration to 50% of the larvae equals to 61.4 h (LT50) and 946.5 □g.mL–1 of diet (LC50). The same group demonstrated that a dichloromethane soluble subfraction rich in 2,4,5-trimethoxystyrene (45.5%, w.w–1) and α-asarone (42.9%, w.w–1), produced a more pronounced killing effect with LC50 and LT50 values of 124 □g.mL–1 of diet and 38.5 h, respectively. Moreover, 100% of mortality was observed 96 h after the treatment (Alves et al., 2020). The discrepancy between the LC50 and LT50 values observed in both studies can be attributed to the fact that in the latter a more concentrated subfraction was used suggesting that the observed effect could be attributed to those phenylpropranoids. Moreover, when the pure compounds were investigated under the conditions previously described, the 2,4,5-trymethoxystyrene was more active than the α-asarone but no synergistic effect was verified (Alves et al., 2020).

Callosobruchus maculatus, Sitophilus zeamais, and Acanthoscelides obtectus are common pests responsible for serious damage in stored grains and cereals. When these insects were introduced in Petri dishes containing cowpea and maize grains pre-treated with 2,4,5-trimethoxystyrene extracted from D. staudtii at concentrations of 0.02, 0.04, 0.08, and 0.16% (w.w–1), it was observed 100% of mortality at all concentration levels. Such effect was time-dependent and occurred between 72 h and 168 h after the feeding (Koona & Bouda, 2004; Koona & Bouda, 2006). Additionally, an inhibition on the oviposition was verified even at the lowest dose. Similar result was observed against Zabrotes subfasciatus, a pest of stored beans and legume seeds (Gonçalves et al., 2017). In this case, when a hexanic partition rich in 2,4,5-trimethoxystyrene (101.1 mg per 11.2 g of the dried fraction; 0.9%, w.w–1), obtained from an ethanolic crude extract of the D. lanceolata leaves, was sprayed over the grains (1.5 g.kg–1), 98% of adult's mortality and a complete eradication of eggs were observed. These results were comparable to those obtained with a commercial insecticide based on deltamethrin (2 g.kg–1). A less pronounced effect against

S. zeamais was verified by Ribeiro and co-workers who demonstrated that a treatment of corn grains with an ethanolic crude extract prepared from the leaves of D. lanceolata (3 g.kg–1) produced only 37.5% of mortality after 10 days (Ribeiro et al., 2016). Th toxic effect of two essential oils obtained from the stem barks and the aerial parts of *D. furfuracea* against *Artemia saline*, revealed that only the oil derived from the barks was active (LC_{50}= 715.2 mg.mL^{-1}) (Vidotto et al., 2013). A fresh volatile oil and petroleum ether extract from the stem barks *D. furfuraceae* were even more active (LC_{50} = 2.6 and 6.1 μg.mL^{-1}, respectively) (da Silva et al., 2007). According to the authors, among the oil constituents were found 2,4,5-trimethoxystyrene (3.25%), α-asarone (4.45%), and (E)-methyl-isoeugenol (0.48%), whereas the asaraldehylde was found in the organic extract (0.25%). In fact, the compounds 2,4,5-trimethoxy-acetophenone and asaraldehyde isolated from *D. staudtii* stem barks were reported to be active against the shrimp, presenting LC_{50} values of 80.5 μg.mL^{-1} and 32.6 μg.mL^{-1}, respectively (Nahar & Sarker, 2006). A former study also demonstrated that the 2,4,5-trimethoxystyrene isolated from the barks of *D. panamensis* was active against the shrimp (LC_{50}= 8 μg.mL^{-1}) (Z. W. Wang et al., 1988). Conversely, no toxicity towards Brine shrimps was observed for the asaraldehyde isolated from *D. gabriuscula* (Siqueira et al., 2001). The reasons for such divergence are inconclusive but could be related to an erroneous identification of the isolated compound or due the test protocol used by the groups.

The isolated compounds (E)–methyl-isoeugenol and α-asarone were effective against Liposcelis bostrychophila. The latter compound presented contact toxicity (LC50= 125.73 μg.cm–2), while the (E)-methyl-isoeugenol presented toxicity by contact or when fumigated (LC50= 55.32 μg.cm–2 and 143.43 μg.L–1 of air, respectively) (Liu et al., 2013).

Based on the evidences already presented, the compounds responsible for the insecticidal effect are naturally lipophilic and are concentrated in the stem barks of the Duguetia species, therefore one can expect that fractions obtained using polar solvents and originated from the aerial parts of these plants will be less effective.

Although the phenylpropanoids seems to be promising for the development of new insecticides, further studies regarding their mechanism of action are still necessary. The effect seems to be species-dependent (Bhardwaj et al., 2010) and to be related to the inhibition of α-amylase (Huang et al., 1999), acetylcholinesterase, gluthathione-S-transferase, and carboxyesterase due the reaction with the enzymatic thiol moieties (Popławski et al., 2000). Moreover, the α-asarone and the 2,4,5-trymetoxystyrene were reported to present a strong antifeedant activity against larvae and adult forms of distinct insects (Alves et al., 2020; Łozowicka & Kaczynski, 2013; Popławski et al., 2000).

Regarding the phytotoxic activity of the phenylpropanoids, the 2,4,5-trimethoxybenzaldehyde and its chemically modified analogues were reported to inhibit the Auxin-binding protein (ABP-1), a molecular target growth regulators and commercial herbicides (R. P. Rodrigues et al., 2020).

3.3.2 Acaricide activity

The acaricidal activities of dichloromethane soluble fractions (10 mg.mL–1) derived from methanolic extracts of the leaves, berry fruits, and stem barks of D. lanceolata against adult's females of Tetranychus tumidus and T. urticae were compared (Alves et al., 2015). Again, only the stem bark fraction promoted a significant killing effect, which was 13-fold higher against T. urticae than T. tumidus after 72 h of contact (survival %: 4.5 ± 4.3 versus 59.0 ±7.4, respectively) (Alves et al., 2015). Moreover, the most abundant compounds found in the active fractions were the 2,4,5-trimethoxystyrene and α-asarone.

A lyophilized dichloromethane soluble fraction of methanolic crude extracts of D. lanceolata stem barks were tested against the poultry red mite Dermanyssus gallinae (Pares et al., 2021). After a topical application toxicity assay (444, 622, 888, 1244, and 1777 μg.cm–2), the calculated LT50 and LC50 values were 39 h and 707.2 μg.cm–2, respectively. The survival

probability of 0.47, representing 53% of mortality, was obtained for a concentration of 1,300 µg.cm–2. The acaricidal activities of the fractions investigated in both studies so far available seems to be species-dependent, however, further studies are still necessary to elucidate the mechanism of action and to establish the effective doses.

Therefore, for those investigating the potential biological activities of the phenylpropanoids from Duguetia species, studies involving the acaricidal effect of non-polar crude extracts from stem barks of Duguetia seem to be a promising topic.

3.3.3 Larvicidal activity

An hexanic extract of the root wood of D. furufuracea, presented a killing effect against the third-stage Aedes aegypt larvae (LC50 =56.5 µg.mL–1), whereas no effect was observed when testing those extracts obtained using ethanol or the aerial parts (A. M. S. Rodrigues et al., 2006). Recently, it was demonstrated that the α-asarone and 2,4,5-trimethoxystyrene extracted from the root bark of D. furfuracea contributes to such activity (de Sousa et al., 2020). According to the authors, the LC50 determined for α-asarone after 24 h, 48 h, and 72 h were 95.47 µg.mL–1, 93.90 µg.mL–1 and 84.45 µg.mL–1, respectively. A more potent effect was observed when associating α-asarone and 2,4,5-trimethylsstyrene (2:1) (LC50 = 67.3 µg.mL–1 after 24h).

Other constituents present in the Duguetia species may also contribute for the overall effect of the extract. Santana and co-workers demonstrated the larvicidal properties of the essential oils extracted from the leaves of three species of the genus Piper (Santana et al., 2015). The phenylpropanoids comprised 75% of the oils tested and among them, the (E)-methyl-isoeugenol was found in the highest amount (27.08%) and the elemicin at 7.82%. Both compounds are also present in plants of the Duguetia genus (da Silva et al., 2007; Rodrigues et al., 2015). In fact, a structure-activity relationship (SAR) study revealed that distinct natural phenylpropanoids and their semisynthetic derivatives were active against the larvae of the tobacco armyworm Spodoptera litura (Bhardwaj et al., 2010).

3.3.4 Anti-inflammatory and anti-nociceptive activities

The evidences that phenylpropanoids can reduce the inflammatory responses by acting in distinct inflammatory pathways were assembled in two previous reviews (L. Korkina et al., 2011; Silveira e Sá et al., 2014). In this sense, the therapeutic use of plants of the genus Duguetia for the treatment of inflammation would be of great value, specially for those individuals living the remote areas of the Amazon Forest and Africa where the access to conventional medicines is restricted.

A pre-clinical study investigated the anti-inflammatory and antinociceptive effects following the oral administration of the essential oil obtained from the bark of the underground stem of D. furfuracea to mice (Saldanha et al., 2019). According to the authors, besides the sesquiterpenes, the essential oil contained 38% of phenylpropanoid derivatives and the main compounds were α-asarone (21.9%), bicyclogermacrene (16.7%), 2,4,5-trimethoxystyrene (16.1%), α-gurjinene (15%), cyperene (7.8%), and (E)-caryophyllene (4.6%). The oil (1, 3, and 10 mg.kg–1) inhibited the paw oedema induced by lipopolysaccharide (LPS) in a dose-dependent manner for 6 h. The dose of 10 mg.kg–1 inhibited the production of tumor necrosis factor alpha (TNF-α), the recruitment of polymorphonuclear leukocytes, and the inducible nitric oxide synthase (iNOS) expression in the paw tissue. Significant analgesia was also observed during the formalin and hot-plate tests for the doses of 10 and 30 mg.kg–1. In part, these effects could be attributed to the presence of the α-asarone, since in a complementary study, its oral administration to mice (3 and 10 mg.kg–1) promoted similar results. In addition, the adenosinergic and opioidergic systems was suggested to be involved in the central and peripheral anti-nociceptive effects of α-asarone (Saldanha et al., 2020). A more recent but similar study from the same group employed a phenylpropanoid-enriched fraction of the essential oil from the D. furfuracea containing 36.4% of α-asarone and 27.8% of 2,4,5-trimethoxystyrene in

addition to bicyclogermacrene (11.1%), α-gurjunene (10.5%), cyperene (5.8%), and (E)-caryophyllene (3.3%) (Saldanha et al., 2021). When comparing the results after the administration of 3 mg.kg–1 of the enriched-phenylpropanoid fraction and the ordinary oil, no difference was observed on their anti-nociceptive effects. On the other hand, the former resulted in a more pronounced reduction of the paw oedema after 2 h and 4 h of intake than the latter (2 h: 90.9% versus 41.7% of inhibition; 4 h: 77.8% versus 63.6%. respectively) (Saldanha et al., 2019; Saldanha et al., 2021). Although these results suggest the phenylpropanoids (α-asarone and 2,4,5-trimethoxystyrene) may have contributed to the anti-inflammatory effects of essential oil, the involvement of the additional phytocompounds cannot be excluded. In fact, a methanolic extract of D. furfuracea leaves, its fractions, and the isolated alkaloid dicentrinone, were able reduce significantly the paw oedema and leukocyte migration induced by carrageenan in mice (dos Santos et al., 2018).

Another species which the anti-inflammatory and anti-nociceptive activities were investigated was the D. lanceolata. The essential oil from the stem barks was given intraperitonially (i.p.) to mice at distinct doses and the inhibitory effects on the carrageenan-induced paw oedema, on the number of acetic acid-induced writhing, and the time of paw licking promoted by formalin were evaluated (Sousa et al., 2004). The essential oil reduced significantly the paw oedema in a dose dependent way after 4 h of its administration (50 mg.kg–1: 20.8%, 100 mg.kg–1: 36.5%, and 200 mg.kg–1: 49.0% of inhibition) when compared to the control group. The effective doses able to reduce in 50% the number of writhing and the time of licking on the first and second phases were 21.8 mg.kg–1 (95% CI: 16.7 - 28.0), 5.3 mg.kg–1 (95% CI: 3.6 - 7.7), and 1.4 mg.kg–1 (95% CI: 0.9 - 2.3), respectively. Similar study was conducted following the oral administration of an ethanolic extract obtained from the leaves of D. lanceolata (Sousa et al., 2008). The extract reduced significantly the paw oedema (50 mg.kg–1: 22.6%, 100 mg.kg–1: 32.3%, and 200 mg.kg–1: 40.3% of inhibition) when compared to the control group. This result is comparable to that observed after the i.p. administration of the essential oil, suggesting that the oral pathway may be a promising route of administration, however, further studies using the same type of preparation are still necessary to evaluate the bioavailability and efficacy. In fact, despite the extract had reduced the number of abdominal contortions significantly when compared with control group, this effect was less effective of that using the essential oil (10 mg.kg–1= 11.4% versus 25%, 50 mg.kg–1= 17.5% versus 50%, 100 mg.kg–1= 37.5% versus 87%, 200 mg.kg–1= 48% versus 100% of inhibition, respectively) (Sousa et al., 2008; Sousa et al., 2004). Doses of the extract from 50 to 200 mg.kg–1 were able to reduce approximately 11% to 83% the time that the animals spent licking the paw and to increment the time that they support the hot plate test from 37% to 102% when compared to the control groups (Sousa et al., 2008). Although these results suggest that D. lanceolata is a potential source of substances with anti-nociceptive and anti-inflammatory properties, the authors did not evaluate the phytochemical composition of the extract. Further studies, suggested that besides the phenylpropanoids, the sesquiterpene (E)-caryophyllene found as a major component in the essential oil of D. lanceolata branches and the alkaloid discretamine, present in the methanolic extract of D. moricandiana fruits can also exert anti-inflammatory and anti-nociceptive activities (Almeida, De Lima, et al., 2011; Sousa et al., 2016).

The investigations regarding the anti-inflammatory and anti-nociceptive activities of Duguetia species were restricted to animals but the results were promising, highlighting the need of further studies not only to discriminate the phytocompounds responsible for the therapeutical effects but also to evaluate their efficacy and safety.

3.3.5 Antitumoral, antimicrobial, and antifungal activities

The essential oil of D. gardneriana leaves was effective against the cell lines B16-F10, HepG2, HL-60, and K562. The concentrations capable of inhibiting 50% of cell growth (IC50) were 16.89 µg.mL–1, 19.16 µg.mL–1, 13.08 µg.mL–1, and 19.33 µg.mL–1, respectively (A. C. B. C. Rodrigues et al., 2015). The in vivo studies conducted by the same authors revealed

that i.p. doses of 40 and 80 mg.kg–1.day–1 given during nine days inhibited 5.37% and 37.52% the tumor growth, respectively, whereas the reduction promoted by the administration of 5-fluoracil (25 mg.kg–1.day–1) was 43.11%. The essential oil investigated was composed predominantly by sesquiterpenes and phenylpropanoid (β-bisabolene: 81%, elemicin: 8.04%, germacrene D: 4.2%, and cyperene: 2.82%), however, the treatment of the cell lines with the major component (β-bisabolene) was not effective (IC50 > 25 μg.mL–1). The other compounds were not individually tested by the authors.

An in vitro cytotoxicity study revealed that an acetogenin-rich extract from Duguetia sp. leaves was active against Ehrlich tumor cells (Castoldi et al., 2020). The percentage of cell viability was reduced by 16% and the number of dead cells increased two-fold independently of the concentration of extract (0.34 mg.mL–1; 0.67 mg.mL–1, and 1.35 mg.mL–1). Unfortunately, the authors did not perform the chemical characterization of the extract. Although the alkaloids have been suggested as the major phytocompounds responsible for the antitumoral activity of the extract from Duguetia species (da Silva et al., 2009; Muhammad et al., 2001; Perez & Cassels, 2010), other components such as β-sitosterol isolated from D. glabriuscula presented a potent activity (IC50= 4.7 μg.mL–1) against human larynx carcinoma cell line (HEp-2) (Matos et al., 2006). Therefore, further studies are still needed to elucidate the contribution of the phenylpropanoids for the anti-neoplastic effects of plants from the genus Duguetia, as well as their mechanism of action.The essential oils of *D. lanceolata* barks collected by hydrodistillation for 2 h (T2) and 4 h (T4) at 100 ºC were reported to inhibit the growth of *Staphylococcus aureus* (MIC_{T2}= 20 μg.mL^{-1}, MIC_{T4}= *125* μg.mL^{-1}), *Streptococcus pyogenes* (MIC_{T2}= μg.mL^{-1}, MIC_{T4}= *40* μg.mL^{-1}), and *Candida albicans* (MIC_{T2}= 60 μg.mL^{-1}, MIC_{T4}= *120* μg.mL^{-1}) (Sousa et al., 2012). According to the authors, only one phenylpropanoid (α-asarone) was detected in the essential oils and the antimicrobial/antifungal activities were attributed mainly to the presence of mono- and sesquiterpenes. Additional study using the essential oils of *D. gardneriana* and *D. moricandiana* leaves demonstrated that they were equally effective against *Staphylococcus aureus* (*MIC*= 12 μg.mL^{-1}) and *C. guillermondii* (MIC_{T4}= *10* μg.mL^{-1}), whereas the latter was also active against *C. albicans* (*MIC*= 12 μg.mL^{-1}) (Almeida et al., 2010). Again, these activities were attributed to the presence of terpenes found in the essential oils. Conversely, solutions of the crude ethanolic extract of *D. furfuracea* leaves and its hexane, ethyl acetate, and methanol fractions did not demonstrate clinical relevance against strains of *Escherichia. coli*, *Pseudomonas. aeruginosa*, *Staphylococcus. aureus*, and *klebsiella pneumoniae* (*MIC*> 1,024 μg.mL^{-1}) (Fernandes et al., 2014). Similar results were found when investigating the antifungal activity of the extract and fractions against standard strains *C. albicans*, *C. tropicalis*, and *C. krusei* (Pinho et al., 2016).

Despite the studies so far available did not correlated the antimicrobial and antifungal activities to the presence of the phenylpropanoids, it is currently known that the phytocompounds such as α- and β-asarone, asaraldehyde, *(E)*-methyl-isoeugenol, and elemicin, already found in the *Duguetia* species, are effective against distinct strains of bacteria and fungi (Ilijeva & Buchbauer, 2016; Lee et al., 2004; Rossi et al., 2007; Wang et al., 2020).

3.3.6 Other pharmacological activities

Studies involving the evaluation of the effect of α-asarone and 2,4,5-trimethoxycinnamic acid on the activity of the enzyme HMG-CoA reductase in Wistar rats revealed that both were able to inhibit enzymatic activity in 50% at concentrations of 3 mM and 60 mM, respectively (Antunez-Solis et al., 2009). Yet, according to the authors, the higher potency of α-asarone may be associated with its greater hydrophobicity and better interaction with the enzyme. On the other hand, it has been suggested that 2,4,5-trimethoxycinnamic acid is a better choice for the next studies in the search for hypocholesterolemic and cholelitholytic agents, due to the higher toxicity of α-asarone. Finally, it is worth mentioning the action of (E)-methyl-isoeugenol in the central nervous system. Behavioral studies in male Swiss mice involving pentylenetetrazole-induced seizure test, dark and light box test, elevated cross maze test, wire suspension, exploratory activity, and forced swimming test revealed

that, although the anticonvulsant activity had not been demonstrated, the phytocompound promoted a sedative effect when administered at a dose of 500 mg.kg–1, as well as anxiolytic and antidepressant effects at doses between 125 and 500 mg.kg–1 (Fajemiroye et al., 2014). This compound was isolated from extracts of the stem of D. furfuracea (da Silva et al., 2007).

Therefore, it is evident the capacity of the phenylpropanoid derivatives to modulate distinct biological activities, evidencing the application of these phytocompounds in the treatment of diseases, as well as, in the control of pests and vectors. We expect that this work can contribute to those interested in further explore the therapeutic and commercial potential of the distinct species of the Duguetia.

4. Conclusion

This review brought together several studies involving the extraction, biological, and pharmacological activities of phenylpropanoid derivatives already isolated from plants of the genus Duguetia. It was evidenced that nonpolar solvents were able to provide the highest yield of 2,4,5-trimethoxystyrene, γ-asarone, and asaraldehyde which were mainly located at the ground stem barks of the plants investigated so far. On the other hand, the α-asarone, elimicin, and (E)-methyl-isoeugenol were isolated from the polar extracts or the essential oils. Such compounds were reported to have distinct biological activities, therefore, future studies investigating additional species of Duguetia and the activities of the phenylpropanoids is a promising topic and may result in prototypes for the development of new compounds with potential applications in both human health and agriculture.

In fact, our research group is current investigating the pharmacokinetic and biopharmaceutic characteristics of the asaraldehyde and α-asarone extracted from Duguetia species as part of the efforts to explore the therapeutic applicability of these compounds.Conflicts of interest statement

The authors declare there are no conflict of interests.

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