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Revisión / Review

Bauhinia Linnaeus: an overview of the chemistry and bioactivity of essential oils

[*Bauhinia* Linnaeus: una descripción general de la química y bioactividad de los aceites esenciales]

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Section Review

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Abstract: *Bauhinia* genus comprises 300 diferent species distributed in tropical and subtropical forests. Infusions of some species have been frequently used in folk medicine to treat several ailments, especially diabetes. Studies are focused on the extracts and little is reported about their essential oils. This review aims to compile data about the chemical composition and biological activities of essential oils from diferent species of the genus *Bauhinia*, in order to show the potential of these oils, since they have a rich composition in terpenoids, with emphasis on sesquiterpenes and diterpenes, which have a broad spectrum of biological actions and can be explored in various application areas.

Keywords: *Bauhinia*; Essential oils; Chemical composition; Terpenes; Biological activity

Resumen: El género *Bauhinia* comprende 300 especies diferentes distribuidas en bosques tropicales y subtropicales. Las infusiones de algunas especies se han utilizado con frecuencia en la medicina popular para tratar varias dolencias, especialmente la diabetes. Los estudios se centran en los extractos y se informa poco sobre sus aceites esenciales. Esta revisión tiene como objetivo recopilar datos sobre la composición química y actividades biológicas de los aceites esenciales de diferentes especies del género *Bauhinia*, con el fin de mostrar el potencial de estos aceites, ya que tienen una composición rica en terpenoides, con énfasis en sesquiterpenos y diterpenos, que tienen un amplio espectro de acciones biológicas y pueden explorarse en diversas áreas de aplicación.

Palabras clave: *Bauhinia*; Aceites esenciales; Composición química; Terpenos; Actividad biológica.

INTRODUCTION

Bauhinia is a genus named by Carolus Linnaeus, in 1753, in honor of Jean Bauhin (1541-1613) and Gaspard Bauhin (1550-1624) Swiss doctors and botanists (Quattrocchi, 2012). It is comprised of 300 species widely distributed in tropical and subtropical forests, 64 of which can be found in Brazil. Such species belong to the subfamily Caesapinoideae and to the Fabaceae family (Vaz & Tozzi, 2005).

Widely used by the Brazilian population for the prevention and treatment of diabetes, plants of the genus *Bauhinia* Linnaeus are popularly known as cow's hoof or ox-claw because of the shape of their bilobed leaves, and they may present arboreal, shrub or climbing plants. In recent years, interest in plants of the genus Bauhinia has increased considerably around the world, since experimental studies have confirmed ethnopharmacological observations. Most species are of Asian origin, but there are species native to Brazil such as *Bauhinia longifolia* and *Bauhinia forficata* (López & Santos, 2015).

Traditionally, there is widespread use of *Bauhinia forficata* Link, which presents white flowers with linear petals. The first pharmacological trial of this species dated back to the beginning of the 20th century, and the findings by Carmela Juliani in 1929 (Juliani, 1941) had already pointed to its hypoglycemic properties. However, in the Cerrado and Amazon regions, folk medicine has also recorded the use of *Bauhinia rufa* Steud. *Bauhinia variegata* L., in turn, is widely employed in Brazil in urban afforestation, mainly in the south and southeast regions, owing to its ornamental potential and frost tolerance (Lorenzi *et al.*, 2003), and the same occurs with *Bauhinia tormentosa* L. and *Bauhinia purpurea* L. However, recent studies have shown that some species, so far considered to be ornamental plants only, e.g., *B. tomentosa* and *B. purpurea*, can present potentially medicinal compounds with antimicrobial activity (Chandrashekar & Kumar, 2011; Gopalakrishnan & Vadivel, 2011).

The scientific literature that addresses the chemical composition and the therapeutic potential of *Bauhinia* species focuses on their organic extracts, with a prevalence of alcoholic and hydroalcoholic extracts, obtained from different parts of the plant, such as leaves, stems, barks or flowers. Free and glycosylated flavonoids are characteristic of the Leguminosae family and possess large occurrence on the *Bauhinia* genus. Quercetin 3-O-α-rhamnoside, kaempferol 3-O-α-rhamnoside, quercetin 3-O-α-arabinoside, quercetin 3-O-α-(2″-galloyl)rhamnoside, kaempferol 3-O-α-(2″-galloyl)rhamnoside, kaempferol 3,7-dirhamnoside (kaempferitrin), Quercetin 3—(2-rhamnosyl)rutinoside are some examples (Santos *et al.*, 2019). Alkaloids are rarely encountered on this genus and only few compounds have been reported so far. Some examples are trigonellin in *Bauhinia candicans* (Iribarren & Pomilio, 1983) and the carbazols mahainbine, bicycloamhanimbine and girinimbine in *Bauhinia variegata* (Zhao *et al.*, 2005)

The results support, for most species, the therapeutic properties of leaf extracts, indicating that they are mainly due to the presence of flavonoids (Paula *et al*., 2002; Pizzolatti *et al*., 2003; Ferreres *et al*., 2012). Such flavonoids in the extracts of plants may also be important for prevention and treatment of diseases which cause an increase in oxidative activity (Salgueiro et al., 2016). Increasing experimental and clinical evidence suggests that oxidative stress can be the pathogenesis of diabetes. Increase of free radicals and the concomitant mitigation of antioxidants lead to increase in lipid peroxidation, development of insulin resistance and damage to cellular organelles and enzymes, which can result in diabetes mellitus complications (Chatterjee et al., 2007; Lyons & Jenkis, 1997).

More recent hypotheses about possible mechanisms of flavonoids have been postulated, including the influence of the interaction of these polyphenols and gut microbiota and the possibility that flavonoids or their metabolites could modify gene expression or act as potential modulators of intracellular signaling cascades (González-Paramás *et al*., 2019)

Among all therapeutic activities presented by the genus *Bauhinia*, hypoglycemic action is the most commonly reported in the literature. Lino *et al.* (2004) evaluated aqueous, ethanolic and hexane extracts of *B. forficata* in a model of alloxan-induced diabetes in rats and found a decrease in the levels of glucose, triglycerides, total cholesterol and LDL, validating the clinical use of this plant for the treatment of type II diabetes mellitus. Similarly, Menezes *et al.* (2007) reported that aqueous extracts obtained from *B. monandra* and *B. forficata* exhibited hypoglycemic activity when evaluated in normoglycemic rats, suggesting that this action may be related to the presence of glycosylated flavonoids.

The composition of polar fractions extracted from *Bauhinia* species are well described in the literature, however, when it comes to the volatile fraction of the plant, that is, their essential oils, data are scarce and controversial. It may be related to the fact that volatile terpenoids, when compared with other classes of secondary metabolites present less taxonomic utility in angiosperms and show irregular occurrence patterns. (Duarte-Almeida, 2004)

Essential oils have been known since antiquity for their biological activity, including antibacterial, antifungal, antiviral and anti-inflammatory effects. In this way, spices and herbs have been suggested to have healing or disinfecting properties. These oils can also be active against higher organisms such as nematodes, helminths, insects, etc. (Joshi *et al*., 2011).

Volatile terpenoids, namely monoterpenes and sesquiterpenes, are major components of volatile oils; in comparison with other classes of secondary metabolites (for example, flavonoids), terpenes have had less taxonomic utility in angiosperms, showing irregular occurrence patterns (Duarte–Almeida, 2004). However, several sesquiterpenes present pleasant and commercial characteristics, and they are recognized for their potential as an aromatic compound. This interesting class of compounds has also been studied in the last years for their biological potential (Néri-Numa *et al.*, 2019).

A high degree of polymorphism in the genus *Bauhinia* determines a large number of subspecies, different varieties and forms, producing essential oils with varied chemical composition, and offering variable level of potential applications (Vaz, 2013). There are few reports in the literature about the chemical composition of essential oils from plants of the genus *Bauhinia*. Essential oils extracted from *Bauhinia* plants, despite presenting low yields, have been reported to possess interesting biological properties. The larvicidal activity of *B. cheilanta, B. pulchella* Benth and *B. ungulata* L. has been recently reported, as well as its cytotoxic potential on lung carcinoma, breast and cervical adenocarcinoma human tumor cells (Silva *et al.*, 2020; De Sousa *et al.*, 2016).

This systematic review aims to provide an overview of the chemical composition and biological activity of essential oils of various species of the genus *Bauhinia*, focusing on available literature data at the last twenty years.

LITERATURE REVIEW

Strategy for study selection

The titles and abstracts were thoroughly studied, and the articles relevant to the research questions (1 - Which are the chemical profiles of the essential oils of the *Bauhinia* plants? 2 - Which are the bioactive properties associated with these essential oils?) were collected and cross-verified by one of the coauthors. Independent reviewers resolved any disagreement about a study as per the inclusion and exclusion criteria as below.

Inclusion criteria

Literature reporting the chemical characterization and bioactive properties of the essential oils (volatile fraction) of plants of the genus *Bauhinia*. This bibliographic review included full texts available in English, Spanish and/ or Portuguese, with paid and/or free access.

Exclusion criteria

Literature reporting the chemical characterization and bioactive properties of the non-volatile fraction of *Bauhinia* plants was excluded from the study. For instance, studies dealing with infusions and hydroalcoholic extracts containing phenolic compounds (like flavonoids) were not included. Furthermore, published theses were not used as resources to collect information.

Databases and resources utilized

Searches were carried out in the following databases: Google Scholar, Periódicos CAPES, Scielo, Science Direct and Pubmed. Furthermore, books were used as resources to collect information.

Keywords searched

"*Bauhinia*", "essential oil", "volatile fraction", "chemical composition", combined in pairs using the Boolean operator "and".

Time period

The literature of the last twenty years was searched; the data was collected and kept updated starting on December 2000 till September 2021.

Articles found

Fourteen papers met the inclusion criteria, describing specifically the chemical composition of essential oils of species of the genus *Bauhinia*, comprising a total of seventeen different species. Among the fourteen selected articles, six of them showed some biological activities for oils. Table No. 1 shows details about the main variables evaluated in each work used in this review.

Chemical composition

Essential oils have been rarely described in the Leguminosae family, except for the genus *Bauhinia* (Duarte-Almeida, 2004; Sartorilli & Correa, 2007). Essential oils can be obtained by expression, fermentation, enfleurage, or extraction, although hydrodistillation is the most common technique (Speranza & Corbo, 2010). In fact, all articles used in the elaboration of this review applied the hydrodistillation technique to isolate the volatile fraction of plant. Concerning extraction yield, all works pointed out to very low and quite variable values. Duarte-Almeida (2004), for example, reported the chemical composition of seven *Bauhina* species, but only two of them (*B. brevipes* and *B. rufa*) had measurable amounts of oil, 0.25 and 0.30%, respectively. In the others, the amount of oil was negligible and immeasurable. It should be noted the studies used different parts of the plant material. While some used fresh leaves and flowers, others used dry leaves, which significantly affects the result of the extraction process yield. Moreover, although all the works used hydrodistillation, time of extraction ranged from 2 to 8 hours. These factors could explain the great variability in the values found, ranging from 0.006 to 0.3%.

Despite showing a low yield in the extraction of the volatile fraction when compared to other species, the elucidation of the chemical composition of essential oils from *Bauhinia* is relevant and related to some aspects. Species of the genus *Bauhinia* are widely used in Brazilian folk medicine in the form of infusions. During this preparation, the volatiles are condensed, returning to the solution. In this way, part of the plant's essential oil can migrate to the infusion, which is consumed, and may be associated with the beneficial effects of this preparation on human health.

In studies conducted to stablish the chemical composition of essential oils, identification of the individual components is often carried out with the aid of gas chromatography coupled with a quadrupole mass spectrometer (GC/MS). However, someone skilled in the art can realize that the identification of these compounds in some works is carried out in a non-reliable way. In these specific studies, the identification is exclusively based on the evaluation of the mass spectra of the compounds. The use of standard compounds and retention indexes (e.g.: Kovats index) is not employed in the identification process to endorse the spectrometric data. Thus, these compounds could not be considered definitely identified, but only tentatively identified, and mistakes must be considered as a real possibility. For instance, this kind of problem can be noted in the manuscript published by Vasudevan *et al*. (2014). They indicated the use of retention times to endorse the spectrometric data. If you don´t have standard compounds as reference to analyze in the same chromatographic conditions used to study the samples, the retention times are not a trustful mean to complete the identification process. On the other hand, although linear retention indexes (LRIs) have been calculated by Vasudevan *et al.* (2013), wrong identifications were also done in their work, probably because they forgot to compare the calculated indexes with those available in the literature. For instance, the compounds 3-hexen-1-ol and octacosane were probably not present in the leaf oil of *Bauhinia acuminata* that was analyzed in this study. Considering non-polar capillary columns, the LRIs attributed for these compounds ($LRI_{3\text{-hexen-1-ol}}$ = 1571; $LRI_{octacosane}$ = 2496) didn´t match the LRIs available in the literature ($LRI_{3\text{-hexen-1-ol}}$ = 852; $LRI_{octacosane}$ = 2800) (Miyazawa *et al*., 2011; Kaib *et al*., 2004). Another important point, when working with the common names of volatile compounds, is to check for synonyms. For instance, De Almeida *et al.* (2015) concluded that elixene was being reported by the first time as a component of *B. pentandra*. However, this compound had been previously indicated as a component of this species by Duarte-Almeida *et al.* in the year 2004, referring to it as γ-elemene (a synonym). In addition, the linear retention index calculated for elixene (1509) by De Almeida *et al*. (2015) is also far from the mean linear retention index (1439) found in the literature (Mondello *et al*., 2002; Shellie *et al*., 2003) for this compound when using the same capillary column (RTX-5), making identification less reliable. So, data available in the literature related to the chemical composition of essential oils must be analyzed with care to avoid such mistakes.

The composition of the essential oil of genus *Bauhinia* investigated during the last twenty years is reported in Table No. 2, while Table No. 3 shows the three major compounds of each oil. One hundred fifty six compounds are listed as components of the essential oils of the seventeen species. Based on the information in this table, it can be seen that all oils have quite a different composition, even when the same species was analyzed by different research groups. β-elemene was identified in twelve species, β-caryophyllene in eleven species and α-humulene (α-caryophyllene), spathulenol and α-copaene were identified in ten species (Figure No. 1).

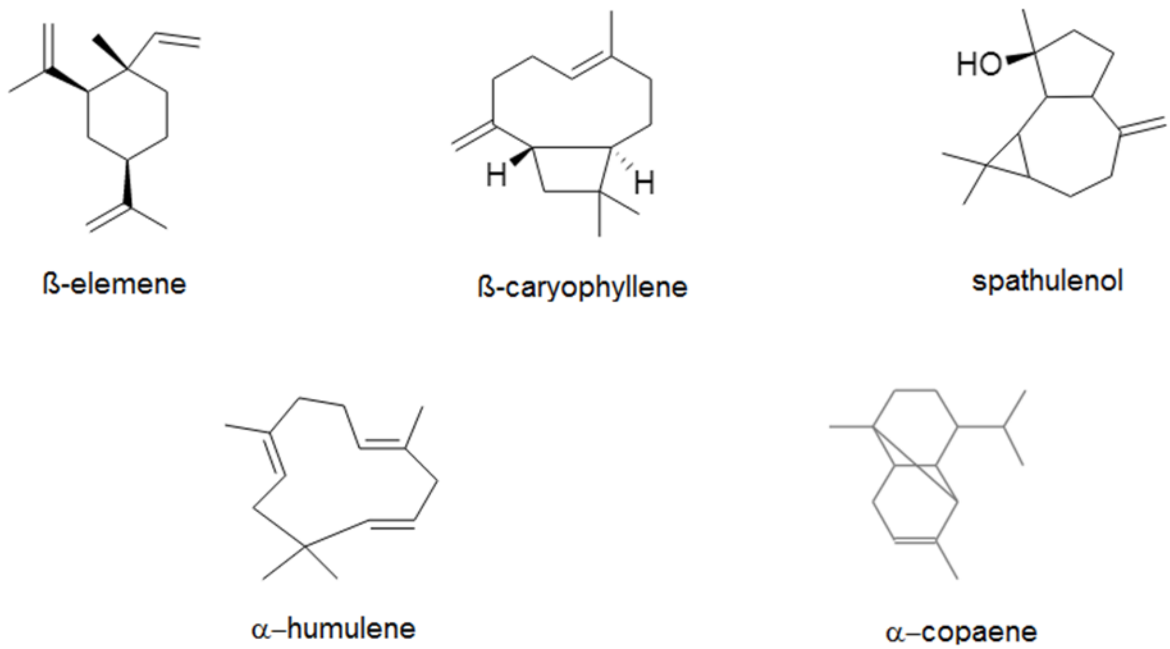

Figure No. 1
Sesquiterpenoid compounds characterized in a higher number of species of *Bauhinia*. (Source: acquired by the author in Chemdraw® software)

β-Elemene, compared with their isomers γ, α and δ, has been shown to be a broad-spectrum anti-tumor drug that exerts effects through multiple pathways and multiple targets. Recent studies have shown that β-elemene exerts anti-tumor effects by inhibiting cell proliferation, arresting the cell cycle and inducing cell apoptosis (Zhai *et al*., 2019). In recent clinical studies, β-elemene has been shown to be a promising adjunctive treatment, providing a synergistic effect in improving patient outcome in the treatment of malignant disease (Wang *et al*., 2012; Zheng *et al*., 2014; Jun *et al*., 2016). This valuable compound is present in 70% of the oils reported in the literature, in concentrations ranging from traces to 56.9%. The δ-elemene isomer also seems to be an important compound of essential oils in the genus *Bauhinia*: it is present in nine oils at relatively high levels (1 - 38.4%) and it also has important antitumor activity, showing positive results against cancer cells of the colon/rectum (XIE *et al*., 2009) and the lungs (XIE *et al*., 2011).

Regarding the class of bicyclic sesquiterpenoids, which have raised attention in the bio-pharmacological field, β-caryophyllene is particularly relevant. This natural compound was approved by the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), and it is used as a flavor enhancer (Machado *et al*., 2018) and in cosmetics (Gertsch, 2008). In nature, β-caryophyllene mainly occurs as trans-caryophyllene ((E)-caryophyllene) mixed with small amounts of the isomers (Z)-β-caryophyllene and α-humulene (α-caryophyllene), and its oxidation derivative, i.e., caryophyllene oxide. Francomano *et* *al.* (2019) published a review of the biological properties of β-caryophyllene in which they demonstrated (with a series of pre-clinical studies) the bioactive potential of this molecule, highlighting antioxidant, anti-inflammatory, neuroprotective, sedative and muscle relaxant activities. α-caryophyllene (or α-humulene), according to the literature, shows cytotoxic activity against tumor cells A-549 (lung carcinoma), HeLa (cervical carcinoma) and HT-29 (adenocarcinoma of colon) (Da Silva *et al*., 2007). In general, α and β-caryophyllene have antiedemic, phage-repellent, anti-inflammatory, anti-tumor, bactericidal, insect-resistant and anti-allergenic actions. Caryophyllene oxide, in turn, has analgesic, anti-inflammatory (Chavan *et al.*, 2010), antitumor (Park *et al.*, 2011) and gastroprotective activities (Sanchez *et al.*, 2014). This set of compounds was identified in a large part of the analyzed oils, with, at least, one of the compounds being found in these samples. They are one of the three major compounds in fourteen of the seventeen oils reported in the literature. β-caryophyllene was characterized as a major compound in *B. pentandra* (46.6%), *B. forficata* (18.5%), *B. longifolia* (17.4%) (Duarte-Almeida, 2004), *B. ungulata* (15.9%) (Medeiros *et al.*, 2016), *B. rufa* (15.8%) (da Silva *et al.*, 2019), *B. pentandra* (13.64%) (de Almeida *et al.*, 2015), *B. acuminata* (13.87%) (Vasudevan *et al.*, 2013) and *B. tormentosa* (14.24%) (Vasudevan *et al.*, 2014). E-caryophyllene was a major constituent in *B. chileanta* (21.65%) (Silva *et al.*, 2020) and B. ungulata (14.5%) (De Sousa *et al.*, 2016). Caryophyllene oxide is one of the three major compounds of *B. ungulata* analyzed by De Sousa *et al*. (2016), Gramosa *et al.* (2008) and Medeiros *et al.* (2016), with percentage concentrations of 23%, 18.3% and 9.2%, respectively.

Another compound that is noteworthy owing to frequency and concentration of appearance in several species of the genus *Bauhinia* is sesquiterpenoid spathulenol. Duarte-Almeida (2004) reported this compound as a major constituent in four species, namely, *B. brevipes* (15.9%), *B. longifolia* (27%), *B. rufa* (14.1%) and *B. variegata* (13.3%). In the oil of B. ungulata studied by Gramosa *et al*. (2009), spathulenol accounts for 47.7% of the total identified constituents, while Gois *et al*. (2011) has reported a concentration of 23.4 % of sphatulenol in the oil of *B. acuruana*. Spathulenol presents activity against Gram-positive and Gram-negative bacteria (Bougatsos *et al.*, 2004). Recently, Dzul-Beh *et al*. (2019) isolated spathulenol from *Azorella compacta* Phil and showed its *in vitro* growth inhibition and bactericidal activity against drug-resistant clinical isolates of *Mycobacterium tuberculosis.*

The works reported in the literature used fresh or dried leaves or fresh flowers for essential oil extraction. In general, the aroma of the flowers must have a different chemical composition from that of the vegetative parts, in order to serve as a reference for specific pollinators (Sahoo *et al.*, 2013; Sharma *et al.*, 2013).

Stefanello *et al*. (2009) showed differences in the composition of essential oils from flowers and leaves of *Eugenia pyriformis* (Myrtaceae). In leaf oils, the main components were β-pinene, limonene, 1,8-cineol and caryophyllene oxide, while in flower oils, the main components were E-caryophyllene (22.8%) and germacrene D (15.3%), which are common volatile compounds of flowers pollinated by bees and wasps. In this review, this comparison can be made with the species *Bauhinia variegata*, since two studies were found on the volatile composition of its flowers and one for the leaves. In the leaf oil, the main compounds described by Duarte-Almeida (2004) were Germacrene D (24.7%), γ-elemene (18.7%) and spathulenol (13.3%). However, data found in the two studies on flower oil are controversial. While Sharma *et al*. (2013) pointed that the major compounds of oils from Indian flowers of Bauhinia variegata were nerolidol (20.8%), α-bisabolol (17%) and β-bisabolene (10%), Sahoo *et al*. (2013) found cis-murrol-5-em-4-α-ol (24%), γ-elemene (19%) and α-pinene (5.1%) as the major components. Although they both were collected in India, they are from different regions of the country and details of the time of collection were not specified, which certainly impacts the variation in the composition of the oils.

It was also possible to compare the essential oils extracted from the leaves and flowers of *Bauhinia rufa*, since two works reported the composition of the leaf oils (Duarte-Almeida et al, 2004; Da Silva et al, 2019) and one work reported the composition of essential oils extracted from flowers from four different locations (De Menezes Filho et al, 2020). Viridiflorol appears as one of the major compounds of flowers (8.32-15.08%) and leafs (26%) of B. rufa. When it comes to chemical classes, there is a consensus that sesquiterpenes represent an overwhelming majority among the identified compounds.

Table No. 1
Summary of descriptive characteristics of included studies

Authors	**Vasudevan *et al.* (2013)**	**Vasudevan *et al.* (2014)**	**Da Silva *et al.* (2019)**	**Medeiros *et al.* (2016)**
Species (yield (w/w%))	*B. acuminata* (0.008)	*B. tormentosa* (0.008); *B. scandens* (0.006); *B. purpurea* (0.008); *B. malabarica* (0.009)	*B. rufa* (0.01); *B. dumosa* (0.03)	*B. ungulata* L. (0.006)
Material	Fresh leaves	Fresh leaves	Fresh leaves	Fresh leaves
Technique/extraction time	HD Clevenger, 6 h	HD Clevenger, 6 h	HD Clevenger, 2 h	HD Clevenger, time not mentioned
Number of identified compounds, method of identification	19 RI, MS	6, 2, 4, 8 RI, MS	25, 22 RI, MS, coinjetion with standards	18 RI, MS
Major class (%)	D (65)	S (49), D (88), D (90), D (62)	S (95), S (97)	S (65)
Biological activity	-	-	Acaricidal against *T. urticae*	Acetylcholinesterase inhibition; antibacterial (Gram negative)

Table No. 1 (cont…)

Authors	**Gois *et al.* (2011)**	**Sahoo *et al.* (2013)**	**De Sousa *et al.* (2016)**	**Duarte-Almeida (2004)**	**Sartorilli & Correa (2007)**
Species (yield (w/w%))	*B. acuruana* (0.01)	*B. variegata* (0.25)	*B. pulchella* Benth (0.01) *B. ungulata* L. (0.02)	*B. aculeata* (im) *B. brevipes* (0.25) *B. forficata* (im) *B. longifolia* (im) *B. pentandra* (im) *B. rufa* (0.3) *B. variegata* (im)	*B. forficata* (0.02)
Material	Fresh leaves	Fresh flowers	Fresh leaves	Air dryed leaves	Fresh leaves
Technique/ extraction time	HD Clevenger, 2h	HD Clevenger, 6h	HD Clevenger, 2h	HD Clevenger, 5h	HD Clevenger, 8h
Number of identified compounds, method of identification	30 RI, MS	51 RI, MS	28, 22 RI, MS	11, 18, 11, 7, 7, 19, 13 MS	15 RI, MS
Major class (%)	S (91.4)	S (78.3)	M (56), S (84.5)	S for all samples (100, 84, 87, 89, 100, 100)	S (96)
Biological activity	Larvicidal *Aedes egipti*	-	Larvicidal *Aedes egipti* and cytotoxic	-	-

Table No. 1 (cont...)

Authors	Silva *et al.* (2020)	De Menezes Filho *et al.* (2020)	Sharma *et al.* (2013)	De almeida *et al.* (2015)	Gramosa *et al.* (2009)
Species (yield (w/w%))	*B. chileanta* S. (0.024)	*Bauhinia rufa* (0.045-0.098)*	*B. variegata* (0.3)	*B. pentandra* (not mentioned)	*B. ungulata* L. (0.007)
Material	Fresh leaves	Flowers	Fresh flowers	Fresh leaves	Air dryed leaves
Technique/ extraction time	HD Clevenger, 3 h	HD Clevenger, 3 h	HD Clevenger, 3 h	HD Clevenger, 5 h	HD Clevenger, time not mentioned
Number of identified compounds, method of identification	44 RI, MS	30-34* RI, MS	27 RI, MS	6 RI, MS	13 RI, MS
Major class (%)	S (78)	S (39-87)*	S (60)	D (59)	S (95)
Biological activity	Larvicidal and cytotoxic	Antifungal against *Candida* *(C. albicans, C. guilliermondi, C. krusei, C. tropicalis)*	-	-	-

HD-hydrodestilation, RI-retention index, MS-mass spectrometry, S-sesquiterpenes and oxygenated sesquiterpenes, D-diterpenes; (-) = not addressed

However, some exceptions were found. Five species of *Bauhinia* presented phytol, a diterpene, as a major constituent: *B. pentandra* (De Almeida *et al.*, 2015), *B. acuminata* (Vasudevan *et al.*, 2013), *B. scandens*, *B. purpurea* and *B. malabarica* (Vasudevan *et al.*, 2014), which were composed by 58.78%, 65.9%, 88.32, 90.38, and 62.17% of this compound, respectively. For those oils, sesquiterpenes and their oxygenated derivatives were the second major groups of compounds. The presence of phytol in essential oils is attributed to the degradation of chlorophyll owing to the excessive desiccation of the vegetal matrix, the high temperatures used in the extraction process and the endogenous enzymatic reaction of chlorophyllase (Kraütler, 2008). Phytol presents interesting applications in cosmetics, fine fragrances, shampoos and is also used as precursor for the manufacture of vitamin E and K1(Vasudevan *et al.*, 2014). Phytol seems to have anti-inflammatory activity in acute inflammation models, mainly by inhibition of neutrophil migration, owing to a reduction of IL-1β and TNF-α levels and oxidative stress (Carvalho *et al.*, 2020).

Biological properties of Bauhinia oils

In recent years, several research studies with natural products, using essential oils as raw materials, were performed.

Experiments on biological activities of essential oils from different *Bauhinia* species were established in only five of the thirteen works that described the chemical composition of oils. Below is the reported of the relevant findings about biological properties of the different essential oils of Bauhinia obtained from different parts of the world.

Table No. 2
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia* (compounds listed in alphabetical order) (Part 1. Monoterpenes and Oxygenated Monoterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Monoterpenes																	
Camphene	-	-	2.2[c]	-	-	-	-	-	-	0.3[b]	-	-	-	-	0.4[m]	-	-
3-Carene	-	-	-	-	-	-	-	0.4-1.0[n]	-	-	-	-	-	-	-	-	-
p-Cymene	-	-	0.9[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Fenchene	-	-	-	-	-	-	-	Tr[d]	-	-	-	-	-	-	-	-	-
Limonene	-	-	1.0[c]	-	-	-	-	-	-	0.3[b]	-	-	-	-	1.2[m]	-	-
Myrcene	-	-	-	-	-	-	-	0.1[l]	-	0.4[b]	-	-	-	-	0.6[m]	-	-
(E)-β-Ocimene	-	-	-	-	-	-	-	-	-	0.2[b]	-	-	-	-	-	-	-
β-Ocimene	Tr[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Pinene	1.5[d]	-	23.9[c]	1.4[c], 0.8[k]	-	-	-	1.1[d], 0.5[l], 0.4-3.2[n]	0.6[l]	5.1[b]	-	-	-	-	11.8[m]	-	-
β-Pinene	Tr[d]	-	12.2[c]	0.2[k]	-	-	-	Tr[d]; 11.2-19.7[n]	0.3[l]	2.2[b]	-	-	-	-	2.4[m]	-	-
α-Phellandrene	-	-	-	-	-	-	-	0.1[l]	-	-	-	-	-	-	-	-	-
Sabinene	Tr[d]	-	1.2[c]	-	-	-	-	1.0-1.2[n]	-	0.1[b]	-	-	-	-	0.4[m]	-	-
α-Thujene	-	-	-	-	-	-	-	-	-	0.3[b]	-	-	-	-	-	-	-
Tricyclene	-	-	7.3[c]	-	-	-	-	-	-	-	-	-	-	-	1.2[m]	-	-
Oxygenated Monoterpenes																	
1,8-Cineole	-	-	0.5[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fenchone	-	-	-	-	-	-	-	0.9[n]	-	-	-	-	-	-	-	-	-
Linalool	-	-	-	-	-	-	-	0.9-3.1[n]	0.2[l]	0.1[b]	-	-	-	-	-	-	-
Myrcenol	-	-	-	-	-	-	-	0.3[l]	-		-	-	-	-	-	-	-
Myrtenal	-	-	-	-	-	-	-	1.2-3.1[n]	-	-	-	-	-	-	-	-	-
E-Pinocarveol	-	-	0.9[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinocarvone	-	-	0.5[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(E)-Sabinene hydrate	-	-	-	-	-	-	-	-	-	0.1[b]	-	-	-	-	-	-	-
Terpinen-4-ol	-	-	0.8[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Terpineol	-	-	0.6[c]	-	-	-	-	-	-	0.1[b]	-	-	-	-	0.2[m]	-	-
E-verbenol	-	-	-	-	-	-	-	4.1-11.0[n]	-	-	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*.
(Part 2a. Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Sesquiterpenes																	
allo-aromadendrene	-	0.7[a]	0.4[c]	3.2[c], 2.1[h]	2.7[d]	-	-	1.2[d]	0.9[l]	1.0[b], 7.4[d]	-	Tr[d]	-	-	0.8[m]	-	-
α-Amorphene	-	-	-	-	4.8[d]	-	-	6.6[d]	-	-	-	-	-	-	-	-	-
δ-Amorphene	-	-	-	-	-	-	-	2.18[n]	-	-	-	-	-	-	-	-	-
Aromadendrene	-	-	-	1.0[k]	7.0[d]	-	5.6[d]	Tr[d], 0.2-1.0[n]	-	Tr[d], 2.0[f]		Tr[d]	-	-	-	-	-
Z-α-Bergamotene	-	0.3[a]	-	-	-	Tr[d]	-	-	-	-	-	Tr[d]	-	-	-	-	-
E-α-Bergamotene	-	0.8[a]	0.2[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bicyclogermacrene	14[d]	0.7[a]	-	-	-	-	12 [d]	7.1[d], 0.9-1.3[n]	-	-	-	-	-	-	8.2[m]	-	-
cis-α-Bisabolene	-	-	-	-	-	-	-	9.1[d]	-	1.2[f]	-	-	-	-	-	-	-
β-Bisabolene	-	-	-	-	-	-	-	-	0.2[l]	10.1[f]	-	-	-	-	-	-	-
β-Bourbonene	-	-	0.5[c]	1.4[c]	Tr[d]	-	-	0.3-1.1[n]	-	0.1[b], Tr[d]	-	12.4[d]	-	-	-	-	-
α-Bulnesene	17.3[e]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cadalene	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	1.5[j]
α-Cadinene	-	-	-	-	-	-	-	-	-	1.6[b]	-	-	-	-	-	-	-
β-Cadinene	-	-	-	-	-	-	-	-	-		-	-	6.1[j]	-	-	-	-
γ-Cadinene	-	0.8[a]	0.9[c]	1.6[c], 2.3[h]	5.8[d]	-	6.9[d]	2.6[d]	-	-	-	-	-	-	-	-	-
δ-Cadinene	-	-	-	1.1[k]	7.5[d]		-	4.5[d]		3.6[b], 8.1[d]	-	-	-	-	-	-	-
α-Calacorene	-	-	-	0.8[c]	-	-	-	-	-	-	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 2b. Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
								Sesquiterpenes									
β-Caryophyllene	18.5[d]	1.5[a]	2.2[c]	4.2[h], 15.9[k], 14.5[c]	-	46.6[d], 13.6[g]	17.4[d]	15.8[l]	6.4[l]	0.7[b], 2.4[d]	13.9[i]	Tr[d]	14.2[j]		21.7[m]	-	-
9-epi-(E)-Caryophyllene	-	-	-	-	-	-	-	0.4[l]	-	-	-	-	-	-	-	-	-
Cyclosativene	-	-	-	1.2[c]	-	-	-	0.2[l]	-		-	-	-	-	-	-	-
α-Copaene	5.6[d]	0.4[a]	1.3[c]	7.2[c], 2.9[h], 3.5[k]	3.4[d]	-	-	2.4[l]	1.0[l]	2.9[d]	-	-	-	-	0.4[m]	-	4.7[j]
β-Copaene	-	0.2[a]	1.3[c]	4.6[c]	-	-	-	-	-	-	-	-	-	-	-	-	-
Copaene Isomer	22.8[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Cubebene	-	-	-	0.6[c]	-	-	-	-	-	-	-	-	-	-	-	-	-
β-Cubebene	-	-	-	-	1.5[d]	-	-	-	-	-	-	-	21.8[j]	-	-	-	-
α-Curcumene	-	-	-	-	-	-	-	-	-	0.8[f]	-	-	-	-	-	-	-
Cyperene	-	-	2.2[c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Elemene	-	-	-	-	-	22.6[d]		-	-	-	-	-	-	-	-	-	-
β-Elemene	9.7[d]	2.3[a]	1.1[c]	4.9[c], 2.3[h], 1.8[k]	1.2[d]	Tr[d]		4.8[l]		2.6[b], 3.4[d]		57[d]	7[j]		4.9[m]	-	2.8[j]
γ-Elemene	Tr[d], 38.4[e]	-	-	1.3[k]	11.8[d]	17.5[d]; 11.7[g]	-	1.0[l]	10.5[l]	19.0[b], 18.7[d]	-	-	-	-	-	-	-
δ-Elemene	-	0.3[a]	-	-	-	-	-	-	-	-	-	-	-	-	7.4[m]	-	-
Eremophyllene	-	-	-	-	-	-	-	-	-	-	-	8.4[d]	-	-	-	-	-
α-Farnesene	-	-	-	-	-	-	-	-	-	-	0.1[i]	-	-	-	-	-	-
(E)-β-Farnesene	-	0.4[a]	-	-	-	-	-	-	1.5[l]	-	-	-	-	-	-	-	-
(Z)-β-Farnesene	9.1[e]	-	-	-	-	-	-	-	-	3.2[f]	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 2c. Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Sesquiterpenes																	
Germacrene A	-	-	-	-	-	-	-	-	-	0.2[b]	-	-	-	-	-	-	-
Germacrene B	-	0.7[a]	-	-	-	-	-	7.1[d], 3.9[l]	37.6[l]	-	-	-	-	-	-	-	-
Germacrene D	-	0.7[a]	-	1.5[h]	7.7[d]	8.4[g]	9[d]	7.2[d], 0.7[l], 3.8-7.9[n]	-	1.1[b], 24.7[d]	-	-	-	-	2.0[m]	-	-
6,9-Guaiadiene	-	-	-	0.8[c]	-	-	-	-	-	-	-	-	-	-	-	-	-
α-Guaiene	-	-	-	0.6[c]	-	-	-	-	-	0.5[b]	-	-	-	-	-	-	
β-Guaiene	-	-	-	-	-	-	-	0.6[l]	0.7[l]		-	-	-	-	-	-	6.5[j]
α-Gurjunene	-	-	-	-	-	-	-	Tr[d]	-	-	-	-	-	-	-	-	-
β-Gurjunene	-	-	-	-	-	-	-	-	-	0.3[b]	-	-	-	-	-	-	-
γ-Gurjunene	-	-	-	-	-	-	-	-	-	0.8[b]	-	-	-	-	-	-	-
α-Humulene	3.5[e]	0.6[a]		0.6[c], 3.5[h], 8.1[k]	Tr[d]	Tr[d], 2.7[g]	-	0.4[l], 0.4-2.0[n]	0.5[l]	0.5[b], Tr[d]	1.8[i]	-	-	-	3.6[m]	-	-
Isocaryophyllene	-	-	-	-	-	-	-	-	-	2.2[d]	-	-	-	-	-	-	-
Isocomene	-	-	-	-	-	-	-	-	-	0.1[b]	-	-	-	-	-	-	-
Ledene	-	-	-	-	Tr[d]	-	-	-	-	7.4[d]	-	Tr[d]	-	-	-	-	-
α-Muurolene	-	-	0.7[c]	2.8[c]	-	-	-	-	-	0.5[b]	-	-	-	-	-	-	-
γ-Muurolene	-	-	-	2.8[h], 1.1[k]	-	-	-	12.2[l]	3.7[l]	0.1[b]	-	-	-	-	-	-	-
γ-Patchulene	-	-	-	-	-	-	-	-	2.0[l]	-	-	-	-	-	-	-	-
Selina-3,7(11)-diene	-	-	-	-	-	-	-	-	-	1.3[b]	-	-	-	-	-	-	-
α-Selinene	-	-	-	-	-	-	-	-	-	1.9[b]	-	-	-	-	-	-	-
β-Selinene	-	0.4[a]	1.3[c]	1.4[c]	1.5[d]	-	-	-	-	0.3[b], 0.7[f]	-	-	-	-	-	-	-
7-epi-α-Selinene	-	-	-	-	-	-	-	-		0.3[b]	-	-	-	-	-	-	-
β-Sesquiphellandrene	-	1.8[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sinularene	-	-	-	-	-	-	-	Tr[d]	-	-	-	-	-	-	-	-	-
Valencene	-	-	-	3.0[c]	-	-	-	7.1[l]	-	-	-	Tr[d]	-	-	-	-	-
β–ylangene	-	-	-	-	-	-	-	2.1[l]	-	-	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 3a. Oxygenated Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Oxygenated Sesquiterpenes																	
α-Bisabolol	0.8[e]	-	-	4.7[k]	-	-	-	0.9[l], 4.1-7.2[n]	0.2[l]	17.1[f]	-	-	-	-	-	-	-
α-Bisabolol oxide	-	-	-	-	-	-	-	-	-	1.7[f]	-	-	-	-	-	-	-
α-Cadinol	3.7[e]	-	0.7[c]	1.0[c], 0.4[h]	7.4[d]	-	-	9.1[d], 10[l]	-	4.6[b]	0.4[i]	-	-	-	-	-	-
epi-α-Cadinol	-	20.7[a]	-	-	-	-	-	12.8[l]	0.8[l]	-	-	-	-	-	-	-	-
trans-Calamenen-10-ol	-	0.5[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caryophylla-4(12),8(13)-dien-5α-ol	-	-	-	-	-	-	-	-	-	-	0.2[i]	-	-	-	-	-	-
Caryophylla-4(12),8(13)-dien-5β-ol	-	-	-	-	-	-	-	-	-	-	1.0[i]	-	-	-	-	-	-
14-Hydroxy-9-epi(E)-Caryophyllene	-	0.6[a]	-	-	-	-	-	-	-	-	-		-	-	-	-	-
Caryophyllene oxide	9.4[e]	16.4[a]	22.4[c]	23.0[c], 18.3[h], 9.2[k]	-	13.3[d], 0.7[g]	-	2.7[l]	1.1[l]	-	3.2[i]	Tr[d]	-	-	4.6[m]	-	-
5-Cedranone	-	-	-	-	-	-	-	-	-	0.4[b]	-	-	-	-	-	-	-
α-Chenopodiol-6-acetate	-	-	-	-	-	-	-	3.0-3.1[n]	-	-	-	-	-	-	-	-	-
Cubenol	-	-	-	1.4[k]; 1.1[c]	-	-	-	0.5[l], 0.5-1.0[n]	-	0.8[b]	-		-	-	-	-	-
epi-Cubenol	-	-	-	-	-	-	-	0.3-0.9[n]	-	0.2[b]	-	-	-	-	-	-	-
1,10-di-epi-Cubenol	-	-	-	-	-	-	-	-	-	1.4[b]	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 3b. Oxygenated Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Oxygenated Sesquiterpenes																	
2,3-Dihydrofarnesol	-	1.4[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8-α-11-elemenediol	-	-	-	2.7[h]	-	-	-	-	-	-	-	-	-	-	-	-	-
Elemol	-	0.1[a]	-	-	-	-	-	1.6-10.2[n]	-	-	-	-	-	-	-	1.9[j]	-
γ-Eudesmol	-	1.0[a]	-	-	-	-	-	0.8-0.9[n]	-	-	-	-	-	-	-	-	-
Epi-γ-Eudesmol	-	-	-	7.5[k]	-	-	-	-	-	-	-	-	-	-	-	-	-
Farnesol	-	-	-	-	-	-	-	-	-	0.7[f]	0.2[i]	-	-	-	-	-	-
(Z,E)-Farnesol	1.6[e]	-	-	1.2[k]	-	-	-	-	-	-	-	-	-	-	-	-	-
(Z,Z)-Farnesol	1.0[e]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Germacrene-D-4-ol	0.7[e]	-	-	-	-	-	-	4.7-7.8[n]	-	1.5[b]	-	-	-	-	-	-	-
Globulol	1.2[e]	2.4[l]	-	-	-	-	-	2.2[d], 3.2-9.0[n]	-	-	-	-	-	-	1.8[m]	-	-
Guaia-3,1-(14)-dien-11-ol	-	-	-	-	-	-	-	2.2-4.1[n]	-	-	-	-	-	-	-	-	-
Guaiol	-	-	-	-	-	-	-	0.3-0.7[n]	-	-	-	-	-	-	-	-	-
Hexahydrofarnesyl acetone	-	-	-	-	-	-	-	-	-	4.4[f]	-	-	-	-	-	-	-
14-Hydroxy-α-humulene	-	-	-	-	-	-	-	-	-	0.9[b]	-	-	-	-	-	-	-
Humulene epoxide II	-	-	1.7[c]	4.6[c], 5.2[h]	-	-	-	-	-	-	0.4[i]	-	-	-	-	-	-
Isoaromadendrene epoxide	-	-	-	-	-	-	-	-	-	-	0.1[i]	-	-	-	-	-	-
Isospathulenol	-	-	-	-	-	-	10.8[d]	-	-	-	-	-	-	-	-	-	-
Junenol	-	-		0.8[c]	-	-	-	-	-	-	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 3c. Oxygenated Sesquiterpenes)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. ung*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Oxygenated Sesquiterpenes																	
Juniper Camphor	-	-	-	-	-	-	-	-	-	0.7[b]	-	-	-	-	-	-	-
Lanceol	-	-	-	-	-	-	-	0.2-3.3[n]	-	1.7[f]	-	-	-	-	-	-	-
Lepidozenol	-	-	-	-	-	-	-	3.1[d]	-	-	-	22.3[d]	-	-	-	-	-
cis-Murrol-5-en-4-α-ol	-	-	-	-	-	-	-	-	-	24.4[b]	-	-	-	-	-	-	-
α-Muurolol	-	0.4[a]	-	-	-	-	-	-	-	-	0.3[i]	-	-	-	1.4[m]	-	-
epi-α-Muurolol	1.7[e]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(E)-Nerolidol	-	2.4[a]	-	3.3[k]	-	-	-	-	29.1[l]	20.8[f]	-	-	-	-	-	-	-
Occidentalol	-	-	-	-	-	-	-	-	-	2.3[b]	-	-	-	-	-	-	-
Oplopanone	-	-	-	-	-	-	-	3.8-10.7[n]	-	-	-	-	-	-	-	-	-
Sclareolide	-	-	-	-	-	-	-	-	-	-	0.2[i]	-	-	-	-	-	-
Spathulenol	2.1[e]	23.4[a]	2.9[c]	1.8[c], 47[h], 2[k]	15.9[d]	-	27.0[d]	14.1[d], 4.4[l]	0.2[l]	13.3[d]	-	-	-	-	4.8[m]	-	-
Valerianol	-	5.7[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Viridiflorol	-	1.6[a]	-	-	2.8[d]	-	-	2.0[l]; 26.0[d], 8.3-15.1[n]	-	-	-	-	-	-	0.7[m]	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 4a. Diterpenes and Miscellaneus)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. una*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Diterpenes																	
Isophytol	3.3[e]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phytol	-	-	-	-	-	58.8[g]	-	-	-	-	65.9[i]	-	10.1[j]	88.3[j]		90.4[j]	62.2[j]
Phytone	-	-	-	-	-	-	-	-	-	-	-	-	32.8[j]	2.5[j]	-	1.9[j]	-
Miscellaneus																	
1[H]Cycloprop[e]azulene (HC)	-	-	-	-	-	-	-	-	-	0.8[f]	-	-	-	-	-	-	-
1-Decanol (A)	-	-	-	-	-	-	-	0.7-5.3[n]	-	-	-	-	-	-	-	-	-
Dichloroacetic acid (CA)	-	-	-	-	-	-	-	-	-	6.6[f]	-	-	-	-	-	-	-
8,11,14-Docosatrienoic acid methyl ester (E)	-	-	-	-	-	-	-	-	-	2.0[f]	-	-	-	-	-	-	-
1,6,10-Dodecatrien-3-ol (A)	-	-	-	-	-	-	-	-	-	-	0.3[i]	-	-	-	-	-	-
Eicosane (HC)	0.2[e]	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
Ethyl 9-hexadecenoate (E)	-	-	-	-	-	-	-	-	-	0.9[f]	-	-	-	-	-	-	-
Ethyl n-heptadecanoate (E)	-	-	-	-	-	-	-	-	-	1.6[f]	-	-	-	-	-	-	-
Hexadecanoic acid (CA)	-	-	-	-	-	-	-	-	-	4.8[f]	-	-	-	-	-	-	-
Hexadecanoic acid, ethyl ester (E)	-	-	-	-	-	-	-	-	-	6.1[f]	-	-	-	-	-	-	-
Hexadecanoic acid, methyl ester (E)	-	-	-	-	-	-	-	-	-	1.4[f]	-	-	-	-	-	-	-
9-Hexadecenoic acid (CA)	-	-	-	-	-	-	-	-	-	0.8[f]	-	-	-	-	-	-	-
Hexadecadienoic acid, methyl ester (E)	-	-	-	-	-	-	-	-	-	0.8[f]	-	-	-	-	-	-	-

Table No. 2 (cont.)
Relative percentage of constituents identified in essential oils of plants of the genus *Bauhinia*
(Part 4b. Diterpenes and Miscellaneus)

Compounds	*B. for*	*B. acur*	*B. pul*	*B. una*	*B. bre*	*B. pen*	*B. lon*	*B. ruf*	*B. dum*	*B. var*	*B. acum*	*B. acul*	*B. torm*	*B. scan*	*B. chei*	*B. purp*	*B. mal*
Miscellaneus																	
3-Hexen-1-ol (A)	-	-	-	-	-	-	-	-	-	-	0.2[i]	-	-	-	-	-	-
β-Ionone (NI)	-	-	-	-	-	-	-	-	-	-	0.1[i]	-	-	-	-	-	-
isomethyl-α-Ionone (NI)	-	-	-	-	-	-	-	-	-	-	0.2[i]	-	-	-	-	-	-
Linoleic acid ethyl ester (E)	-	-	-	-	-	-	-	-	-	3.5[f]	-	-	-	-	-	-	-
2-Methyl-decane (HC)	-	-	-	-	-	-	-	-	-	1.3[f]	-	-	-	-	-	-	-
Myristic acid isopropyl ester (E)	-	-	-	-	-	-	-	-	-	1.2[f]	-	-	-	-	-	-	-
Nonadecane (HC)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.8[j]	-
Octacosane (HC)	-	-	-	-	-	-	-	-	-	-	0.2[i]	-	-	-	-	-	-
Octadecanal (AD)	-	-	-	-	-	-	-	-	-	0.7[f]	-	-	-	-	-	-	-
Octadecane (HC)	-	-	-	-	-	-	-	-	-	0.9[f]	-	-	-	-	-	-	-
1-Octadecene (HC)	-	-	-	-	-	-	-	-	-	-	0.3[i]	-	-	-	-	-	-

Tr=traces. *B. forf, B. forficata* Link; *B. acur, B. acuruana* Moric.; *B. pul, B. pulchella* Benth; *B.ung, B. ungulata* L.; *B. bre, B. brevipes* Vogel; *B. pen, B. pentandra* (Bong.) Steud; *B. lon, B. longifolia* (Bong.) Steud; *B. ruf, B. rufa* (Bong.) Steud; *B. dum, B. dumosa*; *B. var, B. variegata*; *B.* acum, *B. acuminata* L.; *B. acul, B. aculeata* L.; *B. torm, B. tormentosa* L.; *B. scan, B. scandens* L.; *B. chil, B. cheilantha* (Bong.) Steud; *B. pur, B. purpurea* L.; *B. mal, B. malabarica* Roxb; *B. mond, B. monandra* Kurz (a) Gois *et al*. (2011); (b) Sahoo *et al.* (2013) (c) De Sousa *et al.* (2016); (d) Duarte-Almeida *et al.* (2004); (e) Sartorilli & Correa (2007); (f) Sharma *et al*. (2013); (g) De Almeida *et al.* (2015); (h) Gramosa *et al.* (2009); (i) Vasudevan *et al*. (2013); (j) Vasudevan *et al.* (2014); (k) Medeiros *et al*. (2016); (l) Da Silva *et al*. (2019); (m) Silva *et al.* (2020); (n) de Menezes Filho *et al.* (2020).
A = alcohol; AD = aldehyde; CA = carboxylic acid; E = ester; HC = hydrocarbones; NI = norisoprenoid

Larvicidal and acaricidal activity

Several authors have developed their own criteria to characterize the potential of mosquito larvicides based on natural products, since the World Health Organization (WHO) has not established a standard criterion for determining larvicidal activity of natural products. In general, the classification in use takes into account the LC_{50} value, which is the lethal concentration required to kill 50% of the population. Essential oils with LC_{50} > 100 mg/L are considered as not active; LC_{50} < 100 mg/L as active; and those with LC_{50} < 50 mg/L are considered as highly active. In addition, samples whose results are expressed as mortality percentage are considered active when they are able to kill almost 100% of larvae at 100 mg/L. (Komalamisra *et al*., 2005).

Essential oils from some species of the genus *Bauhinia* have shown to be promising in combating *Aedes aegypti* larvae. Gois *et al*. (2011) evaluated the larvicidal potential of the essential oil of *B. acuruana*, exhibiting an LC50 value of 56.2 mg/L, that is, it presented a LC50 value considered to be active. This essential oil was mostly composed of spathulenol (23.4%), epi-α-cadinol (20.7%) and caryophyllene oxide (16.4%). Sesquiterpenes and their oxygenated derivatives, together, accounted for 91.4% of the composition of this oil. In turn, De Sousa *et al*. (2016) evaluated the essential oils of *B. pulchella* and *B. ungulata*. These oils presented LC_{50} values of 105.9 mg/L and 75.1 mg/L, respectively. Importantly, B. ungulata presented an oil rich in sesquiterpenes and its oxygenated derivatives (84.5%), with emphasis on caryophyllene oxide (23%), (E)-caryophyllene (14.5%) and α-copaene (7.2%), while oil from B. pulchella was rich in monoterpenes (55.8%), represented, for instance, by α-pinene

(23.9%), β-pinene (12.2%) and tricyclene (7.3%). Another species of *Bauhinia*, reported in the literature, which also showed important larvicidal activity was *B. cheilantha* (Bong.) Steud. Silva *et al*. (2020) found a LC_{50} value of 40.84 mg/L for this specific oil that was also rich in sesquiterpenes (78.59%), a higher percentage than the one reported for monoterpenes (18.51%). It is noteworthy that the larvicidal activity tests described in all the works on essential oils from *Bauhinia* were performed with the same methodology, against instar III larvae of *Aedes aegypti*, using Temephos® (O,O`-(thiodi-4,1-phenylene)bis(O,O-dimethyl phosphorothioate) as positive control.

It is not easy to determine the relationship between larvicidal activity and the chemical composition of essential oils, since the interaction between the compounds present in the oil can interfere with the activity of the mixture. However, some authors have shown that oils rich in sesquiterpenoid compounds exhibit important larvicidal activity (Feitosa *et al*., 2009; Arriaga *et al*., 2007; Magalhães *et al*., 2010). It can explain the lowest activity of *B. pulchella* oil, since this species showed a majority composition of monoterpenes, while other oils evaluated were mostly composed of sesquiterpenoids.

Simas *et al*. (2004) demonstrated the importance of the lipophilicity of terpenes for larvicidal activity against *Aedes aegypti*, comparing monoterpenes and sesquiterpenes based on their structures. The sesquiterpenoid farnesol, an isomeric form of nerolidol, showed larvicidal activity with LC_{50} of 13 mg/L. However, the monoterpenoid geraniol, a biosynthetic precursor of farnesol, was less active, presenting a LC_{50} value equal to 81.6 mg/L. These results suggest that the higher lipophilicity of the tested sesquiterpenes, when compared to monoterpenes, is an important property for larvicidal activity, since this feature provides sesquiterpenes with a higher ability to disrupt and penetrate the lipoprotein matrix of the insect cell membrane (Satyan *et al*., 2009).

Some authors showed that the synergistic phenomenon exists and results in a higher bioactivity of the mixture when compared to purified compounds (Dias & Moraes, 2014). From a commercial point of view, this information is important, since the economic feasibility for obtaining an extract is much higher than that for obtaining a pure substance, which requires a series of complex isolation processes (Simas *et al*., 2004).

Recently, Da Silva *et al*. (2019) evaluated the acaricidal activity of essential oils from two species of *Bauhinia*, namely *B. rufa* Steud and *B. dumosa* Benth, by determining the fumigant, residual contact and repellency properties of these oils against *Tetranychus urticae.* Both oils were toxic to mites, regardless of the method in use, although they were more effective by fumigation than residual contact. With respect to chemical composition, they were both almost exclusively composed of sesquiterpenes: *B. rufa* was composed of 95.3% and *B. dumosa* of 97.2% of them. The mode of action of essential oils on arthropods and fumigation effectiveness depends on ambient temperature, air intake and the volatile nature of the essential oil (Lim *et al*., 2012). Toxicity of oils has a stronger effect when applied through the airways than through residual contact, since they need to penetrate the coat layers to have an effect on mites. One of the factors that can influence the performance of essential oils in the bioassay of residual contact is the dilution process carried out to apply the oil. The degree of hydrophobicity of the oil solution or compound solution affects its penetration into the body of mites. More hydrophobic oil solutions will have less acaricidal activity (Badawy *et al*., 2010). On the other hand, in the fumigation bioassay, there is no contact of mites directly with the substance tested, but it does not exclude the possibility of synergistic effects of the minority compounds in the hermetically sealed environment, quickly reaching the airways of mites. Essential oils of *B. rufa* and *B. dumosa* seem to affect mites through both mechanisms (fumigation and residual contact), offering considerable advantages for integrated management of *T. urticae* (Da Silva *et al*., 2019). These findings enhance the interest for this potential activity attributed to *Bauhinia* oils.

Cytotoxic and antimicrobial activity

Oils from *B. pulchella* and *B. ungulata* were evaluated by de Sousa *et al*. (2016) against HL-60 (promyelocytic leukemia), MCF-7 (breast adenocarcinoma), NCI-H292 (lung carcinoma) and HEP-2 (cervical adenocarcinoma) cells, using the MTT (3-(4,5-dimethylthiazol-2-yl)2,5-diphenyl-2H tetrazolium bromide) colorimetric method. Doxorubicin was used as positive control. With the exception of the HL-60 cell line, where the two essential oils showed the same degree of cytotoxicity, the essential oil of *B. ungulata* was more active in all other cell lines. The same protocol was used by Silva *et al.* (2020), who evaluated the cytotoxic activity of *B. chileantha* essential oil, presenting more intense activity on MCF-7 and HL-60 cell lines. These are the major compounds present in the oils: caryophyllene oxide (23%), (E)-caryophyllene (14.5%), α-copaene (7.2%) – *B. ungulata;* caryophyllene oxide (22.4%), α-pinene (23.9%) and β-pinene (12.2%) – *B. pulchella;* (E)-caryophyllene (21.65%), α-pinene (11.75) and bicyclogermacrene (8.19%) – *B. chileantha*. The cytotoxic activity of (E)-caryophyllene and caryophyllene oxide are already well established in the literature, as mentioned above. However, it was found that, in addition to direct activity on tumor cells, these compounds act by potentiating the action of classic chemotherapy drugs, such as doxorubicin and paclitaxel, pointing to a potential use of these compounds as therapeutic adjuncts in chemotherapeutic treatments (Ambroz *et al*., 2015; Kim *et al*., 2014; Legault *et al*., 2007).

Table No. 3
Three major compounds identified in essential oils of *Bauhinia* species and local of collection

<table>
<tr><th>Plant species</th><th>major constituents (%)</th><th>Authors (year)</th><th>City, Country (Region)</th></tr>
<tr><td>B. acuruana</td><td>Spathulenol (23.4); epi-α-cadinol (20.7); cariophylene oxide (16.4)</td><td>Gois et al. (2011)</td><td>Ceará, Brazil (Northeast)</td></tr>
<tr><td>B. variegata (flowers)</td><td>Cis-murrol-5-em-4-α-ol (24.4); γ-elemene (19); α-pinene (5.1)</td><td>Sahoo et al. (2013)</td><td>Lucknow, India (Northern)</td></tr>
<tr><td>B. pulchella</td><td>α-pinene (23.9); caryophyllene oxide (22.4); β-pinene (12.2)</td><td rowspan="2">de Sousa et al. (2016)</td><td rowspan="2">Ceará, Brazil (Northeast)</td></tr>
<tr><td>B. ungulata</td><td>Caryophyllene oxide (23); (E)-Caryophyllene (14.5); α-copaene (7.2)</td></tr>
<tr><td>B. aculeata</td><td>β-elemene (56.9); lepidonezol (22.3); β-bourbonene (12.4)</td><td rowspan="7">Duarte-Almeida et al. (2004)</td><td rowspan="7">Minas Gerais, Brazil (Southeast)</td></tr>
<tr><td>B. brevipes</td><td>Spathulenol (15.9); γ-elemene (11.8); germacrene D (7.7)</td></tr>
<tr><td>B. forficata</td><td>Copaene isomer (28.8); β-caryophyllene (18.5); bicyclogermacrene (14)</td></tr>
<tr><td>B. longifolia</td><td>Spathulenol (27); β-caryophyllene (17.4); bicyclogermacrene (12.3)</td></tr>
<tr><td>B. pentandra</td><td>β-caryophyllene (46.6); α-elemene (22.6); γ-elemene (17.5)</td></tr>
<tr><td>B. rufa</td><td>Viridiflorol (26); spathulenol (14.1); α-cadinol (9.1)</td></tr>
<tr><td>B. variegata</td><td>Germacrene D (24.7); γ-elemene (18.7); spathuenol (13.3)</td></tr>
<tr><td>B. forficata</td><td>γ-elemene (38.4); α-bulnesene (17.3); caryophyllene oxide (9.4)</td><td>Sartoreli & Correa (2007)</td><td>São Paulo, Brazil (Southeast)</td></tr>
<tr><td>B. variegata (flowers)</td><td>Nerolidol (20.8); α-bisabolol (17.08); β-bisabolene (10.1)</td><td>Sharma et al. (2013)</td><td>Dehradun, India (North)</td></tr>
</table>

B. pentandra	Phytol (58.78); β-caryophyllene (13.64); elixene (11.73)	de Almeida *et al.* (2015)	Ceará, Brazil (Northeast)
B. ungulata	Spathulenol (47.7); caryophyllene oxide (18.3); humulene epoxide II (5.2)	Gramosa *et al.* (2008)	Ceará, Brazil (Northeast)
B. acuminata	Phytol (65.9); β-caryophyllene (13.87); caryophyllene oxide (3.15)	Vasudevan *et al.* (2013)	Kerala, India (Southwestern)
B. tormentosa	Phytone (32.84); β-cubebene (21.84); β-caryophyllene (14.24)	Vasudevan *et al.* (2014)	Pacha Palode, India (Southwestern)
B. scandens	Phytol (88.32); phytone (2.54)		
B. purpurea	Phytol (90.38); nonadecane (2.82); phytone (1.92)		
B. malabarica	Phytol (62.17); δ-cadinene (12.47); β-guaiene (6.53)		
B. ungulata	β-caryophyllene (15.9); caryophyllene oxide (9.2); α-humulene (8.1)	Medeiros *et al.* (2016)	Roraima, Brazil (North)
B. rufa	β-caryophyllene (15.8); epi-α-cadinol (12.8); γ-murolene (12.2)	da Silva *et al.* (2019)	Brasilia, Brazil (Midwest)
B. dumosa	Germacrene B (37.6); (E)-nerolidol (29.1); γ-elemene (10.5)		
B. chileanta	(E)-Caryophyllene (21.65); α-pinene (11.75); bicyclogermacrene (8.19)	Silva *et al.* (2020)	Ceará, Brazil (Northeast)
*B. rufa (flowers)**	β-pinene (11.23-19.74); viridiflorol (8.32-15.08); trans-verbenol (4.08-11)	De Menezes Filho *et al.* (2020)	Goiás, Brazil (Midwest)

*range of values for oils from four locations

α and β-pinene have aroused interest in the scientific community for having an anti-inflammatory, anti-tumor and anti-microbial potential (Silva *et al*., 2002; Nam *et al*., 2014). Despite being oxygenated monoterpenes, not belonging to the major class of sesquiterpenes, they can be found in some species of *Bauhinia*, in relevant quantities, possibly acting synergistically in the cytotoxic activity of oils.

Particularly for *Bauhinia* essential oils, two works were found in this bibliographic review. Medeiros *et al*. (2016) evaluated the antimicrobial activity of *B. ungulata* against Gram-negative (*Salmonella typhimurium* and *Citobacter freundii*) and Gram-positive (*Staphylococcus aureus* and *Bacillus cereus*) bacteria. They also evaluated antifungal activity against *Candida albicans*. Concentrations assayed were 250, 125, 62.5, 31.25, 15.6, 3.9 and 1.95 µg mL^{-1}, and ampicillin (antibacterial), miconazole and nystatin (antifungals) were used as positive controls. Essential oils, mostly composed of β-caryophyllene (15.9%), caryophyllene oxide (9.2%) and α-humulene (8.1%), showed satisfactory inhibition (inhibition percentage higher than 50%) on the four microorganisms evaluated. Importantly, the inhibition on *S. aureus* was interesting, since the oil showed activity in the eight concentrations tested, ranging from 1.95 to 250 µg mL^{-1}. De Menezes Filho *et al*, (2020) evaluated the antimicrobial activity of essential oils extracted from *B. rufa* flowers on four species of the genus *Candida* (*C. albicans* ATCC 2115-1, *C. guilliermondi* ATCC 2018-2, *C. krusei* ATCC 2047-3 and *C. tropicalis* ATCC 2591-4) using the disk diffusion method and Ketoconazol® as a positive standard. The inhibition results are expressed in millimeters (mm) in a halo of antibiosis caused by the tested strains. At all evaluated concentrations (2, 4, 6 and 8%) the essential oils showed a relevant inhibitory activity, specially at 6 and 8%, presenting halos from 10 to 29 mm, while the positive control presented halos from 25-30 mm. The presence of high concentration of β-pinene in the essential oils of *B. rufa* flowers may contribute for this great antifungal activity. Andrade *et al*, 2018 investigated effectiveness of β-pinene inhibition on *Candida* spp. growth showing that this compound has antifungal activity and most likely acts through interference with the cell wall, through molecular interaction with Delta-14-sterol reductase and, to a lesser extent, with the 1,3-β- glucan synthase. β-pinene also found to effectively reduce *Candida* biofilm adhesion.

CONCLUSION

Plants of the genus *Bauhini*a are still little explored as to the potential of their essential oils, and few studies have been found in the literature. One of the reasons may be the low yield when extracting these oils, which makes it difficult to perform many analyses. On the other hand, plants of this kind are very easily found and abundant, making them an inexpensive alternative in the search for new biological applications.

To the best of our knowledge, this work is the first review that provides an overview of the chemical composition and biological activity of essential oils of various species of the genus *Bauhinia*. This review showed that most essential oils from *Bauhinia* are mainly composed of sesquiterpenes, which have a broad spectrum of biological actions and can be explored in various application areas. However, more studies are needed for proper standardization of essential oils. This is an arduous task, since these secondary metabolites are subjected to great variations, such as metabolic stress of plants, seasonal variations and others

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