Journal of Ethnopharmacology 275 (2021) 114075

Contents lists available at ScienceDirect

Journal of Ethnopharmacology

journal homepage: www.elsevier.com/locate/jethpharm

Review

A review of the aromatic genus *Adenosma*: Geographical distribution, traditional uses, phytochemistry and biological activities

Chen Wang [a,b,1], Hongxia Zhang [b,1], Qing Liu [c], Jinfeng Qi [b], Huifu Zhuang [b], Yi Gou [b], Hongbin Wang [a,**], Yuhua Wang [b,*]

[a] *Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, Kunming, 650500, China*
[b] *Department of Economic Plants and Biotechnology, Yunnan Key Laboratory for Wild Plant Resources, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650201, China*
[c] *Key Laboratory of Tropical Plant Resources and Sustainable Use, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun, Yunnan 666303, China*

ARTICLE INFO

Keywords:
Adenosma R. Br.
Aromatic plant
Traditional medicine
Ethnopharmacology

ABSTRACT

Ethnopharmacological relevance: The strongly scented genus *Adenosma* R. Brown (Plantaginaceae) comprises between 26 and 29 species with mainly southeast Asian distributions. Several species are used traditionally, mostly in Asian countries, for medicinal purposes including the treatment of colds and tumors, as well as stomach, liver, and skin disorders. Some species are also used as insecticides and/or insect repellents against mosquitoes or fleas.
Aim of the review: Although the potential health benefits of *Adenosma* spp. are not yet well-known or well-studied in modern medicine, the aim of the present review is to provide a critical appraisal of the current state of knowledge regarding the geographical distribution, traditional uses, phytochemistry, phytochemicals and biological properties of *Adenosma* spp.
Materials and methods: Electronic databases (Web of Science, Science Direct, Google Scholar, Scifinder, Microsoft Academic, eFloras), Biodiversity Heritage Library (BHL), and the China National Knowledge Infrastructure (CNKI), were searched using the key words “Adenosma”, “毛麝香”, “大头陈”, “茵陈”, “nhân trần”, as well as the scientific names of the species, and a library search was also conducted for articles and books related to the subject published in English, Chinese or Vietnamese, as well as Ph.D. theses and M.Sc. dissertations published before April 2020.
Results: Adenosma spp. is traditionally used to treat gastrointestinal disorders, hepatitis, colds, and skin problems. Phenolic acids, flavonoids, and terpenoids constitute the main phytochemicals in these plants. Several evaluations based on bioassays have demonstrated biological activity for *Adenosma* spp., including antidiabetic, anticancer, and insecticidal activities; extracts and isolated compounds have also shown effective biological activity. However, current research has focused only on a few species, and on limited geographical regions, mainly in China and Vietnam. More and broader ethnopharmacological studies are therefore needed to provide further evidence of the health benefits of these plants.
Conclusions: Adenosma spp. are plants rich in essential oils, particularly terpenoids, and the crude extracts have valuable bioactive properties. Certain lines of research based on cell lines and animal models show the potential value in different areas of health management. Further investigation into the traditional knowledge in southeast Asian and Pacific island regions, as well as the into the toxicity and identity of the bioactive compounds and their mechanisms of action is necessary.

1. Introduction

Aromatic plants have been used since prehistoric times for their

* Corresponding author.
** Corresponding author.
E-mail addresses: whb1974@126.com (H. Wang), wangyuhua@mail.kib.ac.cn (Y. Wang).
[1] Chen Wang and Hongxia Zhang equally contributed to this work.

https://doi.org/10.1016/j.jep.2021.114075
Received 26 October 2020; Received in revised form 7 March 2021; Accepted 24 March 2021
Available online 3 April 2021
0378-8741/

Abbreviations

ABTS	2,2-azino-bis-3-ethylbenozothiazonline-6-sulfonic acid
CNKI	China National Knowledge Infrastructure
CVH	Chinese Virtual Herbarium
DPPH	2,2-diphenyl-1picrylhydrazyl
EOs	Essential Oils
FRAP	Ferric Reducing/Antioxidant Power assay
GBIF	Global Biodiversity Information Facility
HepG2	Hepatocellular carcinoma cells
HPLC	High Performance Liquid Chromatography
HPTLC	High Performance Thin Layer Chromatography
HSV	*Herpes simplex* virus
LD50	Median lethal dose
MBC	Minimum Bactericidal Concentration
MIC	Minimum Inhibitory Concentration
NSII	National Specimen Information Infrastructure
NVOCs	Non-Volatile Compounds
PDE4	Phosphodiesterase 4
VOCs	Volatile Compounds

culinary and aromatic properties (Franz et al., 2010; Guidi and Landi 2014; Surburg and Panten 2016). Furthermore, certain aromatics are used as additives in cosmetics and animal feeds (Pandey et al., 2020), and many play important roles in the treatment and prevention of human diseases (Silva and Fernandes 2010).

Herbal remedies in the management of human health is the most common use for plants containing essential oils. Plants have been used as medicines through all periods of human history, and this practice is still important in many areas of the world, particularly in developing countries (Guidi and Landi 2014; Piccolella et al., 2018). Plants have formed the basis of sophisticated traditional medicine systems, of which the traditional Chinese and Ayurvedic medicinal systems continue to flourish and contribute to the current popularity of herbal medicines throughout the world (Gurib-Fakim, 2006).

Certain aromatic plant genera have been relatively well-studied, such as *Thymus* L., while others have been almost completely overlooked. For example, very little is known about the oriental genus *Adenosma,* which comprises aromatic herbs, although some taxa in this genus have been investigated because of their frequent use as medicinal plants by certain ethnic peoples. Research has shown that *Adenosma* are not only rich in essential oils but also contain certain important phytochemical compounds (including isoscutellarein-8-O-β-D-glucopyranoside with antidiabetic activity; carvacrol, carvacrol methyl ether, and adenosmin A with insecticidal activity; ursolic acid and betulin with anti-inflammatory activity) with potential roles in human healthcare (Tan 2017; Ma 2018; Fan et al., 2019; Ma et al., 2019; Huu Du et al., 2020; Nguyen et al., 2020).

Adenosma R. Br. belongs to the family Plantaginaceae, and comprises between 26 and 29 species. *Adenosma* species are erect or creeping annual herbs, and are glandular-pubescent or villous and usually strong-scented. Interestingly, harvested plants turn black when drying (Hooker, 1885; Hong et al., 1998).

The utilization of *Adenosma* species in traditional medicine is mentioned in both the Chinese and Ayurvedic medicinal systems. Certain species, including *A. glutinosum*, *A. indianum*, *A. caeruleum*, *A. bracteosum*, and *A. capitatum*, are included in pharmacopoeia and traditional herbal medicine books from China and Vietnam (Dô, 1993), and China's State Administration of traditional Chinese medicine (1998) recommends the use of both the whole plant (including aerial parts and roots) and its essential oils for the treatment of respiratory disorders, gastro-intestinal disorders, and hepatitis (China's State Administration of traditional Chinese medicine, 1998). *Adenosma* species are known to contain volatile oils and phenylpropanoids (Dô, 1993; China's State Administration of traditional Chinese medicine, 1998).

Many of the names of this genus reflect its fragrance. The scientific name, "*Adenosma*", comes from the Greek words *aden-* (gland), and *osme* (smell); the leaves of *Adenosma* species bear odoriferous glands (Chibber 1916). The Chinese name is similar, "毛麝香", meaning "covered with hairs and emitting a musky smell". *Adenosma glutinosum* was mentioned in the Classics of Traditional Chinese Medicine-Collection Records: Lingnan Medicinal Materials (Ling Nan Cai Yao Lu, 岭南采药录) as follows: "毛麝香" is a herb, with fragrant roots, bark, branches and leaves, which can be used as a herb for promoting the penetration of medicines through the skin; the medicinal effect is similar to musk, hence the name (Xiao 2009).

In the same way that thyme was accorded religious status and considered to be a symbol of elegance and grace in ancient Greece, but was also used medically (in baths for the Roma) and as an antiseptic (the ancient Egyptians) (Spiewak et al., 2001; Figueiredo et al., 2008), *Adenosma buchneroides* was regarded as a tribal symbol for the Akha people in Mengla County, China (Gou et al., 2018). *A. buchneroides* is carried by Akha women in a small bundle attached to their caps, or is put into the earhole, and is worn with a sense of pride and belonging, indicating these people are different from other tribes (Shen et al., 1991; Gou et al., 2018).

With the growing consumer interest in organic and herbal-based products, especially products utilizing medicinal and aromatic plants, we reviewed the literature discussing the aromatic genus *Adenosma.* This review aims to provide a summary of the reports on the botany, traditional uses, geographical distribution, phytochemistry, and biological activities of the genus *Adenosma*, as well as any relevant safety concerns, and to highlight the gaps in our knowledge for future research.

2. Materials and methods

For this review, we considered any literature published before 1810 and up to April 2020 that discusses the geographical distribution, and traditional uses of the genus *Adenosma*, or the phytochemistry, biological activity or toxicity of the extracts, essential oils, and isolated compounds from the genus.

For species names and synonyms, we relied on The Plant List (2013) and local Floras. The distribution data and biogeographic information were obtained from Tropicos (2020), the Global Biodiversity Information Facility (GBIF) (2020), the National Specimen Information Infrastructure (NSII) (2020) and research articles.

The scientific names of all the species belonging to genus *Adenosma*, and the vernacular names of the above-mentioned plants in Chinese ("毛麝香", "大头陈", "茵陈") and in Vietnamese ("nhân trần") were used as keywords in literature searches. Much of the research for this review was carried out using the following electronic databases: Web of Science, Science Direct, Google Scholar, Scifinder, Microsoft Academic, eFloras (http://www.efloras.org/), Biodiversity Heritage Library (BHL), and the China National Knowledge Infrastructure (CNKI); an online library search for Ph.D. theses and M.Sc. dissertations was also conducted. Relevant conference notes written in either English or Chinese were also used in this review. A total of 173 references were obtained (36 in Chinese, 15 in Vietnamese, and 121 in English), and of which 85 references had detailed information about the geographical distribution, traditional uses, phytochemistry and biological activities of *Adenosma* species.

Our findings regarding the traditional uses, phytochemical analyses (from both extracts and essential oils), and biological activities are summarized in Tables 1–4, respectively. The chemical structures of all mentioned compounds were sought in the Scifinder and PubChem databases and were redrawn using the ChemDraw Pro 16.0 software.

Table 1
Geographical distributions of *Adenosma* species obtained from the literature survey.

No.	Scientific name	Distribution countries and regions	References
1	*A. annamense* T. Yamaz.	Vietnam	(Yamazaki, 1985)
			(Phuong, 2005)
2	*A. bilabiata* (Roxb.) Merr.	Philippine: Luzon, Palawan, Mindanao; DIST: India to Malaya	(Merrill, 1923)
		Java	(Backer and Brink, 1965)
3	*A. bracteosum* Bonati	Vietnam: Saigon	(Muséum national d'histoire naturelle, 1909)
		Cambodia, Laos and southern Vietnam	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
	A. bracteosum var. *cambodianum* Bonati.	Laos: Bassac	(Muséum national d'histoire naturelle, 1909)
4	*A. caeruleum* R. Br.	India: Khasia; Malaysia: Tenasserim and Malacca; Singapore, Indonesia: Java and Borneo; Australia	(Hooker, 1885)
		Thailand: Klong Sarlakpet; DIST: From India throughout Malaya to Australia	(Clarke, 1900)
		Australia: Queensland; Also met with in Indonesia (Java&Borneo), and India	(Bailey, 1901)
		Australia: Queensland	(Bentham, 1869)
		Malaysia: Sarawak; Indonesia: Borneo; DIST: Vietnam to Australia	(Merrill, 1921)
		Malayan Peninsula: Selangor, Perak; Malaysia: Malacca; Singapore; DIST: Vietnam, Australia	(King, 1907)
		Java	(Backer and Brink, 1965)
		Solomon Islands	(Guppy, 1887)
		Cambodia, Laos, Vietnam	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
5	*A. camphoratum* Hook.f.	Sri Lanka: Ceylon	Hooker, 1885
			(Henry, 1898)
6	*A. cordifolium* Bonati	Vietnam: Ti Cô;	(Muséum national d'histoire naturelle, 1909)
7	*A. debilis* Bonati	Thailand, Laos, Vietnam	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
8	*A. elsholtzioides* T. Yamaz.	southeastern Thailand and Laos	(Yamazaki, 1985)
9	*A. glutinosum* (L.) Druce	China: Macao, Kwangtung, Guangxi, Hainan, Jiangxi, Fujian, Yunnan	(Xing, 2007)
		China: Macao, Kwangtung	(Merrill, 1917)
		China, Cambodia, India, Indonesia, Laos, Malaysia, Thailand, Vietnam, Australia, Oceania	(Wu et al., 1998)
10	*A. hirsutum* (Miq.) Kurz	Bornean. DIST: Malay Peninsula, Indonesia (Sumatra, Banca)	(Merrill, 1921)
		DIST: India (Nicobars); Malaysia (Sumatra, Borneo, Wellesley), Indonesia (Bangka);	(King, 1907)
		Cambodia, Laos	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
11	*A. indianum* (Lour.) Merr.	India: outer lower Himalaya, from Kumaon to Sikkim; Bengal and Assam to Malacca, Travancore and Ceylon; DIST:India, Malaysia, Myanmar, China, Sri Lanka	Hooker, 1885
			(Henry, 1898)
		Sri Lanka: Ceylon; DIST: India, Myanmar, Malaysia, China.	
		Thailand: Koh Chang; DIST: Common in India and the Malay Peninsula; also in India (Banka), Malaysia (Borneo), Vietnam (Tonkin).	(Clarke, 1900)
		Bornean: Sarawak; British North Borneo; DIST: tropical Asia and Malaysia	(Merrill, 1921)
		Malaysia (Penang, Malacca, Negri Sembilan, Pedas, Pahang, Wellesley); Singapore; DIST: Throughout S.E. Asia.	(King, 1907)
		Thailand: Chiengmai; DIST: S. E. Asia	(Craib, 1912)
		Bhutan: Balasun, Darjeeling, Siliguri; Nepal	(Grierson and Long, 2001)
		Singapore	(Turner, 1993)
		Sri Lanka, India, Myanmar, southern China, Cambodia, Laos, Vietnam, Thailand, the Malaysian Peninsula, Java, Borneo and the Philippines	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
		China, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, Philippines, Sikkim, Thailand, Vietnam	(Wu et al., 1998)
12	*A. inopinatum* Prain	Malaysia: Malacca; Singapore	(King, 1907)
		Singapore	(Turner, 1993)
13	*A. javanicum* (Blume) Koord.	Philippine (Luzon, Samar, Panay, Mindanao); DIST: Myanmar and Vietnam through Malaysia to the Indonesia (Moluccas).	(Merrill, 1923)
		Bornean: north Borneo; DIST: Vietnam to Malaysia and the Philippines;	(Merrill, 1921)
		Northeastern New Guinea	(Pennell, 1943)
		Java	(Backer and Brink, 1965)
		Singapore	(Turner, 1993)
		Cambodia, Laos, Vietnam	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
		China, Cambodia, India, Indonesia, Laos, Malaysia, New Guinea, Philippines, Thailand, Vietnam	(Wu et al., 1998)
14	*A. macrophyllum* Benth.	Myanmar: banks of the Irawaddi, Wallich	Hooker, 1885
15	*A. malabaricum* Hook. f.	India: Malabar	Hooker, 1885
16	*A. microcephalum* Hook.f.	Myanmar: Tenasserim, Moulmein; DIST: Cambodia	Hooker, 1885
		Southern Myanmar, Thailand, Cambodia, Laos and Vietnam	(Yamazaki, 1985)
		Vietnam	(Phuong, 2005)
17	*A. muelleri* Benth.	Australia: Macarthur river	(Ewart and Davies, 1943)
		Australia: Macarthur River	(Bentham, 1869)
18	*A. ovatum* (Benth.) Benth.	Malay peninsula; from Myanmar (Tenasserim), to Malaysia (Malacca). DIST: Indonesia (Sumatra, Java), Malaysia (Borneo)	Hooker, 1885
		Malayan Peninsula: Malaysia (Perak, Gunong Tundul; Penang, Malacca; Singapore; DIST: Vietnam, Malaysia	(King, 1907)
		Papua New Guinea: Bismarck Archipelago, New	(Schumann and Lauterbach, 1901)

(continued on next page)

Table 1 (*continued*)

No.	Scientific name	Distribution countries and regions	References
		Mecklenburg, Southwest Kute. DIST: common in Malaysia	
19	*A. papuana* Schltr.	Northeastern Papua New Guinea	(Pennell, 1943)
20	*A. punctata* Pennell	Northeastern Papua New Guinea: Morobe District, Malolo Mountains	(Pennell, 1943)
21	*A. ramosum* Bonati	Vietnam	(Muséum national d'histoire naturelle, 1909)
22	*A. retusilobum* P.C. Tsoong & T.L.Chin	China	(Wu et al., 1998)
23	*A. subrepens* Benth. ex Hook.f.	Sri Lanka: Ceylon	Hooker, 1885 (Henry, 1898)
24	*A. ternata* Pennell	Papua New Guinea	(Pennell, 1943)
25	*A. thorelii* Bonati	Cambodia: Oudong	(Muséum national d'histoire naturelle, 1909)

3. Distribution

Adenosma species are found throughout South and South-East Asia, China, and the Pacific Islands (Hong et al., 1998). The main distribution area is consistent with the developing regions of Asia. In these areas, many local cultures still use medicinal and aromatic plants as the main cures for human diseases. However, although the cultures are rich in traditional knowledge regarding these plants, modern research, especially into the biological activity of *Adenosma,* is rare.

The name *Adenosma* was first published by Robertus Brown as a member of the Scrophulariaceae, and the type species, *A. caerulea*, was described in "Prodromus florae Novae Hollandiae et insulae Van-Diemen" (Brown 1810). In the reclassification following phylogenetic work from the Angiosperm Phylogeny Group, *Adenosma* was placed in the family Plantaginaceae (Albach et al., 2005; Byng et al., 2016). Hooker (1961) reported that the Indian *Adenosma* flora consisted of a very few tropical Asiatic plants, while the Flora of China (2020) reported 15 species, of which 4 are endemic to China, and the Plant List (2013) included 26 accepted species and 3 unresolved species of *Adenosma*. A total of 26 species are currently recognized, and the genus has a distribution spanning more than 20 countries and regions. The distribution records of *Adenosma* species taken from the monographs studied here are summarized in Table 1.

We obtained occurrence data from *Adenosma* herbarium specimens viewed in the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) and the Chinese Virtual Herbarium (CVH, http://v5.cvh.ac.cn/). Geographical distributions of the species in the genus *Adenosma* are given in Fig. 1.

The *Adenosma* species were found to have distributions mainly in the subtropical and tropical regions of Asia, the Pacific Islands, and Oceania. The six species for which detailed geographical distribution information was available are highlighted with circles (Fig. 2).

4. Traditional uses

Seven species (*A. bracteosum, A. buchneroides, A. caeruleum, A. glutinosum, A. indianum, A. retusilobum,* and *A. triflora*) of the genus are reported to be used in folk health care systems, as herbal medicines, insecticides, tonics, and for other purpose. A summary of the seven *Adenosma* species studied, as well as their vernacular names, the parts used, and the modes of preparation is presented in Table 2. In this review, the traditional preparations and way of use mainly refers to the folk knowledge of use inherited and handed down from one generation to the next by custom and tradition, and prepared easily (Asia 2011).

All parts of the plants are utilized, the aerial parts being the most frequently used. The aerial parts of *Adenosma* plants are used in both fresh and dried form, as medicines, perfumes, insect repellents and as animal feed medication (Shen et al., 1991; Dũng et al., 1996; Xu et al., 2008; Gou et al., 2018; Fan et al., 2019). Fresh leaves are crushed rubbed onto an insect bite or acne to relieve itching (Hou 1956; Gou et al., 2018), or can be used to make a medicinal tea to treat coughs and colds, stomach-ache or loss of appetite (Parham 1939; Dô, 1993). Plants to be used dried are harvested when in full bloom, as material harvested at this stage is considered to produce the most efficacious medicines (Shen et al., 1991; Dũng et al., 1996; Gou et al., 2018). The plant parts investigated in phytochemical and pharmacological studies are either the aerial parts or the whole plant, which correspond to those parts most commonly used traditionally; however, to date the chemical composition and pharmacological activity of *Adenosma* species at different developmental stages and the activities of different tissue parts have not been reported.

In human healthcare, the plants are described as being most widely prepared as infusions (herbal teas) and decoctions for oral administration. If *Adenosma* is to be used as an insecticide, bunches of cut plants are commonly placed in rooms or plants are spread on beds (Shen et al., 1991; Gou et al., 2018; Ma et al., 2019). As with most herbal medicines, these plants are often mixed with other herbs when used in traditional medicine. When used as a spice or an insect repellent, however, *Adenosma* is used alone. When used for its scent, however, it is used either alone or in combination with other herbs (Shen et al., 1991; Dô, 1993; Gou et al., 2018).

From the literature, it can be seen that the seven *Adenosma* species found to have traditional uses have similarities, but also have their own characteristics. The traditional uses of these seven plants vary widely, and more than ten uses are reported, especially from the well-studied species in ethnopharmacology: *A. bracteosum*, *A. buchneroides*, *A. caeruleum*, *A. glutinosum*, and *A. indianum*. Nevertheless, species that have been widely reported as having traditional uses have also been chosen to be the subjects of more chemical composition and pharmacological activity studies than other species. It is therefore important to realize that the abundance of traditional uses of seems to be proportional to the number of reports in the literature reviewed, as can be seen from the abundance of knowledge of the traditional uses of *A. buchneroides*. The question then arises of whether the literature covers all the traditional uses, and conversely, whether the species with fewer scientific reports are equally important for the local communities but underrepresented in the literature?

In general, the traditional uses of plants of the reviewed *Adenosma* species can be divided into four types: medicines, insecticides, veterinary medicines, and condiments. Among these, of particular importance are the treatments for hepatitis, skin diseases, and colds, and the improvement of immunity, particularly for women post-partum. A further widespread use is as an insect repellent, especially against blood-sucking insects such as mosquitoes and fleas. *A. caeruleum* has been reported to be used in the treatment of the serious infectious disease yellow fever, although this may be related to the use as an insect-repellent, with the production of terpenoids. Whether *A. caeruleum* is effective as a febrifuge in yellow fever patients, and whether it is active against the yellow fever virus or the mosquitoes are questions worthy of in-depth study.

Both *A. caeruleum* and *A. glutinosum* are used traditionally to strengthen the immune system of humans and other animals (Dũng et al., 1996; Chi et al., 2017), although to date there are no scientific reports of the chemical components or pharmacological activity. Given the current COVID-19 epidemic raging around the world, any herbs which are able to improve immunity are worthy of attention and systematic research.

In China, four species were recorded as being used as herbal medicines, namely *A. buchneroides*, *A. glutinosum*, *A. indianum,* and *A. retusilobum* (Shen et al., 1991; Chen et al., 2016; Gou et al., 2018; Fan et al., 2019; Yao et al., 2020).

Table 2
Traditional uses of *Adenosma* spp.

Species	Vernacular name	Traditional uses	Used parts	Preparation and administration	Country/ region	Reference
A. bracteosum Bonati	Nhân trần tía,nhân trần Tây Ninh, nhân trần cải, chè cát	hepatitis jaundice, cholecystitis	stems, branches with leaves and flowers	decoction	Vietnam	Dô, 1993
		treating skin disease		wash with water or crush into the sore spot		
		regulate menstrual cycle		decoction (with other herbs)		
		treating viral hepatitis		decoction (with other herbs)		
A. buchneroides Bonati	Lao-wo-shou-du	insecticide	dried aerial parts	bundles in rooms or spread on beds	China	(Shen et al., 1991; Xu et al., 2008)
		decoration and perfume		bundles wear in ear-holes or only in right side ear-hole; small bundle linked with woman's cap		
		family health care		decoction		
	Lawrzaq Ghawadov	repelling mosquitoes&fleas	aerial parts	laying or hanging in house		Fan et al. (2019)
	Lang-suo-du; La-san-suo-du	perfume; decoration	aerial parts	placed in samll bundles and worn in ear-holes or on caps	China, Laos	Gou et al. (2018)
		headache; stuffy nose			China	
		insect repellent		hung on the window/placed on the floor or bed		
		praying for a bumper harvest		placed in samll bundles and hung on the wall of granaries	Laos	
		influenza, diarrhea	whole plant	infusion	China	
		insecticide		boiled in water used as body lotion		
		insecticide		planted around the house		
		insect bites, acne	leaves	crushed leaves rubbed on a wound		
		condiment	leaves	as a fragrance taste	Laos	
A. caeruleum R.Br.	Nhân trần	stimulate appetite, improve blood circulation	dried aerial parts	used in daily drinks	Vietnam	Dũng et al. (1996)
		postpartum rehabilitation		decoction		Dô, 1993
		treating yellow fever		decoction (with other herbs)/ 3times a day		
		treating heatstroke, headache, fever		decoction (with Allium cepa)		
		treating jaundice		decoction (with other herbs)		
		veterinary medicine-treating diseases of white shit		tonic		
A. glutinosum (L.) Druce	Nhân Trần	enhance the immunological status of shrimp	aerial parts	boiling with other herbs and mixed with feed pellets	Vietnam	(Chi et al., 2017)
		treating hepatitis, tonic for woman		–		Ueda et al. (2002)
	Nhân trần nhân sâm; nhân sâm; Sâm; tam thất	good for health		decoction		Peltzer et al. (2017)
	Mao she	rheumatic arthritis, traumatic injury	whole plant	decoction, compress	China	Chen et al. (2016)
	解菜	dispel wind and relieve pain, dispel blood stasis and swelling, detoxify and relieve itching	whole plant	–		Hong and Pan (2006)
	毛麝香	indications for rheumatism, sore and itching	leaves	alternative to musk		Hou (1956)
A. indianum (Lour.) Merr.	Nhân trần bồ bồ	treating jaundice, biliary tract disease and postpartum women's disease	whole plant at flowering stage washed and air-dried	daily dose of 10–20g for 3 times	Vietnam	(Nguyen et al., 1990)
		preventing and treating flu	dried stems, branches with leaves and flowers	decoction	Vietnam	Dô, 1993
	大头陈	curing influenza	aerial parts	Sanjin cold Tablet take orally 3 times a day	China	Yao et al. (2020)
	Adenosyl	treatment	whole plant	–	Laos	Peltzer et al. (2016)
	野薄荷	cold, fever, headache, indigestion	whole plant	decoction	China	Hong and Pan (2006)
A. retusilobum P.C. Tsoong & T.L.Chin	钝裂毛麝香	treat bruises and beriberi	whole plant	using essential oils on skin	China	Hong and Pan (2006)
A. triflora Seem.	Damoli; Tamola	coughs and colds; stomach-ache & loss of appetite	leaves	decoction	Fiji	Parham (1939)

Four species are also employed in Vietnam for the treatment of various disorders in humans and shrimps. The species include *A. bracteosum, A. caeruleum, A. capitatum,* and *A. glutinosum* (Nguyen et al., 1990; Dô, 1993; Dũng et al., 1996; Ueda et al., 2002; Peltzer et al., 2017; Chi et al., 2017). The use of *Adenosma* for the treatment of disease in postpartum women has a long history in Vietnam, and a traditional mothers' song, "Nhân trần, ích màu đi đâu, để cho gái để đơn đâu thế này" (Where is Nhân trần, good for women? To give a painful girl like

Table 3
Main phytochemicals identified from *Adenosma* spp. (excluding essential oil).

Phytochemical category	Structure No.	Phytochemical name	Species	Parts used	Extract	Reference
Monoterpenoids	1	7-Hydroxy-piperitone	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	2	Monoterpenoid peroxide-2	*A. caeruleum* R.Br.	aerial parts	$CHCl_3$	Adam et al. (1992)
	3	Monoterpenoid peroxide-3	*A. caeruleum* R.Br.	aerial parts	$CHCl_3$	Adam et al. (1992)
	4	Monoterpenoid peroxide-1	*A. caeruleum* R.Br.	aerial parts	$CHCl_3$	Adam et al. (1992)
	5	(*R*)-2-(3-hydroxyl-4-methylphenyl) propan-1-ol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	6	Carvacrol-*β*-*D*-glucopyranoside	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	7	(6*R*)-menthiafolic acid	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
Iridoids	8	Glycoside adenosmoside	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	9	Aucubin	*A. caeruleum* R.Br.	aerial parts	chloroform ext.	Tran (1997)
Diterpenoids	10	13-epi-sclareol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	11	Sclareol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
Triterpenoids	12	Betulinic acid	*A. bracteosum* Bonati	aerial parts	Ethanol	Quynh et al. (2013)
			A. buchneroides Bonati	whole plant	Methanol	Ma (2018)
			A. caeruleum R.Br.	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
			A. caeruleum R.Br.	aerial parts	chloroform ext.	Tran (1997)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
			A. indianum (Lour.) Merr.	aerial parts	Ethanol	Lu et al. (2014)
			A. indianum (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	13	Betulin	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
			A. indianum (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	14	30-oxo-betuklinic acid	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	15	3*β*-Hydroxy-urs-11-en-13*β*, 28-olide	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	16	Ursolic acid	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	17	Squalene	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
Phenylpropanoids	18	*Trans*-*p*-Hydroxylcinnamic acid	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	19	Coniferaldehyde	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	21	Acetylmartynoside C	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	20	Sinapaldehyde	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	22	Eugenol-*β*-*D*-glucopyranoside	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	23	Erigeside II	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	24	Crenatoside	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	25	Verbascoside	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	26	Campneoside I	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	27	Campneoside II	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	28	Cistanoside F	*A. caeruleum* R.Br.		Methanol	

(*continued on next page*)

Table 3 (*continued*)

Phytochemical category	Structure No.	Phytochemical name	Species	Parts used	Extract	Reference
				aerial parts		De Abreu et al. (2009)
	29	Threo-buddlenol A	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	30	Erythro-buddlenol A	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	31	(8*r*)-evofolin b	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	32	(−)-Balanophonin	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	33	(+)-syzygiresinol A	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	34	Sesamin	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	35	(+)-Medioresinol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	36	(+)-Syringaresinol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	37	Syringaresinol-4-*O*-*β*-*D*-glucopyranoside	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	38	(+)-4″-*De*-*O*-methylmagnolin	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
Phenols	39	Precocene II	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	40	*P*-Hydroxybenzoic acid	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	41	*P*-Hydroxybenzaldehyde	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	42	*P*-Hydroxybenzoic acid	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	43	4-Hydroxy- Benzeneethanol	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
	44	*P*-Hydroxybenzyl alcohol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	45	*P*-HHHydroxyacetophenone	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	46	Arbutin	*A. caeruleum* R.Br	aerial parts	chloroform ext.	Tran (1997)
	47	1,3,5-Trimethoxybenzene	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	48	*P*-Methoxybenzyl alcohol	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	49	3,5-Dimethoxyacetophenone	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	50	4,4′-Dihydroxydibenzyl ether	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
Flavonoids	51	5,6-Dihydroxy-7,8,4′-trimethoxy-flavone	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	52	Apigenin	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	53	Isoscutellarein-8-*O*-*β*-*D*-glucopyranoside	*A. bracteosum* Bonati	whole plant	Ethanol	Nguyen et al. (2020)
	54	6-Methoxyl-scutellarin	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	55	6-Methoxy-3-*O*-methylkaempferol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	56	Apigenin7-*O*-*β*-*D*-glucuronopyranoside	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	57	Apigenin-7-*O*-*β*-*D*-glucopyranoside	*A. caeruleum* R.Br.	aerial parts	Methanol	De Abreu et al. (2009)
	58	Apigenin-*7-0*-*β*-*D*-glucuronide butyl ester	*A. glutinosum* (L.) Druce	whole plant	Ethanol	Yu et al. (2018)
Sterols and Glycosides	59	*Β*-Sitosterol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
			A. caeruleum R.Br	aerial parts	chloroform ext.	Tran (1997)
			A. caeruleum R.Br	aerial parts	n-hexane- and Et acetate- ext. Ethanol	Nguyen et al. (2012)

(*continued on next page*)

Table 3 (*continued*)

Phytochemical category	Structure No.	Phytochemical name	Species	Parts used	Extract	Reference
			A. glutinosum (L.) Druce	whole plant		(Tan 2017; Yu et al., 2018)
			A. indianum (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	60	*Β*-Daucosterin	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	61	7*α*-Hydroxysitosterol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	62	*Β*-Sitosteryl-3*β*-glucopyranoside-6′-*O*-palmitate	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	63	Stigmasterol	*A. bracteosum* Bonati	aerial parts	Ethanol	Quynh et al. (2013)
			A. caeruleum R.Br	aerial parts	chloroform ext.	Tran (1997)
			A. glutinosum (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	64	Campesterol	*A. caeruleum* R.Br	aerial parts	chloroform ext.	Tran (1997)
Organic Acids	65	Fumaric acid	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	66	Muconic acid	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Tan et al., 2017)
	67	Palmitic acid	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	68	Octadecanoic acid	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
			A. indianum (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	69	Triacontanoic acid	*A. caeruleum* R.Br	whole plant	ethyl acetate	Nguyên (2017)
	70	Tetratriacontanoic acid	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	71	Pentatriacontanoic acid, methyl ester	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	72	Heptatriacontanoic acid	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	73	(9Z,12Z)-9,12-Octadecadienoic acid	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
	74	Balansenate I	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	75	1-Linoleoylglycerol	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)
	76	Triacontanoic acid, 2-(4-hydroxyphenyl)ethyl ester	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
	77	9,12-Octadecadienoic acid (9Z,12Z)-,1,1'-[1-[[(1-oxooctadecyl)oxy]methyl]-1,2-ethanediyl] ester	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
	78	*A, β*-Dilinoleostearin	*A. caeruleum* R.Br	whole plant	ethyl acetate	Nguyên (2017)
N-alkanes and Alcohols	79	Nonacosanol	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	80	Hentriacontanol	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	81	Tetracontane	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	82	Tritetracontane	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	83	Hexacosyl alcohol	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
	84	1-Heptacosanol	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
			A. caeruleum R.Br	whole plant	ethyl acetate	Nguyên (2017)
	85	1-Tritetracontanol	*A. indianum* (Lour.) Merr.	whole plant	Ethanol	(Ya et al., 2011b)
	86	Glycerine	*A. caeruleum* R.Br	aerial parts	n-hexane- and Et acetate- ext.	Nguyen et al. (2012)
Alkaloids	87	Indole-3-carboxaldehyde	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
	88	Indole-3-carboxylic acid	*A. buchneroides* Bonati	whole plant	methanol and aqueous methanol (40:60)	(Ma 2018; Ma et al., 2018)
Quinonoids	89	Physcion	*A. glutinosum* (L.) Druce	whole plant	Ethanol	(Tan 2017; Yu et al., 2018)
Other compounds	90	*D*-Allitol	*A. glutinosum* (L.) Druce	whole plant	Ethanol	Yu et al. (2018)
	91				Methanol	Ma (2018)

(continued on next page)

Table 3 (*continued*)

Phytochemical category	Structure No.	Phytochemical name	Species	Parts used	Extract	Reference
		(3*R*)-Octen-3-yl *β-D*-Glucopyranoside	*A. buchneroides* Bonati	whole plant		
	92	(1*R*,2*R*)-2-[(2*Z*)-5-Hydroxy-2-penten-1-yl]-3-Oxocyclopentaneacetic- acid	*A. buchneroides* Bonati	whole plant	Methanol	Ma (2018)

this), teaches girls that *A. bracteosum* can be used to regulate the menstrual cycle, and *A. caeruleum* for postpartum rehabilitation (Dô, 1993).

A. buchneroides and *A. indianum* are reported to be used as perfumes in Laos (Peltzer et al., 2016; Gou et al., 2018), and *A. triflora* is used in the islands of Fiji to treat colds and stomach diseases (Parham 1939).

Adenosma species contain aromatic oils, and many species are used for medicinal purposes (Wu et al., 1998). However, despite the wide geographical distribution of *Adenosma*, studies into the genus are very few and only available from the countries: China, Vietnam and Laos, with a single simple description of the traditional uses of *Adenosma* from Fiji. It is clear that many of the regions in which *Adenosma* species grow lack research, and in these regions, it is unclear whether, and if so how, *Adenosma* species are used in these communities. These topics are worthy of further in-depth study.

5. Phytochemistry

Adenosma species contain a wide variety of phytochemical classes. Terpenoids, phenylpropanoids, phenols, flavonoids, sterols, fatty acids and esters, N-alkanes and alcohols, alkaloids, quinonoids, and essential oils have been isolated from five *Adenosma* species (Ji and Pu 1985; Nguyễñ and Dô, 1991; Dũng et al., 1996; Ma et al., 2019). Furthermore, whole plant extracts have been made of *Adenosma* species and subjected to HPLC and HPTLC, to illucidate the chemical composition of these plants (Tan et al., 2017; Ma et al., 2018). Detailed and extensive chemical investigation of seven widely used *Adenosma* species (*A. bracteosum*, *A. buchneroides*, *A. caeruleum*, *A. capitatum*, *A. glutinosum*, and *A. indianum*) has led to the characterization of a large number of bioactive constituents (Adam et al., 1992; Tran 1997; De Abreu et al., 2009; Ya et al., 2011b; Nguyen et al. 2012, 2020; Quynh et al., 2013; Lu et al., 2014; Nguyên 2017; Tan 2017; Tan et al., 2017; Ma 2018; Yu et al., 2018), the isolation of new compounds (Adam et al., 1992; De Abreu et al., 2009; Ma 2018; Nguyen et al., 2020), and the isolation for the first time in the genus *Adenosma* of a series of compounds, mainly terpenoids (Tran 1997; Ya et al., 2011b; Nguyen et al., 2012; Tan 2017; Tan et al., 2017; Ma 2018; Yu et al., 2018). Our literature review revealed a total of 229 known chemical constituents from *Adenosma* species, of which 59.8% are volatile compounds (VOCs), and 40.2% are non-volatile compounds (NVOCs). The NVOCs from the whole plant extracts of different *Adenosma* species are listed in Table 3, their structures are given in Fig. 3, and the chemical constituents of the VOCs are summarized in Table 4. The majority of the compounds identified are terpenoids and phenylpropanoids.

5.1. Terpenoids

Terpenoids, which are formed by condensation of isoprene or isopentane units, are some of the most numerous and structurally diverse natural products, and comprise most of the phytochemicals in the genus *Adenosma*. They also play a key role in the biological activity of this genus, particularly as insect repellents and in their treatment of gastrointestinal diseases.

Several classes of terpenoids have been identified from *Adenosma*, including monoterpenoids, iridoids, diterpenoids, and triterpenoids. Of these, monoterpenoids (**1–7**) (Adam et al., 1992; Tan 2017; Tan et al., 2017; Ma 2018; Ma et al., 2018) and triterpenoids (**12–17**) (Tran 1997; Ya et al., 2011b; Nguyen et al., 2012; Quynh et al., 2013; Lu et al., 2014; Tan 2017; Tan et al., 2017; Ma 2018; Yu et al., 2018) are the most commonly reported compounds in the genus, while two diterpenoids (**10, 11**) (Ma 2018) were isolated from *A. buchneroides*, and two iridoids (**8, 9**) (Tran 1997; De Abreu et al., 2009) were isolated from *A. caeruleum*.

The most frequently mentioned study species is *A. buchneroides*, from which eight terpenoids ((R)-2-(3-hydroxyl-4-methylphenyl) propan-1-ol (**5**), carvacrol-*β*-D-glucopyranoside (**6**), (6R)-menthiafolic acid (**7**), 13-epi-sclareol (**10**), sclareol (**11**), betulinic acid (**12**), betulin (**13**), squalene (**17**) were isolated by Ma et al. (Ma 2018; Ma et al., 2018).

5.1.1. Monoterpenoids

Monoterpenoids, a class of terpenes, have a ten-carbon backbone consisting of two isoprene units. They can be widely found in plant secretory structures such as glandular trichomes, oil cells and resin ducts, and are chief constituents of the essential oils (Ludwiczuk et al., 2017). Monoterpenoids are the most commonly reported terpenoids from *Adenosma*, and seven have been reported from the genus to date: 7-hydroxy-piperitone (**1**); monoterpenoid peroxide-2 (**2**); monoterpenoid peroxide-3 (**3**); (6R)-menthiafolic acid (**4**); monoterpenoid peroxide-1 (**5**); (R)-2-(3-hydroxyl-4-methylphenyl) propan-1-ol (**6**); and carvacrol-β-D-glucopyranoside (**7**) (Adam et al., 1992; Tan 2017; Tan et al., 2017; Ma 2018; Ma et al., 2018).

These monoterpenoids can be divided into two subgroups: acyclic and monocyclic. Of these, (**7**) is an acyclic monoterpenoid, and (**1–6**) are monocyclic.

5.1.2. Iridoids

A further subgroup of monoterpenoids, the iridoids, has a six-membered ring with an oxygen atom fused to a cyclopentane ring (the iridane skeleton), and can be divided into four main groups: iridoid glycosides, nonglycosylated iridoids, secoiridoids, and bisiridoids (Ludwiczuk et al., 2017).

At present, only two iridoid glucosides, glycoside adenosmoside and aucubin, are known from *Adenosma*. Glycoside adenosmoside, (**8**), was first isolated by De Abreu et al. (2009) from a methanol extract of the aerial parts of *A. caeruleum*, and is a colorless amorphous powder (De Abreu et al., 2009). Aucubin (**9**) is the most common iridoid glycoside and has a wide range of biological activities, and has been isolated from the same species, *A. caeruleum* (Tran 1997).

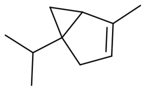
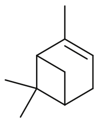
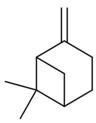
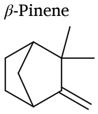
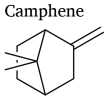
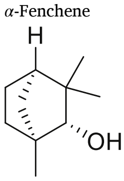
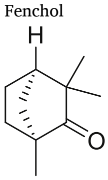
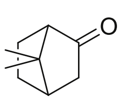
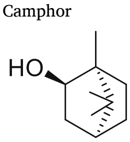
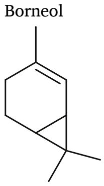
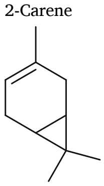
5.1.3. Diterpenoids

Diterpenoids include many medicinally and industrially relevant compounds, all containing 20 carbon atoms based on four isoprene units. To date, only two bicyclic diterpenoids, 13-epi-sclareol (**10**) and sclareol (**11**), have been isolated from the genus (from *A. buchneroides*), by Ma et al. (Ma 2018).

5.1.4. Triterpenoids

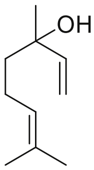
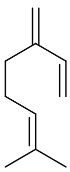
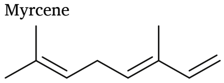
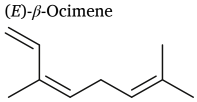
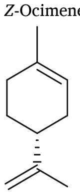
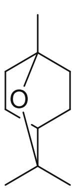
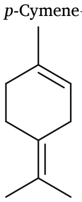
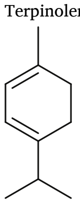
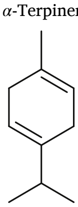
Triterpenoids consist of a 30-carbon backbone (6 isoprene units). Betulinic acid (**12**) is the most commonly identified terpene compound in *Adenosma*, and has been reported to have anti-bacterial activity. It has been found in *A. bracteosum*, *A. buchneroides*, *A. caeruleum*, *A. glutinosum*, and *A. indianum* (Tran 1997; Ya et al., 2011b; Nguyen et al., 2012; Quynh et al., 2013; Lu et al., 2014; Tan 2017; Tan et al., 2017; Ma 2018). Betulin (**13**) has been isolated from *A. indianum* (Ya et al., 2011b), *A. buchneroides* (Ma 2018) and *A. glutinosum* (Tan 2017; Tan et al.,

Table 4
Main phytochemicals identified in the essential oil obtained from *Adenosma* spp.

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
1	 α-Thujene	*A. caeruleum* R.Br.	2.40%	aerial parts	Dũng et al. (1996)
2	 α-Pinene	*A. buchneroides* Bonati	1.24%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	21.08%	aerial parts	Nguyêñ and Dô, 1991
			22.70%	aerial parts	Dũng et al. (1996)
		A. glutinosum (L.) Druce	6.98%	leaves	Yang et al. (2013)
			4.80%	aerial parts	Wang et al., 2008
		A. indianum (Lour.) Merr.	5.65%	aerial parts	Nguyêñ and Dô, 1991
			6.04%	whole plant	(Ya et al., 2011a)
			5.52%	aerial parts	Ji and Pu (1985)
			1.17%	aerial parts	Zeng et al. (2013)
3	 β-Pinene	*A. indianum* (Lour.) Merr.	4.07%	aerial parts	Ji and Pu (1985)
4	 Camphene	*A. glutinosum* (L.) Druce	1.26%	leaves	Yang et al. (2013)
5	 α-Fenchene	*A. caeruleum* R.Br.	9.00%	aerial parts	Nguyêñ and Dô, 1991
		A. indianum (Lour.) Merr.	1.13%	aerial parts	Nguyêñ and Dô, 1991
			1.09%	whole plant	(Ya et al., 2011a)
6	 Fenchol	*A. capitatum* (Benth.) Benth. ex Hance	2.08%	aerial parts	Bhuiyan et al. (2010)
			2.08%	aerial parts	Chowdhury et al. (2011)
		A. indianum (Lour.) Merr.	2.85%	aerial parts	Nguyêñ and Dô, 1991
			1.85%	whole plant	(Ya et al., 2011a)
			1.40%	whole plant	(Huang et al., 2011)
			1.40%	whole plant	Wu et al. (2010)
			4.34%	aerial parts	Zeng et al. (2013)
7	 Fenchone	*A. capitatum* (Benth.) Benth. ex Hance	21.59%	aerial parts	Bhuiyan et al. (2010)
			21.59%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	19.36%	leaves	Yang et al. (2013)
		A. indianum (Lour.) Merr.	33.50%	aerial parts	Le (1977)
			24.84%	aerial parts	Nguyêñ and Dô, 1991
			1.71%	whole plant	Huang et al. (2013)
			11.70%	whole plant	(Huang et al., 2011)
			11.70%	whole plant	Wu et al. (2010)
			13.90%	aerial parts	Ji and Pu (1985)
			31.81%	aerial parts	Zeng et al. (2013)
8	 Camphor	*A. bracteosum* Bonati	1.10%	aerial parts	Tsankova et al. (1994)
		A. indianum (Lour.) Merr.	6.85%	aerial parts	Nguyêñ and Dô, 1991
9	 Borneol	*A. bracteosum* Bonati	2%	aerial parts	Dai et al. (2015)
			4.80%	aerial parts	Tsankova et al. (1994)
		A. indianum (Lour.) Merr.	1.35%	whole plant	Wu et al. (2010)
			1.42%	aerial parts	Nguyêñ and Dô, 1991
10	 2-Carene	*A. capitatum* (Benth.) Benth. ex Hance	17.64%	aerial parts	Bhuiyan et al. (2010)
			17.64%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	1.54%	leaves	Yang et al. (2013)
11	 3-Carene	*A. buchneroides* Bonati	1.24%	aerial parts	Ma et al. (2019)
			1.67%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	1.30%	aerial parts	Dũng et al. (1996)

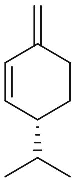
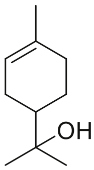
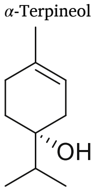
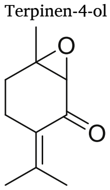
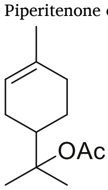
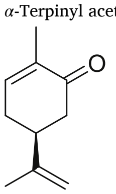
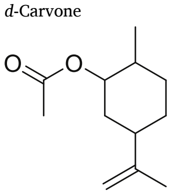
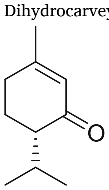
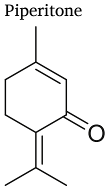
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
12	 Linalool	*A. bracteosum* Bonati	13.10%	aerial parts	Tsankova et al. (1994)
			8.99%	aerial parts	Nguyêñ and Dô, 1991
			13.10%	aerial parts	Tsankova et al. (1994)
		A. indianum (Lour.) Merr.	7.29%	aerial parts	Ji and Pu (1985)
13	 Myrcene	*A. caeruleum* R.Br.	1.50%	aerial parts	Dũng et al. (1996)
14	 (*E*)-*β*-Ocimene	*A. caeruleum* R.Br.	4.00%	aerial parts	Dũng et al. (1996)
15	 *Z*-Ocimene	*A. capitatum* (Benth.) Benth. ex Hance	1.15%	aerial parts	Bhuiyan et al. (2010)
			1.15%	aerial parts	Chowdhury et al. (2011)
16	 Limonene	*A. buchneroides* Bonati	1.75%	aerial parts	Ma et al. (2019)
			2.49%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	1.22%	aerial parts	Nguyêñ and Dô, 1991
			24.74%	aerial parts	Bhuiyan et al. (2010)
			24.74%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	24.40%	leaves	Yang et al. (2013)
			3.59%	aerial parts	Wang et al., 2008
		A. indianum (Lour.) Merr.	22.60%	aerial parts	Le (1977)
			43.39%	aerial parts	Nguyêñ and Dô, 1991
			24.72%	whole plant	(Ya et al., 2011a)
			13.46%	whole plant	(Huang et al., 2011)
			13.46%	whole plant	Wu et al. (2010)
			12.36%	aerial parts	Ji and Pu (1985)
			20.59%	aerial parts	Zeng et al. (2013)
17	 1,8-Cineole	*A. bracteosum* Bonati	–	aerial parts	Châu and Van Hông (1992)
			1.03%	aerial parts	Nguyêñ and Dô, 1991
		A. caeruleum R.Br.	49.11%	aerial parts	Nguyêñ and Dô, 1991
			18.20%	aerial parts	Dũng et al. (1996)
		A. glutinosum (L.) Druce	19.82%	leaves	Yang et al. (2013)
			33.04%	aerial parts	Wang et al., 2008
		A. indianum (Lour.) Merr.	8.22%	whole plant	(Ya et al., 2011a)
			2.17%	whole plant	Wu et al. (2010)
18	*p*-Cymene+1,8-cineol	*A. indianum* (Lour.) Merr.	12.79%	aerial parts	Ji and Pu (1985)
19	 Terpinolene	*A. caeruleum* R.Br.	4.14%	aerial parts	Nguyêñ and Dô, 1991
			6.80%	aerial parts	Dũng et al. (1996)
		A. indianum (Lour.) Merr.	27.84%	whole plant	(Ya et al., 2011a)
20	 *α*-Terpinene	*A. bracteosum* Bonati	1.20%	aerial parts	Dai et al. (2015)
		A. buchneroides Bonati	1.77%	aerial parts	Ma et al. (2019)
			4.05%	aerial parts	Xu et al. (2008)
21	 *γ*-Terpinene	*A. bracteosum* Bonati	9.20%	aerial parts	Dai et al. (2015)
			8.50%	aerial parts	Tsankova et al. (1994)
		A. buchneroides Bonati	34.86%	aerial parts	Ma et al. (2019)
			40.26%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	16.90%	aerial parts	Dũng et al. (1996)
		A. capitatum (Benth.) Benth. ex Hance	3.04%	aerial parts	Bhuiyan et al. (2010)
			3.04%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	6.87%	leaves	Yang et al. (2013)

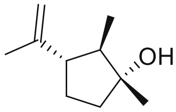
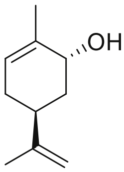
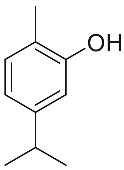
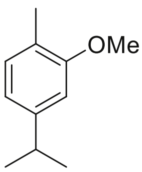
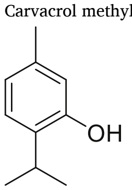
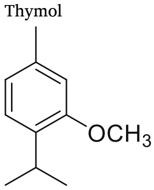
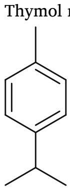
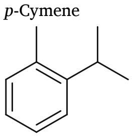
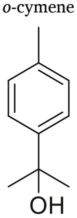
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
22	 *β*-Phellandrene	*A. buchneroides* Bonati	11.86%	whole plant	Shen et al. (1991)
23	 *α*-Terpineol	*A. glutinosum* (L.) Druce *A. indianum* (Lour.) Merr.	1.03% 1.20% 1.44% 1.02%	leaves whole plant whole plant aerial parts	Yang et al. (2013) (Ya et al., 2011a) Wu et al. (2010) Ji and Pu (1985)
24	 Terpinen-4-ol	*A. bracteosum* Bonati *A. indianum* (Lour.) Merr.	1.50% 2.35%	aerial parts aerial parts	Nguyêñ and Dô, 1991 Ji and Pu (1985)
25	 Piperitenone oxide	*A. indianum* (Lour.) Merr.	1.74% 1.02% 1.16% 2.92%	whole plant whole plant whole plant aerial parts	(Ya et al., 2011a) Huang et al. (2013) Wu et al. (2010) Zeng et al. (2013)
26	 *α*-Terpinyl acetate	*A. glutinosum* (L.) Druce	3.96%	aerial parts	Wang et al., 2008
27	 *d*-Carvone	*A. indianum* (Lour.) Merr.	2.25%	aerial parts	Ji and Pu (1985)
28	 Dihydrocarveyl acetate	*A. indianum* (Lour.) Merr.	2.30%	aerial parts	Ji and Pu (1985)
29	 Piperitone	*A. caeruleum* R.Br. *A. capitatum* (Benth.) Benth. ex Hance	5.80% 1.04% 1.04%	aerial parts aerial parts aerial parts	Nguyêñ and Dô, 1991 Bhuiyan et al. (2010) Chowdhury et al. (2011)
30	 piperitenone	*A. indianum* (Lour.) Merr.	1.28% 1.28% 2.24%	whole plant whole plant aerial parts	(Huang et al., 2011) Wu et al. (2010) Zeng et al. (2013)

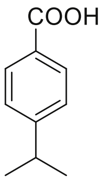
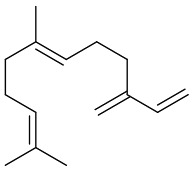
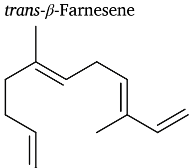
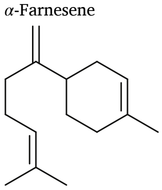
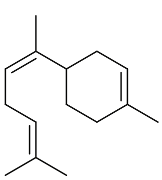
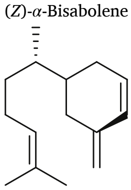
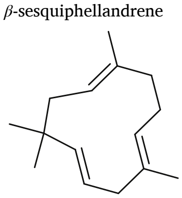
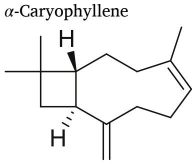
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
31	 Cyclopentanol, 3-isopropenyl-1,2-dimethyl	*A. glutinosum* (L.) Druce		aerial parts	Wang et al., 2008
32	 trans-Carveol	*A. indianum* (Lour.) Merr.	1.96%	aerial parts	Ji and Pu (1985)
33	 Carvacrol	*A. bracteosum* Bonati	34.00%	aerial parts	Châu and Van Hông (1992)
			33.97%	aerial parts	Nguyêñ and Dô, 1991
			37.20%	aerial parts	Dai et al. (2015)
			1.50%	aerial parts	Tsankova et al. (1994)
		A. buchneroides Bonati	22.20%	aerial parts	Ma et al. (2019)
			34.98%	aerial parts	Xu et al. (2008)
34	 Carvacrol methyl ether	*A. bracteosum* Bonati	18.90%	aerial parts	Châu and Van Hông (1992)
			18.88%	aerial parts	Nguyêñ and Dô, 1991
			23.20%	aerial parts	Dai et al. (2015)
		A. buchneroides Bonati	11.87%	aerial parts	Ma et al. (2019)
			3.42%	aerial parts	Xu et al. (2008)
35	 Thymol	*A. bracteosum* Bonati	25.30%	aerial parts	Tsankova et al. (1994)
			25.60%	aerial parts	Tsankova et al. (1994)
		A. buchneroides Bonati	52.48%	whole plant	Shen et al. (1991)
36	 Thymol methyl ether	*A. bracteosum* Bonati	8.40%	aerial parts	Tsankova et al. (1994)
37	 *p*-Cymene	*A. bracteosum* Bonati	9.23%	aerial parts	Nguyêñ and Dô, 1991
			2.20%	aerial parts	Dai et al. (2015)
			4.80%	aerial parts	Tsankova et al. (1994)
		A. buchneroides Bonati	4.40%	whole plant	Shen et al. (1991)
			12.10%	aerial parts	Ma et al. (2019)
			6.60%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	6.40%	aerial parts	Dūng et al. (1996)
		A. indianum (Lour.) Merr.	2.73%	aerial parts	Nguyêñ and Dô, 1991
38	 *o*-cymene	*A. glutinosum* (L.) Druce	–	aerial parts	Wang et al., 2008
39	 *p*-Cymene-8-ol	*A. indianum* (Lour.) Merr.	1.10%	aerial parts	Nguyêñ and Dô, 1991
40		*A. buchneroides* Bonati	11.17%	whole plant	Shen et al. (1991)

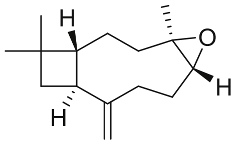
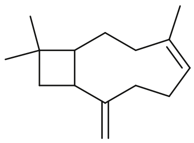
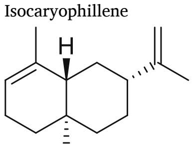
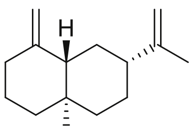
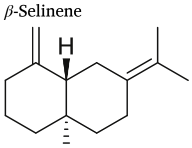
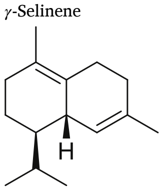
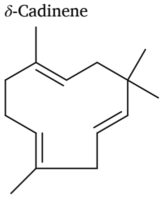
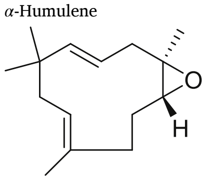
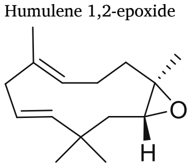
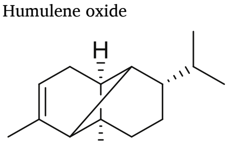
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
	 Cuminic acid				
41	 *trans-β*-Farnesene	*A. bracteosum* Bonati	9.50%	aerial parts	Tsankova et al. (1994)
			9.50%	aerial parts	Tsankova et al. (1994)
		A. indianum (Lour.) Merr.	1.25%	whole plant	Wu et al. (2010)
42	 *α*-Farnesene	*A. caeruleum* R.Br.	2.16%	aerial parts	Nguyễn and Dô, 1991
		A. glutinosum (L.) Druce		aerial parts	Wang et al., 2008
43	 *β*-Bisabolene	*A. bracteosum* Bonati	16.70%	aerial parts	Châu and Van Hông (1992)
			16.66%	aerial parts	Nguyễn and Dô, 1991
		A. buchneroides Bonati	10.57%	whole plant	Shen et al. (1991)
			7.96%	aerial parts	Ma et al. (2019)
			1.34%	aerial parts	Xu et al. (2008)
		A. caeruleum R.Br.	1.27%	aerial parts	Nguyễn and Dô, 1991
			5.30%	aerial parts	Dũng et al. (1996)
		A. capitatum (Benth.) Benth. ex Hance	2.80%	aerial parts	Bhuiyan et al. (2010)
			2.80%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	8.24%	leaves	Yang et al. (2013)
		A. indianum (Lour.) Merr.	4.56%	whole plant	(Huang et al., 2011)
			4.56%	whole plant	Wu et al. (2010)
			1.56%	whole plant	Wu et al. (2010)
44	 (*Z*)-*α*-Bisabolene	*A. bracteosum* Bonati	15.90%	aerial parts	Dai et al. (2015)
45	 *β*-sesquiphellandrene	*A. indianum* (Lour.) Merr.	1.92%	whole plant	Wu et al. (2010)
46	 *α*-Caryophyllene	*A. capitatum* (Benth.) Benth. ex Hance	1.62%	aerial parts	Bhuiyan et al. (2010)
			1.62%	aerial parts	Chowdhury et al. (2011)
		A. glutinosum (L.) Druce	1.83%	leaves	Yang et al. (2013)
		A. indianum (Lour.) Merr.	6.23%	whole plant	(Ya et al., 2011a)
			2.25%	whole plant	Huang et al. (2013)
			2.04%	whole plant	Wu et al. (2010)
			2.72%	aerial parts	Ji and Pu (1985)
			10.32%	aerial parts	Zeng et al. (2013)
47	 *β*-Caryophyllene	*A. bracteosum* Bonati	5.10%	aerial parts	Tsankova et al. (1994)
		A. caeruleum R.Br.	3.90%	aerial parts	Nguyễn and Dô, 1991
			2.70%	aerial parts	Dũng et al. (1996)
		A. indianum (Lour.) Merr.	1.24%	aerial parts	Nguyễn and Dô, 1991
			5.93%	whole plant	(Ya et al., 2011a)
			2.20%	whole plant	Huang et al. (2013)
			10.19%	aerial parts	Zeng et al. (2013)
		A. capitatum (Benth.) Benth. ex Hance	1.14%	aerial parts	Bhuiyan et al. (2010)
			1.14%	aerial parts	Chowdhury et al. (2011)
		A. indianum (Lour.) Merr.	9.53%	whole plant	(Huang et al., 2011)
			9.53%	whole plant	Wu et al. (2010)
48		*A. indianum* (Lour.) Merr.	2.05%	whole plant	(Ya et al., 2011a)

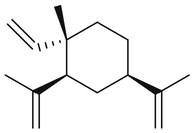
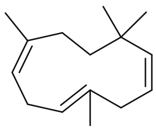
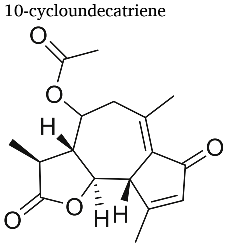
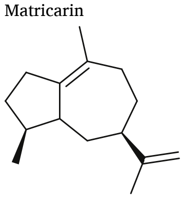
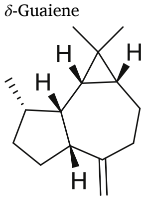
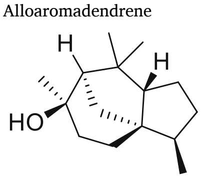
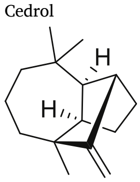
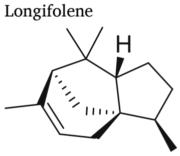
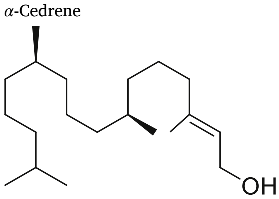
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
	 Caryophyllene oxide		1.37%	whole plant	(Huang et al., 2011)
			1.37%	whole plant	Wu et al. (2010)
			5.40%	whole plant	Wu et al. (2010)
			3.50%	aerial parts	Zeng et al. (2013)
49	 Isocaryophillene	*A. indianum* (Lour.) Merr.	3.16%	whole plant	Wu et al. (2010)
50	 *α*-Selinene	*A. indianum* (Lour.) Merr.	1.67%	aerial parts	Zeng et al. (2013)
51	 *β*-Selinene	*A. bracteosum* Bonati	2.20%	aerial parts	Dai et al. (2015)
		A. indianum (Lour.) Merr.	1.36%	whole plant	(Huang et al., 2011)
			1.36%	whole plant	Wu et al. (2010)
			1.10%	aerial parts	Zeng et al. (2013)
52	 *γ*-Selinene	*A. indianum* (Lour.) Merr.	1.06%	whole plant	(Huang et al., 2011)
			1.06%	whole plant	Wu et al. (2010)
53	 *δ*-Cadinene	*A. caeruleum* R.Br.	1.10%	aerial parts	Dũng et al. (1996)
54	 *α*-Humulene	*A. bracteosum* Bonati	3.74%	aerial parts	Nguyêñ and Dô, 1991
			2.80%	aerial parts	Tsankova et al. (1994)
		A. caeruleum R.Br.	1.22%	aerial parts	Nguyêñ and Dô, 1991
		A. indianum (Lour.) Merr.	11.60%	aerial parts	Le (1977)
			1.75%	aerial parts	Nguyêñ and Dô, 1991
			1.31%	aerial parts	Ji and Pu (1985)
55	 Humulene 1,2-epoxide	*A. indianum* (Lour.) Merr.	1.22%	whole plant	(Huang et al., 2011)
			1.22%	whole plant	Wu et al. (2010)
			3.01%	aerial parts	Zeng et al. (2013)
56	 Humulene oxide	*A. indianum* (Lour.) Merr.	1.97%	whole plant	(Ya et al., 2011a)
57	 *α*-Copaene	*A. indianum* (Lour.) Merr.	1.38%	aerial parts	Ji and Pu (1985)
58		*A. indianum* (Lour.) Merr.	2.58%	aerial parts	Ji and Pu (1985)

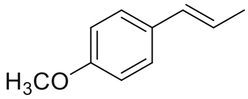
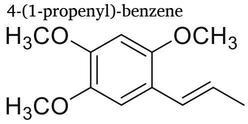
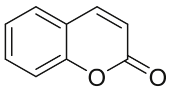
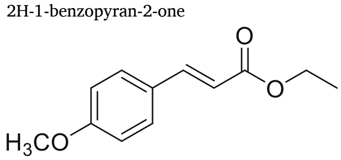
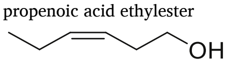
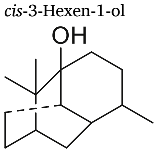
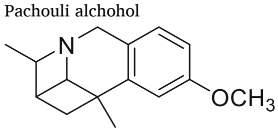
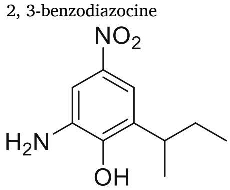
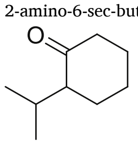
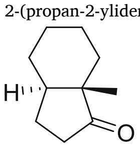
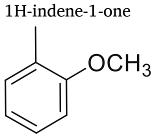
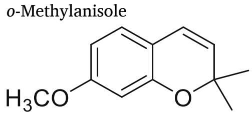
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
	 *β*-Elemene				
59	 1,1,4,8-tetramethyl-4, 7, 10-cycloundecatriene	*A. glutinosum* (L.) Druce *A. indianum* (Lour.) Merr.	1.07% 8.20% 8.20%	aerial parts whole plant whole plant	Wang et al., 2008 (Huang et al., 2011) Wu et al. (2010)
60	 Matricarin	*A. indianum* (Lour.) Merr.	2.13%	whole plant	Wu et al. (2010)
61	 *δ*-Guaiene	*A. indianum* (Lour.) Merr.	5.27%	aerial parts	Ji and Pu (1985)
62	 Alloaromadendrene	*A. indianum* (Lour.) Merr.	1.28%	aerial parts	Ji and Pu (1985)
63	 Cedrol	*A. indianum* (Lour.) Merr.	26.02% 26.02%	whole plant whole plant	(Huang et al., 2011) Wu et al. (2010)
64	 Longifolene	*A. indianum* (Lour.) Merr.	1.39%	whole plant	Wu et al. (2010)
65	 *α*-Cedrene	*A. indianum* (Lour.) Merr. *A. indianum* (Lour.) Merr.	1.47% 1.47%	whole plant whole plant	(Huang et al., 2011) Wu et al. (2010)
66	 Phytol	*A. capitatum* (Benth.) Benth. ex Hance	1.89% 1.89%	aerial parts aerial parts	Bhuiyan et al. (2010) Chowdhury et al. (2011)
67		*A. indianum* (Lour.) Merr.	2.28%	whole plant	Wu et al. (2010)

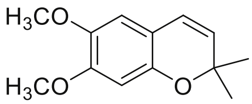
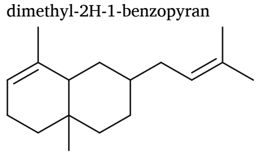
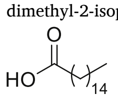
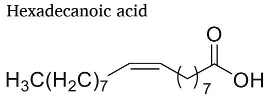
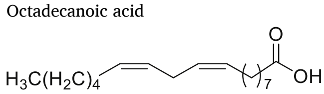
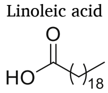
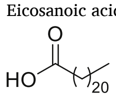
(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
	 4-(1-propenyl)-benzene				
68	 Asarone	*A. indianum* (Lour.) Merr.	1.02%	whole plant	Wu et al. (2010)
69	 2H-1-benzopyran-2-one	*A. indianum* (Lour.) Merr.	6.56%	whole plant	Wu et al. (2010)
70	 3-(4-methoxypheny)-2-propenoic acid ethylester	*A. indianum* (Lour.) Merr.	1.26%	whole plant	Wu et al. (2010)
71	 *cis*-3-Hexen-1-ol	*A. glutinosum* (L.) Druce	1.36%	leaves	Yang et al. (2013)
72	 Pachouli alchohol	*A. indianum* (Lour.) Merr.	2.56%	aerial parts	Ji and Pu (1985)
73	 3, 4, 5, 6-tetrahydro-8-methoxy-3, 6, 11-trimethyl-1H-2, 6-methano-2, 3-benzodiazocine	*A. indianum* (Lour.) Merr.	1.22%	whole plant	Wu et al. (2010)
74	 2-amino-6-sec-butyl-4-nitrophenol	*A. indianum* (Lour.) Merr.	1.42%	whole plant	Wu et al. (2010)
75	 2-(propan-2-ylidene) cyclohexanone	*A. glutinosum* (L.) Druce	1.17%	leaves	Yang et al. (2013)
76	 Trans-octahydro-7a-methyl-1H-indene-1-one	*A. capitatum* (Benth.) Benth. ex Hance	14.32% 14.32%	aerial parts aerial parts	Bhuiyan et al. (2010) Chowdhury et al. (2011)
77	 *o*-Methylanisole	*A. indianum* (Lour.) Merr.	5.27%	aerial parts	Ji and Pu (1985)
78	 7-methoxy-2, 2-dimethyl-2H-1-benzopyran	*A. indianum* (Lour.) Merr.	2.95%	whole plant	Wu et al. (2010)
79		*A. indianum* (Lour.) Merr.	9.99%	whole plant	Wu et al. (2010)

(*continued on next page*)

Table 4 (*continued*)

No.	Pytochemical name	Species	Amount % (w/w)	Plant part	Reference
	 6, 7- dimethoxy-2, 2-dimethyl-2H-1-benzopyran				
80	 1,2,3,4,4,5,6,8a-octahydro-4a,8-dimethyl-2-isopropenyl-naphthalene	*A. caeruleum* R.Br.	1.20%	aerial parts	Dũng et al. (1996)
81	 Hexadecanoic acid	*A. indianum* (Lour.) Merr.	14.45%	whole plant	Huang et al. (2013)
82	 Octadecanoic acid	*A. indianum* (Lour.) Merr.	4.25% 13.98%	whole plant whole plant	Huang et al. (2013) Huang et al. (2013)
83	 Linoleic acid	*A. indianum* (Lour.) Merr.	46.18%	whole plant	Huang et al. (2013)
84	 Eicosanoic acid	*A. indianum* (Lour.) Merr.	1.05%	whole plant	Huang et al. (2013)
85	 Docosanoic acid	*A. indianum* (Lour.) Merr.	1.29%	whole plant	Huang et al. (2013)
86	 Triacontane	*A. indianum* (Lour.) Merr.	1.21%	whole plant	Huang et al. (2013)

2017). *A. glutinosum* is also reported to contain 30-oxo-betuklinic acid (**14**), 3*β*-hydroxy-urs-11-en-13*β*, 28-olide (**15**), and ursolic acid (**16**) (Tan 2017; Tan et al., 2017; Yu et al., 2018). Finally, squalene (**17**) has been identified from the whole-plant methanol extract of *A. buchneroides* (Ma 2018).

5.2. Phenylpropanoids

Phenylpropanoids are relatively simple secondary metabolites that are derived from the amino acids phenylalanine or tyrosine (Stevenson and Aslam 2006).

Adenosma is abundant in phenylpropanoid compounds, and to date 21 phenylpropanoids have been isolated from the genus, all classified as phenylpropionic acids (**18–31**) with a C_6-C_3 carbon skeleton, or lignans (**32–38**) formed by oxidative polymerization of phenylpropion. The isolated phenylpropanoids are known from three *Adenosma* species: *A. buchneroides*, *A. caeruleum*, and *A. glutinosum*, and of these, *A. buchneroides* contains the highest levels of phenylpropanoids (**18–23; 29–33; 35–38**) (Ma 2018; Ma et al., 2018). *A. buchneroides* is used as an herbal medicine in China to treat a variety of disorders (Shen et al., 1991; Gou et al., 2018; Fan et al., 2019), and extracts from this plant has insecticidal properties (Ma et al., 2019). Five phenylpropanoids, crenatoside (**24**), verbascoside (**25**), campneoside I (**26**), campneoside II (**27**), and cistanoside F (**28**), have been isolated from the aerial parts of *A. caeruleum* by De Abreu et al. (De Abreu et al., 2009).The two phenylpropanoids trans-*p*-hydroxylcinnamic acid (**18**) and sesamin (**34**) have also been reported from *A. glutinosum* (Tan 2017; Tan et al., 2017; Yu et al., 2018).

5.3. Phenols

Phenols probably constitute the largest group of plant secondary metabolites, and vary in size from a simple structure with an aromatic ring to complex polymeric compounds. In the genus *Adenosma*, 12 simple phenols (**39–50**) have been isolated and characterized from three species, *A. buchneroides*, *A. caeruleum*, and *A. glutinosum*. From *A. buchneroides*, 8 simple phenols (*p*-hydroxybenzoic acid (**40**), *p*-hydroxybenzaldehyde (**41**), *p*-hydroxybenzoic acid (**42**), *p*-hydroxybenzyl alcohol (**44**), *p*-hydroxyacetophenone (**45**), 1,3,5-trimethoxybenzene (**47**), *p*-methoxybenzyl alcohol (**48**) and 4,4′-dihydroxydibenzyl ether (**50**)), were isolated and identified by Ma et al. (Ma 2018; Ma et al., 2018). *P*-hydroxybenzoic acid (**40**), *p*-hydroxybenzaldehyde (**41**), and 1,3,5-trimethoxybenzene (**47**), together with another two simple phenols precocene II (**39**) and 3,5-dimethoxyacetophenone (**49**), were isolated from ethanol extracts of the aerial parts of *A. glutinosum* (Tan 2017; Tan et al., 2017; Yu et al., 2018). Extracts of the aerial parts of *A. caeruleum* were found to contain 4-hydroxy- benzeneethanol (**43**) and arbutin (**46**) (Tran 1997; Nguyen et al., 2012).

5.4. Flavonoids

The flavonoids form a class of phenolic compounds found widely in plants. To date, eight phenolic compounds (**51–58**) have been isolated from the genus *Adenosma*, of which most are flavones and one is a flavonol, 6-methoxy-3-O-methylkaempferol (**55**). Isoscutellarein-8-O-*β*-D-glucopyranoside (**53**), a flavone, was identified from the ethanol extract of *A. bracteosum*. Isoscutellarein-8-O-*β*-D-glucopyranoside has strong inhibitory activity against *α*-glucosidase, with the anti-hyperglycemic effect being similar to that of the drug glibenclamide (Nguyen et al., 2020). The flavonol 6-methoxy-3-O-methylkaempferol

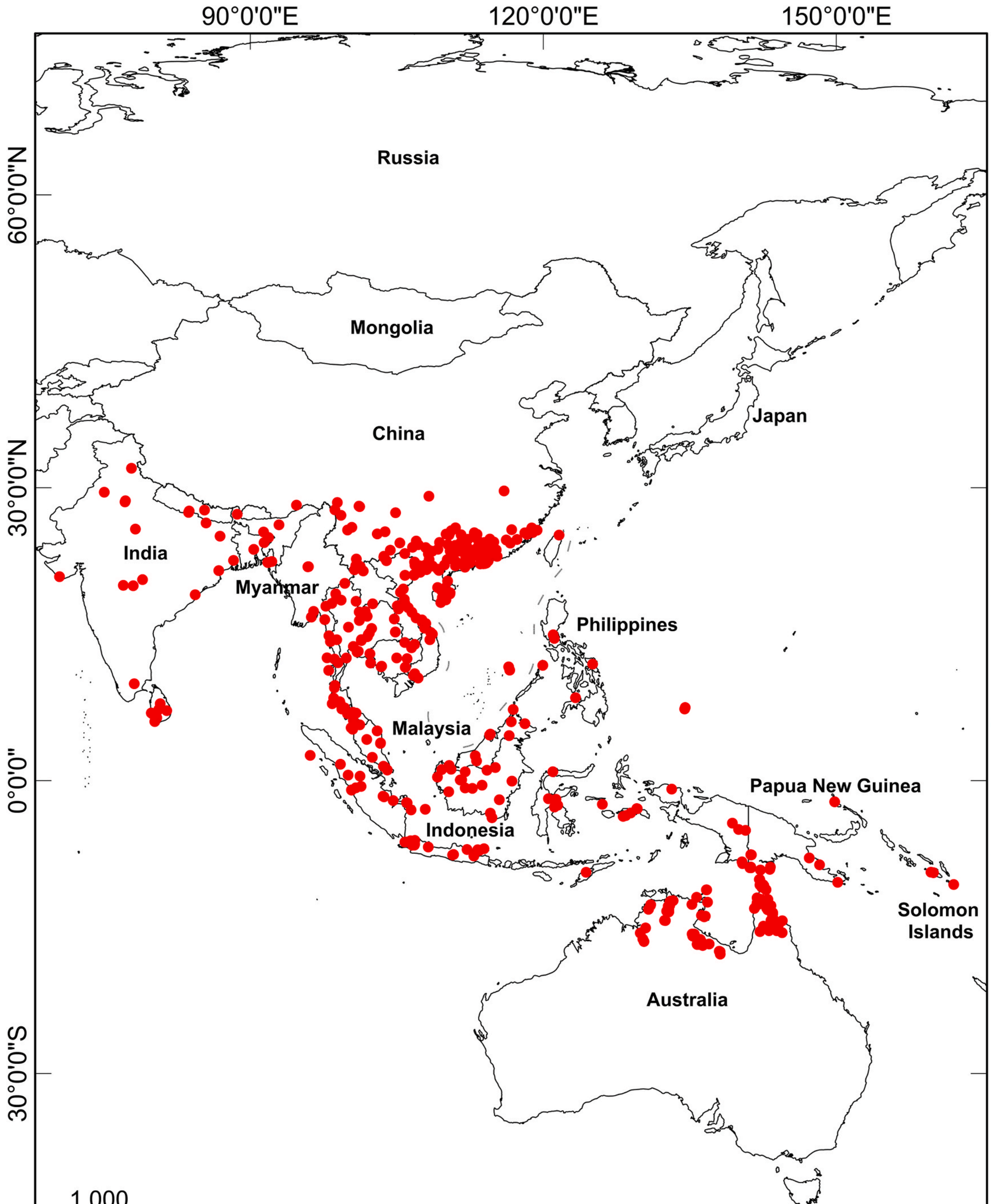


Fig. 1. Geographical distributions of the genus *Adenosma*.

(**55**), together with two flavones, apigenin (**52**), and 6-methoxyl-scutellarin (**54**), was isolated from *A. buchneroides* (Ma 2018; Ma et al., 2018). *A. caeruleum* was found to contain apigenin 7-O-β-D-glucuronopyranoside (**56**) and apigenin 7-O-β-D-glucopyranoside (**57**) (De Abreu et al., 2009). Whole-plant ethanol extracts of *A. glutinosum* were found to contain the flavones 5,6-dihydroxy-7,8,4′-trimethoxy-flavone (**51**) and apigenin-7-O-β-D-glucuronide butyl ester (**58**) (Tan 2017; Tan et al., 2017; Yu et al., 2018).

5.5. Sterols

Sterols are a class of four-cyclic compounds with a cyclopentanoperhydrophenanthrene nucleus (Morales-Lázaro and Rosenbaum 2017). In the genus *Adenosma*, four steroids have been discovered to date, of which β-sitosterol (**59**) is the most common, isolated from *A. buchneroides* (Ma 2018), *A. caeruleum* (Tran 1997; Nguyen et al., 2012), *A. glutinosum* (Tan 2017; Yu et al., 2018) and *A. indianum* (Ya et al., 2011b). The other three sterols isolated from *Adenosma* species are

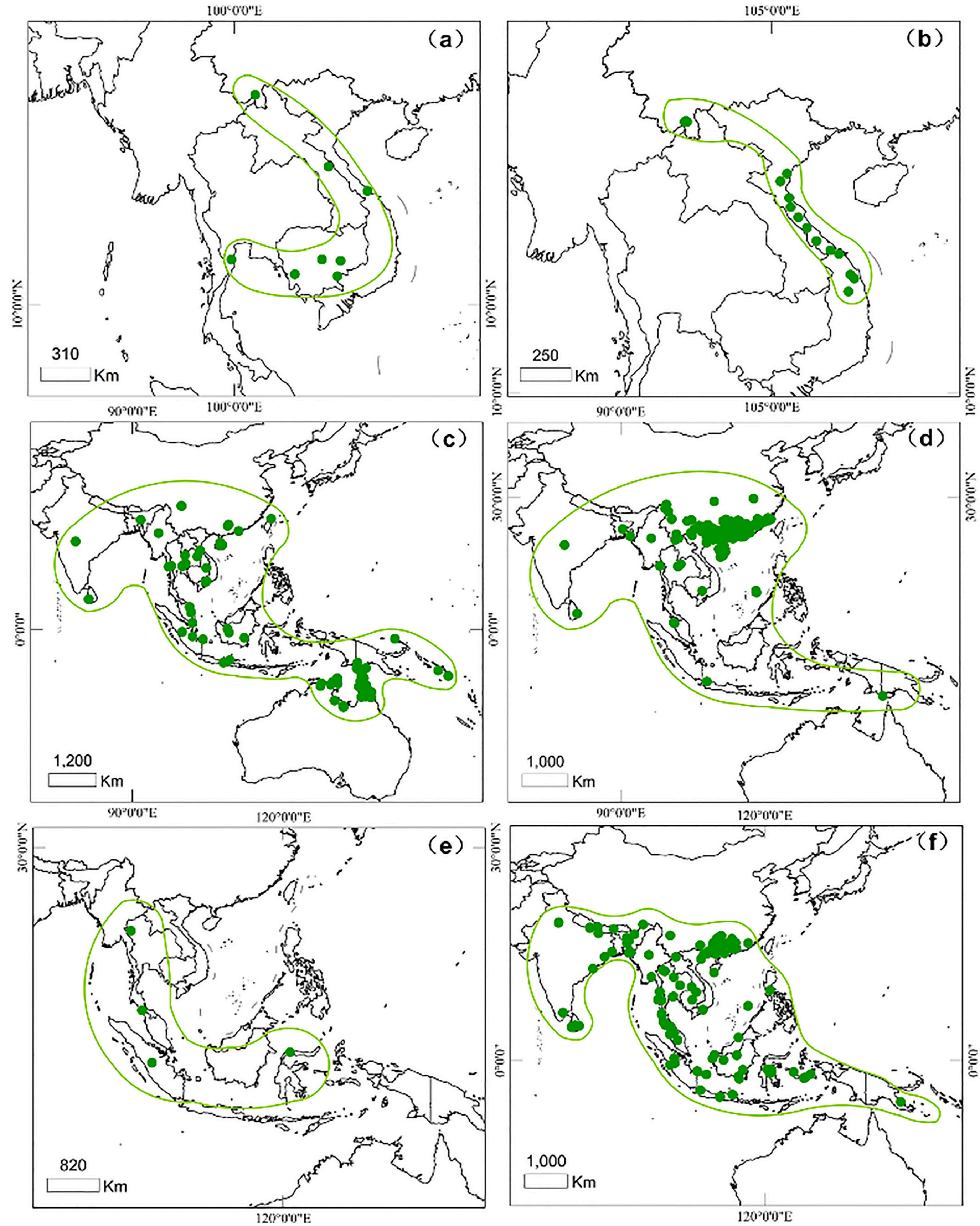


Fig. 2. Geographical distributions of six *Adenosma* species (a-*A. bracteosum*; b-*A. buchneroides*; c-*A. caeruleum*; d-*A. glutinosum*; e-*A. hirsutum*; f-*A. indianum*).

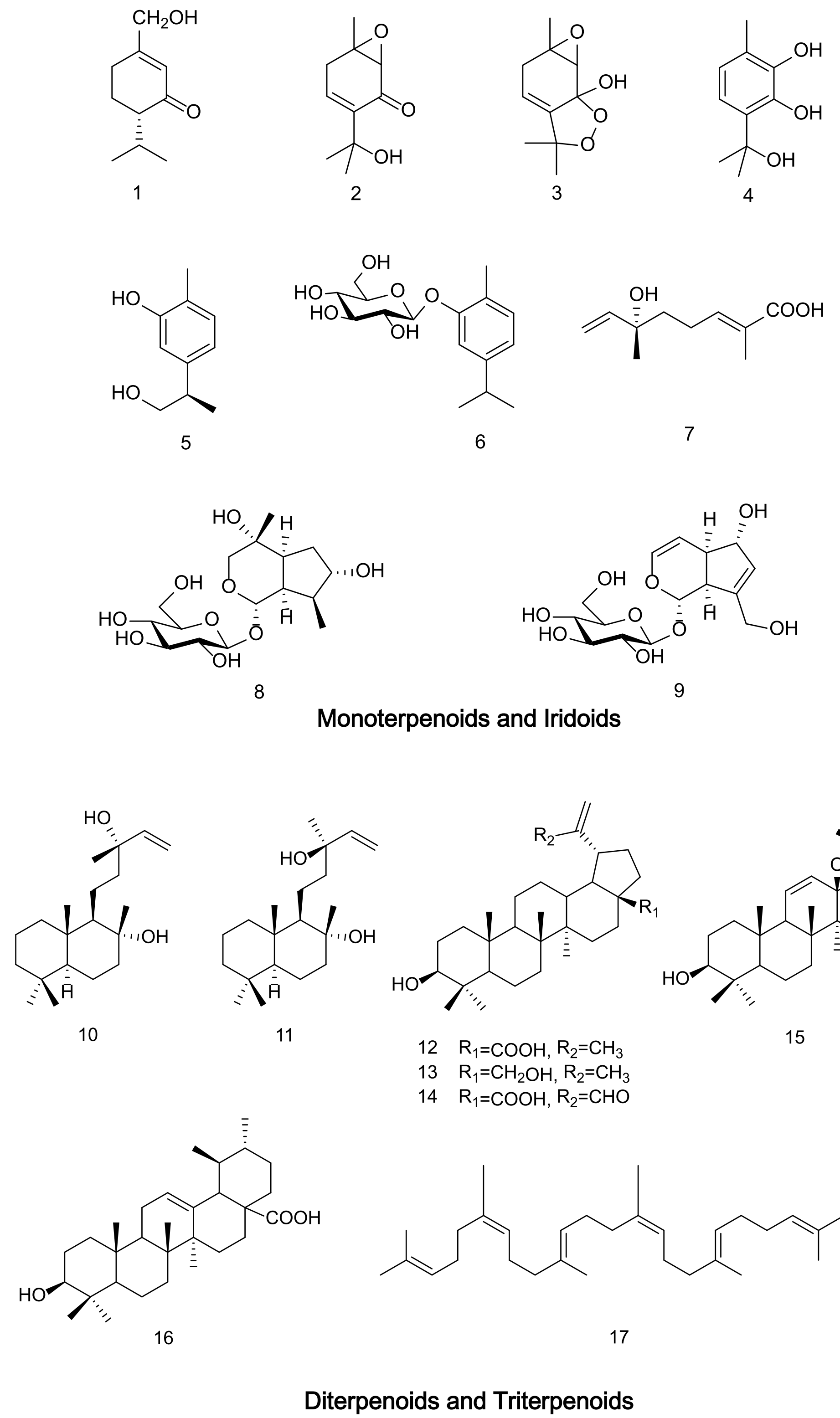
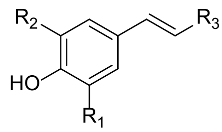
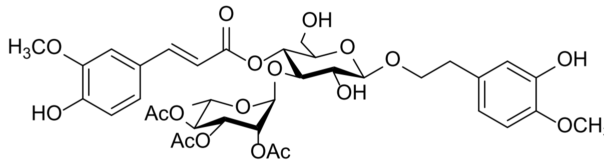


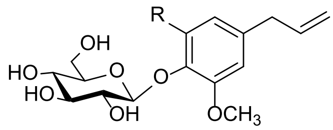
Fig. 3. The structures of the chemical constituents isolated from the extracts of *Adenosma* species.



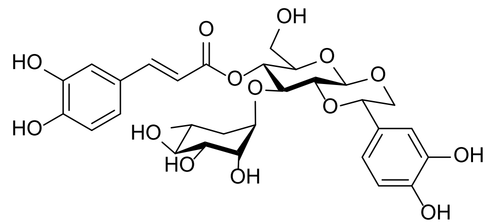
18 R_1=H, R_2=H, R_3=COOH
19 R_1=OCH_3, R_2=H, R_3=CHO
20 R_1=OCH_3, R_2=OCH_3, R_3=CHO



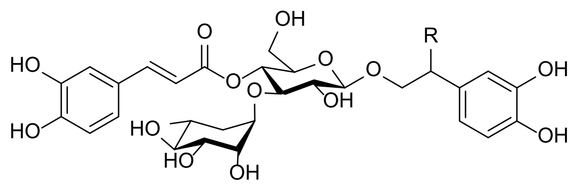
21



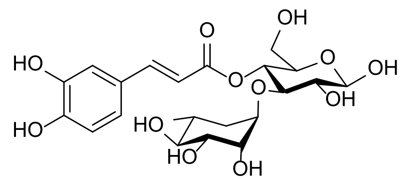
22 R=H
23 R=OCH_3



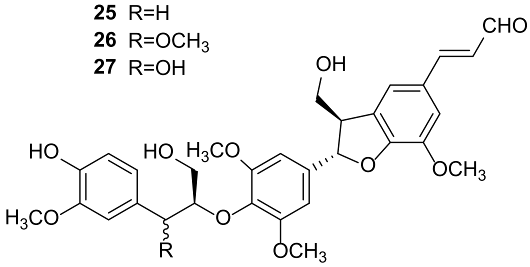
24



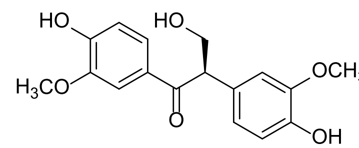
25 R=H
26 R=OCH_3
27 R=OH



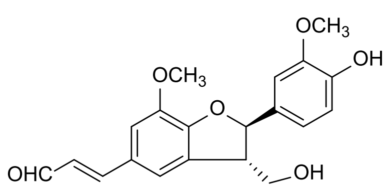
28



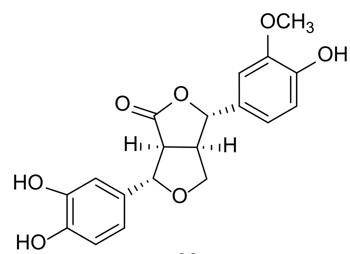
29 R=α -OH
30 R=β -OH



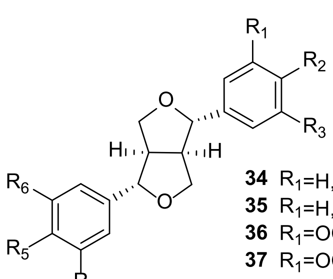
31



32



33



34 R_1=H, R_2= R_3=OCH_2O R_4=H, R_5= R_6=OCH_2O
35 R_1=H, R_2=OH, R_3=OCH_3, R_4=OCH_3, R_5=OH, R_6=OCH_3
36 R_1=OCH_3, R_2=OH, R_3=OCH_3, R_4=OCH_3, R_5=OH, R_6=OCH_3
37 R_1=OCH_3, R_2=OH, R_3=OCH_3, R_4=OCH_3, R_5=O-β -D-Glc, R_6=OCH_3
38 R_1=OCH_3, R_2=OCH_3, R_3=H, R_4=OCH_3, R_5=OH, R_6=OCH_3

Phenylpropanoids

Fig. 3. (*continued*).

7α-hydroxysitosterol (**61**), stigmasterol (**63**) and campesterol (**64**). Two glycosides, β-daucosterin (**60**) and β-sitosteryl-3β-glucopyranoside-6′-O-palmitate (**62**), were isolated from the methanol extract of *A. buchneroides* (Ma 2018).

5.6. *Fatty acids and esters*

Eight fatty acids (**65–73**) and five esters (**74–78**) have been discovered in *Adenosma* species. Fumaric acid (**65**), muconic acid (**66**), and

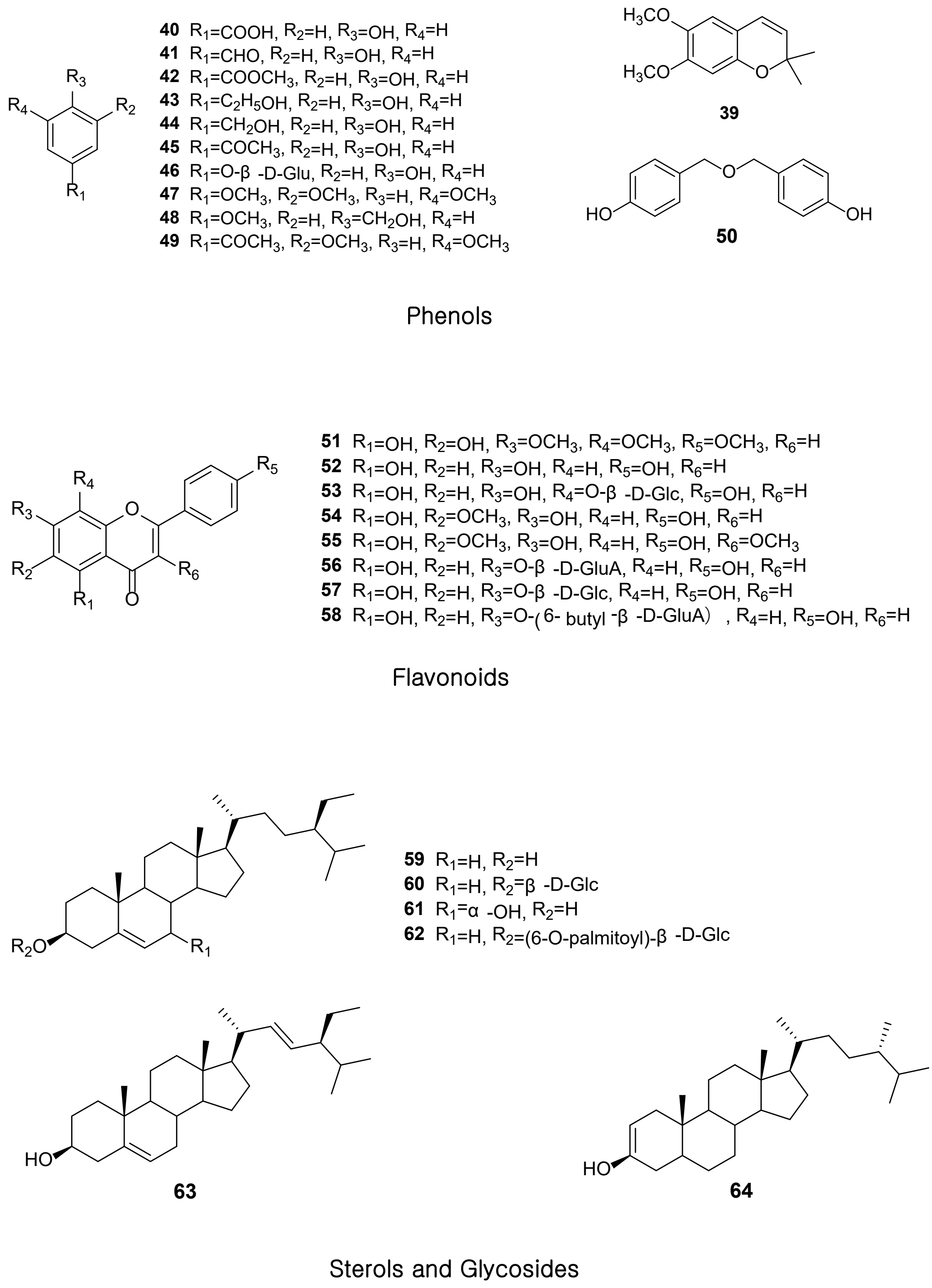


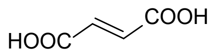
Fig. 3. (*continued*).

palmitic acid (**67**) have been reported from *A. glutinosum* (Tan 2017; Tan et al., 2017; Yu et al., 2018). Four fatty acids, octadecanoic acid (**68**), tetratriacontanoic acid (**70**), pentatriacontanoic acid, methyl ester (**71**), and heptatriacontanoic acid (**72**) have been identified from the ethanol extract of *A. indianum* (Ya et al., 2011b). The methanol extract of *A. buchneroides* was found to contain balansenate I (**74**) and 1-linoleoyl-glycerol (**75**) (Ma 2018).

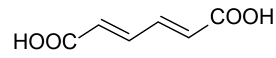
In addition, six fatty acids have been identified by Nguyen et al. from the n-hexane and ethyl acetate extracts of *A. caeruleum*: octadecanoic acid (**68**), triacontanoic acid (**69**), 9,12-octadecadienoic acid (9*Z*,12*Z*)-(**73**), triacontanoic acid, 2-(4-hydroxyphenyl) ethyl ester (**76**), 9,12-octadecadienoic acid (9Z,12Z)-,1,1'-[1-[[(1-oxooctadecyl)oxy] methyl]-1,2-ethanediyl] ester (**77**), and *α*, *β*-dilinoleostearin (**78**) (Nguyen et al., 2012; Nguyên 2017).

5.7. Other compounds

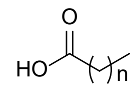
Other metabolites belonging to several other families, including n-alkanes, alcohols, alkaloids, and quinones, have also been documented from the genus *Adenosma*.



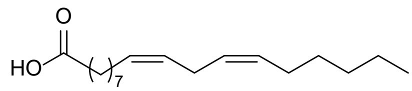
65



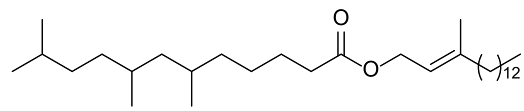
66



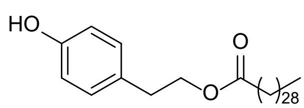
67 n=14
68 n=16
69 n=28
70 n=32
71 n=33
72 n=35



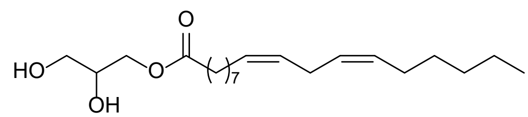
73



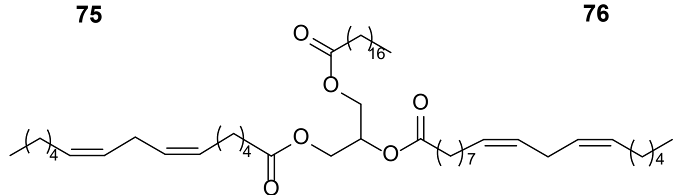
74



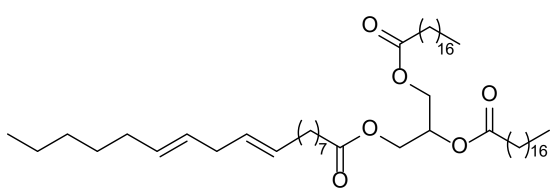
75



76

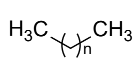


77

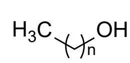


78

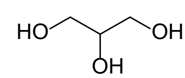
Fatty acids and Esters



79 n=27
80 n=29
81 n=38
82 n=41

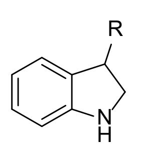


83 n=25
84 n=26
85 n=42

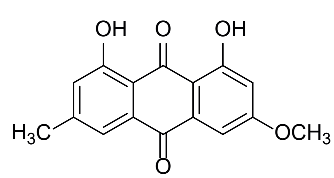


86

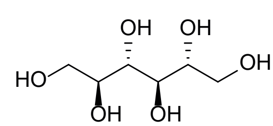
N-alkanes and Alcohols



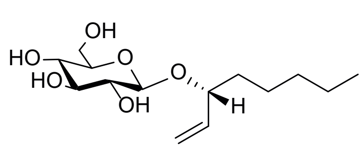
87 R=CHO
88 R=COOH



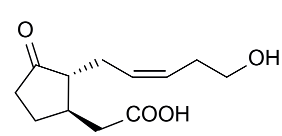
89



90



91



92

Alkaloids, Quinonoids and Other compounds

Fig. 3. (*continued*).

Four n-alkanes (**79–82**) and four alcohols (**83–86**) have been identified from *Adenosma* species (Ya et al., 2011b; Nguyen et al., 2012; Nguyên 2017; Tan 2017; Yu et al., 2018).

Two alkaloids (**87, 88**) have been isolated from the methanol extract of *A. buchneroides* (Ma 2018; Ma et al., 2018), and physcion (**89**), a quinone, was identified from the ethanol extract of *A. glutinosum* (Tan 2017; Yu et al., 2018).

Finally, d-allitol (**90**) has been determined to be present in the ethanol extract of *A. glutinosum* using spectroscopic analysis and a literature comparison method (Yu et al., 2018), and (3R)-octen-3-yl β-d-glucopyranoside (**91**) and (1R, 2R)-2-[(2Z)-5-hydroxy-2-penten-1-yl]-3-oxocyclopentaneacetic-acid (**92**) have been isolated from an extract of *A. buchneroides* (Ma 2018).

Our literature survey suggested that to date a total of 92 compounds have been isolated from *Adenosma* spp. (excluding the essential oil), which can be categorized into seven major chemical classes: terpenoids, phenylpropanoids, phenols, flavonoids, sterols, fatty acids and esters, and other compounds. The major class phenylpropanoids represents 22.8% of these compounds. Terpenoids compromise 18.5% of them, phenols account for 13.0%, flavonoids 8.7%, sterols 6.5%, fatty acids and esters 15.2%, and other compounds 15.2%. The most active compounds in the existing literature are terpenoids, phenols, and flavonoids. Of these, only three compounds [betulin (**13**), ursolic acid (**16**), and isoscutellarein-8-O-β-D-glucopyranoside (**53**)] have been studied in *in vitro* bioassays as medicines in the genus. More studies *in vitro* and *in vivo* are needed to explore the full medicinal potential of these compounds.

5.8. Essential oils from the genus Adenosma

The genus *Adenosma* is a source of essential oils (EOs). Across different geographical regions, the use of *Adenosma* is often associated with its aromatic nature. For the Hani people of Xishuangbanna, China, *A. buchneroides* is used as both a decoration and a perfume, and it has also been used as an aromatic in Vietnam (Shen et al., 1991). In China, *A. glutinosum* and *A. indianum* are used to treat rheumatism and unbalanced qi and blood, because these plants contain essential oils (China's State Administration of traditional Chinese medicine, 1998). Species of *Adenosma* have also been used as insecticides, mainly because of the strong scent of both the fresh and dried herbs (Shen et al., 1991; Gou et al., 2018; Ma et al., 2019). The average yield of essential oil from *Adenosma* species ranges from 0.4 to 1% of fresh weight of whole plant, and up to 1.86% of flower yield (Shen et al., 1991; Dô, 1993; Xu et al., 2008).

Several studies have been performed on different species and different parts of the plants, including the aerial parts and leaves, as well as the whole plants. Terpenes, mainly monoterpenes and sesquiterpenoids, are the major constituents of EOs obtained from this genus. There is a large amount of data concerning the EOs from the *Adenosma* genus from a considerable number of studies. The constituents of EOs from *A. bracteosum* aerial parts are reported to contain mainly bisabolene, carvacrol and its derivatives, thymol, and linalool (Nguyêñ and Dô, 1991; Châu and Van Hông 1992; Tsankova et al., 1994; Dai et al., 2015). The EOs from *A. buchneroides* aerial parts contain carvacrol, carvacrol methyl ether, *p*-cymene, thymol, β-bisabolene, β-phellandrene, and γ-terpinene (Shen et al., 1991; Xu et al., 2008; Ma et al., 2019), and those from *A. caeruleum* aerial parts, α-pinene, 1,8-cineole, and γ-terpinene (Nguyêñ and Dô, 1991; Dũng et al., 1996). The major constituents of EOs from *A. capitatum* aerial parts include 2-carene, limonene, fenchone, and trans-octahydro-7a-methyl-1h-indene-1-one (Bhuiyan et al., 2010; Chowdhury et al., 2011), those from *A. glutinosum* leaf oil are limonene, cineole, and fenchone (Wang et al., 2008; Yang et al., 2013), and those from oil from *A. indianum* aerial parts include cedrol, fenchone, limonene, linoleic acid, and terpinolene).

In a comparison between the volatile oil compositions of *A. indianum* obtained from either supercritical fluid extraction or steam distillation, the former method offered higher essential oil yield than did the latter (Wu et al., 2010).

The major compounds (>1%) of the essential oils in *Adenosma* species are summarized in Table 4. The two monoterpenoids α-pinene and linalool are the most common constituents of *Adenosma* EOs and to date have been detected in six different species: *A. bracteosum, A. buchneroides, A. caeruleum, A. capitatum, A. glutinosum,* and *A. indianum*. The next most common constituents are five monoterpenoids, (borneol, α-thujene, β-pinene, limonene, sabinene, and γ-terpinene), and the sesquiterpinoid β-bisabolene, all of which have been found in five species. The other monoterpenoids (β-myrcene, 3-carene, *p*-cymene, α-terpinene, limonene, myrcene, α-humulene), and the sesquiterpenoids β-caryophyllene, caryophyllene oxide, and β-elemene have each been found in four species: *A. caeruleum, A. capitatum, A. glutinosum,* and *A. indianum.*

In these studies of essential oils in *Adenosma*, some findings deserve more attention and further research.

First, the method of extraction used can affect the essential oil content and composition. For example, the content of the bicyclic monoterpene fenchone, a component of *A. indianum* essential oil, in a whole-plant extract from *A. indianum* has been reported to be between 1.71% by solvent extraction (Huang et al., 2013) but 11.70% by hydrodistillation (Huang et al., 2011). The only difference between these two reports is the extraction method; the former study used a petroleum ether extraction, while the latter conducted a steam distillation. This phenomenon can also be observed in other studies into EOs in *Adenosma* species (Wu et al., 2010). Further research into the effect of different methods of extraction on the concentrations and compositions of EOs is therefore necessary.

Additionally, the concentration of a particular chemical can differ between plant parts within a species. For instance, a monocyclic monoterpene, limonene, from *A. glutinosum*, is present at 24.40% in the leaves (Yang et al., 2013), while in the aerial parts it is present at 13.59% (Wang et al., 2008).

Finally, the chemical profiles of the same species of plant may also vary. For example, twelve compounds in essential oils were characterized by (Tsankova et al., 1994) from the aerial parts of *A. bracteosum* from the southern parts of Vietnam, with the major components including thymol (25.6%), linalool (13.1%), and (E)-β-farnesene (9.5%); however, in plants collected from Vinh Phuc province in the northern part of Vietnam, the major compounds included carvacrol (37.2%), carvacrol methyl ether (23.2%), α-bisabolene (15.9%) and γ-terpinene (9.2%) (Dai et al., 2015). The plant material in the former study was collected at the flowering stage, while that used in the latter was collected before the flowering stage. Generally speaking, the volatile components of plants can vary with different developmental stages, but such large differences are not explained by different developmental stages, and may also be influenced by different chemical ecotypes in different regions.

These findings indicate that the chemical profiles and essential oil content within a single species may vary between different geographic origins or harvest times. These differences will also influence the biological activities for ethnopharmacological applications.

Of the 86 EO compounds, three compounds (carvacrol, carvacrol methyl ether and a new fragrant compound, adenosmin A) (Ma et al., 2019), have been studied *in vivo* to test for insecticidal activity. Future studies are needed to explore the activities of the other compounds and the synthesis of the representative ingredients in *Adenosma.*

6. Biological activities

Because of the traditional usage and phytochemical characters, several different biological activities have been assessed in five *Adenosma* species (*A. bracteosum*, *A. buchneroides*, *A. caeruleum*, *A. glutinosum*, and *A.* indianum). Antidiabetic, anticancer, and insecticidal activities are the most studied and *A. bracteosum* is the most investigated species. Most of the studies have been performed using

Table 5
Biological activities of *Adenosma* spp.

Species	Biological activity	Part	extract	Model	Dosage or concentration	Results	Reference
A. bracteosum Bonati	Antidiabetic activity	aerial parts	ethanol/aqueous extract	In vitro: glucose-induced hyperglycemic mice through oral delivery	40, 50 mg/kg.bw	Similar to the standard drug glibenclamide	Nguyen et al. (2018)
A. bracteosum Bonati	Antidiabetic activity	aerial parts	ethanol/aqueous extract	In vitro: α-glucosidase inhibition	26.55, 42.63 μg/ml	Anti-hyperglycemic	Nguyen et al. (2020)
A. bracteosum Bonati	Antidiabetic activity	aerial parts	ethanol/aqueous extract	In vivo: streptozotocin- induced diabetes in mice	50 μg/ml	Blood glucose levels reduced 64.42% and 57.69%	Nguyen et al. (2020)
A. bracteosum Bonati	Antioxidant activity	aerial parts	ethanol/aqueous extract	In vitro: ferric reducing/ antioxidant power assay (FRAP); 1,1-diphenyl-2-picryl-hydrazyl (DPPH) free radical scavenging assay	–	Strong *in vitro* antioxidant capacity	Nguyen et al. (2018)
A. bracteosum Bonati	Antioxidant activity	aerial parts	ethanol/aqueous extract	In vivo: damaged livers induced by acute CCl 4 in mice	–	Effective against acute CCl 4 -induced hepatic	Nguyen et al. (2018)
A. bracteosum Bonati	Antioxidant activity	aerial parts	ethanol/aqueous extract/IG (Isoscutellarein-8-O-β-D-glucopyranoside)	In vitro: 2,2-diphenyl-1picrylhy-drazyl (DPPH) & 2,2-azino-bis-(3-ethylbenozothiazonline-6-sulfonic acid (ABTS) radical scavenging assay	DPPH IC_{50}: 6.61, 10.12, 11.93 μg/ml; ABTs IC_{50}: 10.33, 11.17, 11.40 μg/ml	Strong free radical scavenging activity	Nguyen et al. (2020)
A. bracteosum Bonati	Bile secretion	dried aerial parts	ethanol extract	In vivo: guinea pigs	300 mg/kg.bw	Bile secretion increased by 24.7%	Dô, 1993
A. buchneroides Bonati	Insecticide	aerial parts	essential oil	In vitro: arm in cage	0.019 ± 0.007 mg/ cm^2	Strong mosquito repellent Activity compared to DEET	Ma et al. (2019)
A. buchneroides Bonati	Insecticide	aerial parts	essential oil	In vitro: *Aedes albopictus* larvae	62–75.1 ppm.	Positive larvicidal activity	Ma et al. (2019)
A. caeruleum R. Br.	Antiangiogenic	aerial parts	methanol extract	In vitro: Angiogenesis assay, Cancer cell B16 murine melanoma cell growth	30 μg/ml	The concentration that causes 50% reduction in B16 melanoma cell growth greater than 100 μg/ ml	Nam et al. (2003)
A. caeruleum R. Br.	Anti-inflammatory	aerial parts	methanol extract	In vitro: Nuclear factor-kappa B (NF-κB) inhibitory activity-RAW264.7 cell growth	>100 μg/ml	No inhibition	Nam and Jae (2009)
A. caeruleum R. Br.	Cytotoxic activity	whole plant	methanol extract	In vitro: five human cancer cell lines (A549&MCF-7&HT1080&Huh-7& HepG2)	2.0–8.4 μg/ml	↓Cell viability	Thu et al. (2010)
A. glutinosum (L.) Druce	Anti-inflammatory	aerial parts	ethanol extract	In vitro: PDE4 inhibitor activity	10 μM	Inhibitory rate at 72–77%	Tan (2017)
A. indianum (Lour.) Merr.	Antiviral	aerial parts	aqueous extract	In vitro: Herpes simplex virus	–	Inhibition	Health (1975)
A. glutinosum (L.) Druce	Cytotoxic activity	whole plant	ethanol extract	In vitro: human hepatoma cell line (SMMC7721)	>100,000 mg/ml	Inhibitory rate at 20.88%	Chen et al. (2009)
A. glutinosum (L.) Druce	Mushroom tyrosinase activity	aerial parts	ethanol extract	In vitro: active of mushroom tyrosinase	0.4 mg/ml	Activate rate 68.2%	(Chen et al., 2008)
A. indianum (Lour.) Merr.	Anti-bacterial activity	whole plant	essential oil	In vitro: Antibacterial activity against *Staphylococcus aureus* and its drug-resistan strains, *Escherichia coli, Pseudomonas aeruginosa*	6,250, 6,250, 2,500, 12,500, 12,500 mg/ ml	MICs: 3150–12,500 mg/ml; MBCs: 6250–25,000 mg/ml	(Huang et al., 2011)
A. indianum (Lour.) Merr.	Antidiarrheal	whole plant	aqueous extract mixed with Eos	In vivo: *Folium sennae* induced diarrhea in mice	4000 mg/ml mixture of aqueous extract and EOs at two levels:10,000, 40,000 mg/kg.bw	Inhibition of diarrhea	Zhang et al. (2011)
A. indianum (Lour.) Merr.	Anti-inflammatory	whole plant	aqueous extract mixed with Eos	In vivo: P-xylene induced ear edema in mice	4000 mg/ml mixture of aqueous extract and EOs at two levels: 10,000, 40,000 mg/ kg.bw	↓Ear edema	Zhang et al. (2011)
A. indianum (Lour.) Merr.	Insecticide	aerial parts	essential oil water; distilled water	In vitro: insecticidal activity - hookworm and roundworm	–	Hookworm dies after explored 10–15 min; roundworm dies after explored 2–3 h	Dô, 1993
A. indianum (Lour.) Merr.	Sedative activity	whole plant	aqueous extract	In vivo: Spontaneous activity in Kunming mice	4000 mg/ml mixture of aqueous extract and EOs at two levels:	↓Mouse's independent active number of times	Zhang et al. (2011)

(continued on next page)

Table 5 (*continued*)

Species	Biological activity	Part	extract	Model	Dosage or concentration	Results	Reference
					10,000, 40,000 mg/kg.bw		
A. indianum (Lour.) Merr.	Toxicity	whole plant	aqueous extract	In vivo: Stomach irrigation of Kunming mice	at four levels: 52,000, 64,000, 80,000, 100,000 mg/kg	Poisoning, high dose group induced death, LD_{50}: 81,470 mg/kg.bw	Zhang et al. (2011)
A. indianum (Lour.) Merr.	Toxicity	whole plant	essential oil	In vivo: Stomach irrigation of Kunming mice	at four levels: 52,000, 64,000, 80,000, 100,000 mg/kg	No death	Zhang et al. (2011)

extracts of the aerial plant parts, and essential oils and some isolated compounds have also been tested.

We have collated the data regarding biological activity together with information as to the plants' traditional uses and summarized it in Table 5.

6.1. Antidiabetic activity

Nguyen (Nguyen et al. 2018, 2020) evaluated the antidiabetic activity of an extract of *A. bracteosum* in *in vivo* and *in vitro* models, and the relevant compounds have been isolated. A study of the anti-hyperglycemic effect of *A. bracteosum* in a streptozotocin-induced diabetic mice model, exhibited inhibition through oral delivery with ethanolic extracts (at a dose of 40 mg/kg) and aqueous extracts (at a dose of 50 mg/kg), which is similar to the standard drug glibenclamide (Nguyen et al., 2018).

Nguyen (Nguyen et al., 2020) further investigated the potential antidiabetic activity of ethanol and aqueous extractions of *A. bracteosum* both *in vitro* and *in vivo*. *In vitro*, both extracts showed a significant α-glucosidase inhibitory activity, which was more effective than acarbose at the same concentration. *In vivo*, both ethanol and aqueous extracts showed a strong anti-hyperglycemic activity, and at 50 mg/kg extract presented 64.42% and 57.69% reductions in the blood glucose levels, respectively, when compared with the diabetic control group on day 21 ($p > 0.05$). Isoscutellarein-8-O-β-D-glucopyranoside (**53**), similarly isolated from the ethanol extract of *A. bracteosum*, also showed a strong antidiabetic activity against α-glucosidase *in vitro*, with ten times higher potency than the positive control acarbose. Indeed, at a dose of 10 mg/kg, this chemical produced a similar anti-hyperglycemic effect ($p > 0.05$) to the negative control (Nguyen et al., 2020).

In Vietnam, *A. bracteosum* was reported to have antioxidant, anti-gout, hepato-protective, and anti-hyperglycemic activities, used in liver disease therapy traditionally (Tsankova et al., 1994; Hong et al., 2018). The above results observed *in vitro* and *in vivo* studies indicate that *A. bracteosum* is a potential source of natural anti-hyperglycemic agents, which could be further developed into anti-diabetic drugs (Nguyen et al., 2020). Moreover, Nguyen et al., first reported the anti-diabetic activity of the flavonoid isoscutellarein-8-O-β-D-glucopyranoside, identified from the ethanol extract of *A. bracteosum* (Nguyen et al., 2020). To date, there are few studies on the pharmacological properties of isoscutellarein-8-O-β-D-glucopyranoside (**53**), and whether it has other activities remains unknown.

6.2. Anticancer activity

Anticancer activity is reported from extracts of two species of *Adenosma*: *A. caeruleum* and *A. glutinosum* (Nam et al., 2003; Chen et al., 2009; Thu et al., 2010). The traditional applications of these plants do not involve treatment of tumors, however both plants are widely used in medicine, and some of their uses are slightly related to anticancer activities.

*A. caeruleum*is traditionally used in Vietnam to improve blood circulation and to treat jaundice. Two categories of bioassay were conducted in order to determine the anti-cancer activities (if any) of these plants: inhibition of angiogenesis and cytotoxicity. Nam studied the activity of methanol extracts of the areal parts of *A. caeruleum* against the tube-like formation of human umbilical venous cells in an *in vitro* angiogenesis assay; they showed a 50% reduction in B16 melanoma cell growth only in extract concentrations above 100 mg/ml (Nam et al., 2003). This result showed that methanol extracts of *A. caeruleum* aerial parts exhibited no significant antiangiogenic activity.

In 2010, Thu et al., inspired by the traditional plant usage in Vietnam, conducted a whole plant methanol extraction of *A. caeruleum* and tested this extract against tumor cells (Thu et al., 2010). The study found that the methanol extract of *A. caeruleum* inhibited tumor cell viability in the following human cell lines: carcinoma A549 (human lung carcinoma); MCF7 (human breast carcinoma); HepG2 (hepatocellular carcinoma cells); fibrosarcoma HT1080 (human fibrosarcoma cells); and Huh7 (human hepatoma fibrosarcoma cells) in the classic MTT cell viability assay. The best results were inhibition of A549, MCF7, and HepG2 cells, with IC_{50} values of 2.1 ± 0.0 μg/mL, followed by 3.3 ± 0.1 μg/mL (in HT 1080), and 8.4 ± 0.2 μg/mL (in Huh-7 cells) (Thu et al., 2010). Jaundice is an important clinical presentation and occurs in 5–44% of patients with hepatocellular carcinoma (Lai and Lau, 2006); so these results verified the rationality of the traditional use in treating jaundice, however, further studies on the cytotoxic constituents of *A. caeruleum* seem to be worthwhile (Thu et al., 2010). The different activities demonstrated by the extracts from the whole plant and the areal parts only may be due to the differences in the cancer cells used, but it may also be possible that certain active ingredients are only found in the roots, a point which needs further study.

A. caeruleum is traditionally used in China and Vietnam to enhance the immunological status of shrimps, to treat hepatitis, rheumatic arthritis, traumatic injury, and skin disorders, and as a tonic for woman (Hou 1956; Ueda et al., 2002; Hong and Pan 2006; Chen et al., 2016; Peltzer et al., 2017; Chi et al., 2017). In 2009, a study into the cytotoxicity of an ethanol extract of *A. glutinosum* on tumor cells found that this extract showed only low toxicity against the human hepatoma cell line (SMMC7721), with an IC_{50} value above 100 mg/L (20.88% inhibition of cell viability) (Chen et al., 2009).

A. caeruleum and *A. glutinosum* have the same vernacular name "Nhân Trần" in Vietnam, and are traditionally both used for treating hepatitis. However, the anticancer activity bioassays differed between the two species. It is possible that the differences stem from the different cell lines used in the experiment, or it may be that because the species share a vernacular name they have been confused.

In general, this research provides a scientific base for the development of new anti-tumor drugs from traditional herbs, however the above results are all based on plant extracts, and the individual compounds responsible for the anticancer activity of the extracts are yet to be isolated. The future isolation and characterization of the active compounds using bio-guided assays should therefore be a priority.

6.3. Nematocide and insecticidal activity

A. indianum is employed in Vietnam as a nematocide to treat intestinal parasites in humans (Dô, 1993). The essential oil and aqueous extraction of the aerial parts are active against hookworms and roundworms. In an *in vitro* bioassay, hookworms were found to die after 10–15 min exposure to the essential oil water, and roundworms die after 2–3 h exposure, while the effects of water distilled from this plant is weaker (Dô, 1993).

In the above study, only simple descriptions of the experimental results were shown, however the traditional use is partly explained. We therefore call for further isolation and characterization of the nematocidally active compounds using rigorous bio-guided assays.

A. buchneroides is traditionally used in China as mosquito and flea repellent (Shen et al., 1991; Fan et al., 2019). A scientific study was therefore conducted to investigate the effects and activity of *A. buchneroides* essential oil and its components against *Aedes albopictus*. Through mosquito repellent bioassays, the essential oil of the plant was found to be active against *A. albopictus* larvae. Indeed, it showed strong mosquito repellent activity, with a minimum effective dosage of 0.019 $\pm$ 0.007 mg/cm^2, less than the reference standard N, N-diethyl-3-methylbenzamide (0.031 $\pm$ 0.014 mg/cm^2) (Ma et al., 2019).

Furthermore, 26 compounds, representing 97.8% of the essential oil, were isolated, and the active compounds carvacrol, carvacrol methyl ether and a new fragrant compound, adenosmin A were identified. Carvacrol is a phenol monoterpene found in aromatic plants, particularly in those of the Lamiaceae family, and is an important volatile oil component. Carvacrol is widely used as a food additive, a flavoring, an antimicrobial, an agrochemical and an anticancer agent (Burt 2004; Yu et al., 2012; Sánchez et al., 2015; Suntres et al., 2015; Herrera-Calderon et al., 2020), and is a legally registered flavoring in both the EU and the USA (Burt 2004). Other studies have found that carvacrol and ether of carvacrol are potent pest management agents, having activity against different agricultural as well as public health pests (Nikumbh et al., 2003). These studies provide clear evidence for the efficacy of the chemicals found in *Adenosma* species as insecticidal agents and insect repellents, and help explain why these plants have been traditionally used in this way. Other insecticidal constituents may be found in *Adenosma* with further research.

6.4. Antioxidant activity

The antioxidant activity of *A. bracteosum* has been well described both *in vitro* and *in vivo*. The activities of ethanol and aqueous extracts, as well as isolated compounds from the plant, have been studied using a 2,2-diphenyl-1picrylhydrazyl (DPPH) radical scavenging assay, a ferric reducing/antioxidant power assay (FRAP), and a 2,2-azino-bis-3-ethylbenozothiazonline-6-sulfonic acid (ABTS) radical scavenging assay, and also in mice with livers damaged by acute CCl_4 poisoning (Nguyen et al. 2018, 2020). All the tested extracts and compounds were found to have a strong scavenging activity *in vitro*, and were effective against acute CCl_4 -induced hepatic poisoning in mice.

In a DPPH radical scavenging assay (Nguyen et al., 2020), reported that the IC_{50} values of the *A. bracteosum* ethanol and aqueous extracts, and IG from *A. bracteosum* were 6.61, 10.12, and 11.93 μg/mL, respectively, inhibiting the DPPH radicals by 2.29, 3.50, and 4.13 times less than the pure ascorbic acid. In an ABTS radical scavenging assay, the IC_{50} values of ethanol, aqueous extracts, and IG were found to be 10.33, 11.17, and 11.40 μg/mL, respectively.

These antioxidant activity studies are promising, for oxidative stress plays a role in the pathogenesis of chronic hepatitis, and antioxidant therapy is thought to have a beneficial effect in the treatment of these liver diseases (Singal et al., 2011), and this could therefore support the traditional uses of *A. bracteosum* as a treatment for liver diseases. The polyphenol and flavonoid components in this species may play a crucial role in its antioxidant activity (Nguyen et al., 2020).

Other compounds with good antioxidant activities include phenolic acids, flavonoids, and terpenes, many of which are commonly present in *Adenosma* plants (Fierascu et al., 2018). These compounds have been reported from several *Adenosma* species (*A. bracteosum, A. buchneroides, A. caeruleum*, and *A. glutinosum*), however, antioxidant activity has only been reported from *A. bracteosum*, while antioxidant activity from the other *Adenosma* plant species may therefore be profitable.

6.5. Anti-inflammatory activity

Inflammation as the first biological response of the animal immune system to infection, injury or irritation, and anti-inflammatory medicines have long been used to relieve the resulting discomfort. Three *Adenosma* species have been investigated for their anti-inflammatory properties: *A. caeruleum*, *A. glutinosum*, and *A. indianum*.

Nam (2009) studied the anti-flammatory potential of *A. caeruleum in vitro* using inhibitory activity against nuclear factor-kappa-light-chain-enhancer of activated B cells (NF-kB), for NF-kB signaling pathway is a key regulator of inflammation (Hou et al., 2015), and found that the methanol extracts of the plant exhibited no inflammatory inhibition at all (Nam and Jae 2009).

Tan (2017) reported that *A. glutinosum* exhibits anti-inflammatory properties *in vitro*. Of the compounds isolated from the plant, only ursolic acid (**16**) and betulin (**13**) were found to have inhibitory activity against phosphodiesterase 4 (PDE4), resulting in an inhibitory rate of 72% and 77%, respectively, at 10 μM (Tan 2017).

Ursolic acid is a pentacyclic triterpenoid, and is a major component of many herbs used as traditional medicines. It has been shown to have a wide range of biological functions, including antioxidative, anti-inflammation, and anticancer activities (Ikeda et al., 2008). Betulin is also a natural pentacyclic triterpenoid, also with a wide range of biological functions, including antiviral, analgesic, anti-inflammatory, and antineoplastic activities (Alakurtti et al., 2006). These results suggest that *A. glutinosum* not only plays an important role in traditional medicine, but also has relevance in modern medicine.

Zhang et al. (2011) evaluated the anti-inflammatory potential of *A. indianum* extracts, which are used against dermatitis in China (China's State Administration of traditional Chinese medicine, 1998; Liang and Zhong 2005). Aqueous extracts of whole plants mixed with EOs from *A. indianum* at two dose concentrations (10, 40 g/kg) were tested, and high concentration doses (40 g/kg) were found to have significant anti-inflammatory activity *in vivo* ($p < 0.01$) against P-xylene induced ear edema in mice (Zhang et al., 2011).

6.6. Antidiarrheal, anti-bacterial and antiviral activity

A. indianum is used in China and Vietnam as an herbal medicine to treat many diseases, including biliary tract disease, indigestion disorders, influenza, and colds (Nguyen et al., 1990; Dô, 1993; Hong and Pan 2006; Peltzer et al., 2016; Yao et al., 2020). Because of this, research into the antidiarrheal, anti-bacterial and antiviral activities of *A. indianum* extracts has been conducted.

Zhang et al. (2011) investigated the antidiarrheal properties of a mixture of the aqueous extract and the EOs of *A. indianum in vivo*. *A. indianum* was found to have significant antidiarrheal activity ($p < 0.01$) against *Folium sennae* induced diarrhea in mice at 40 g/kg (Zhang et al., 2011).

The inhibitory effects of the EOs of *A. indianum* against five bacterial species (*Staphylococcus aureus,* methicillin-resistant *Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa,* and *Sonne bacillus*) were investigated *in vitro*. The EO had low activity against *Escherichia coli* and moderate anti-bacterial activity against *Pseudomonas aeruginosa* and *Sonne bacillus*. However, it displayed good antibacterial activity against *Staphylococcus aureus* and methicillin-resistant *Staphylococcus aureus*, with the minimum inhibitory concentration (MIC) value at 3.125 g/L, and the minimum bactericidal concentration (MBC) value at 6.25 g/L (Huang et al., 2011). The results provide a scientific basis for the effectiveness of *A. indianum* in the treatment of certain intestinal diseases (Hong and Pan 2006).

A. indianum is also used as medicine to treat influenza (Hong and Pan 2006; Yao et al., 2020). The crude aqueous extract of the aerial parts of *A. indianum* exhibited anti-viral activity against *Herpes simplex virus* (HSV), as reported by (Health 1975). The mode of antiviral action against HSV was evaluated at different periods during the viral replication cycle. Antiviral effects were revealed when aqueous extract of *A. indianum* was added to host cells prior to viral infection, during and after entry of HSV into the cells, as well as following direct interaction with the free virus.

The above results partly explained the traditional usage of *A. indianum,* but this research focuses on the crude extracts and employs only simple bioassay into specific activities; more research is required to isolate and identify the active compounds from *A. indianum* in a more sophisticated and biologically rigorous way.

6.7. Other biological activities

A study from (Chen et al., 2008) investigated whether ethanol extracts from the aerial parts of *A. glutinosum* exhibit activity towards mushroom tyrosinase, and, if so, how this activity affects mushroom tyrosinase. The results showed that mushroom tyrosinase can be activated by ethanol extracts from *A. glutinosum* at a dose of 0.4 mg/ml, with activation rate of 68.2%. The kinetic features of the enzymatic reaction system were analyzed, and the study concluded that the extract not only affected the combination of substrate and enzyme, but also contributed to conformational changes in the enzyme molecule (Chen et al., 2008).

A. bracteosum is reported to cause increases in bile secretion in guinea pigs (Dô, 1993). At a dose of 300 mg/kg, the ethanol extract of dried aerial parts increased bile secretion by 24.7%. Thus, these findings are consistent with the traditional practice of using *A. bracteosum* as an herbal remedy to treat hepatitis.

The purpose of these pharmacological studies is to elucidate the mechanisms of action (if any) of traditional medicinal plants, and to combine information from traditional knowledge, chemical composition, and pharmacological activity to 1) provide potential lead compounds for the development of new drugs based on these natural products, and 2) comprehensively improve the general health and resistance to disease in these populations.

7. Safety concerns

Very little is known regarding the toxicity of *Adenosma* species, with only one study dealing with the sedation and acute toxicity following *A. indianum* ingestion. To assess the sedative effects of the aqueos extract of *A. indianum* (Zhang et al., 2011), orally administered the aqueous extracts to mice, and at 10 and 40 g/kg times of spontaneous motility of the mice significantly decreased ($p < 0.01$ at 0.5h, $p < 0.05$ at 1h), with the inhibition rates being 0.554 ± 0.347, 0.623 ± 0.365 at 0.5h, and 0.660 ± 0.508, 0.830 ± 0.180 at 1h, respectively (Zhang et al., 2011).

To investigate the acute toxicity of aqueous extracts and essential oils from *A. indianum,* mice were treated with aqueous extract at doses of 0.35 mL/10g at four levels (52, 64, 80, 100 g/kg) through stomach irrigation. Four mice in the high dosage group died after 24h, giving an LD_{50} value of 81.47 g/kg. However, no mortality was observed following treatment with essential oils. These *in vivo* studies suggest that toxic ingredients of *A. indianum* are mainly in the aqueous solution (Zhang et al., 2011).

8. Future perspectives and conclusions

This review provides a summary of the current knowledge of the geographical distribution, traditional uses, phytochemistry, biological activity and toxicity of the genus *Adenosma*. The genus comprises several South- and East Asian, Chinese and Pacific Island species, and plants of the genus tend to be strong scented and turn black when drying. Several species are known to have traditional uses as herbal remedies or aromatics.

Adenosma is rich in essential compounds, including monoterpenoids, sesquiterpenoids, fatty acids, phenols, and phenylpropanoids. Extracts of *Adenosma* species were also found to be rich in diverse phytochemical compounds, mainly terpenoids and phenylpropanoids. Many biological activities have been investigated, in particular antidiabetic, anticancer, insecticidal, antioxidant, and anti-inflammatory activities. Most of the studies focused on crude extracts, and only a few active compounds have been identified and evaluated. These studies were performed on several species and are very infrequent.

Although several studies into the properties of this genus exist, there are still gaps between the current state of scientific knowledge and the traditional uses, particularly regarding the toxicity.

Adenosma species are mainly distributed in developing countries, and the medicinal plants, especially those containing essential oils, continue to play an important role in health management for local people. With the developing economies in these areas, the research work of *Adenosma* species also needs to be developed, for their utilized diversity and significant role in the healthcare for local people.

There are 26 accepted species and 3 unresolved species in the genus *Adenosma*, which are widely distributed throughout South and South-East Asia, China, and the Pacific Islands. Seven species are commonly used for different purpose because of their aroma, but compared with the breadth of their distribution, there are many areas in which the traditional uses are unknown: 1) to date, only a quarter of the species (7: 29) were reported to have traditional uses (and these include reports with only short utilization descriptions). Are the other species are used in folk medicine, and, if so, how? 2) The existing research into traditional uses is currently limited to three countries with origins of samples: China, Vietnam, and Laos. In these reports there is a single sentence describing the use of *A. triflora* on the Fiji islands (Parham 1939). The specific knowledge of the traditional use of *A. triflora* and the other species in other areas are worthy of in-depth study. These studies may give us clues as to the biological activities of any chemicals isolated from the plants.

The phytochemical composition and pharmacological activity of *Adenosma* aerial parts have been reported, but only five species at flowering stage were extensively studied. However, although the phytochemical characteristics of *Adenosma* aerial parts at the flowering stage do represent a promising source of pharmacological activity compounds, further research should be performed while considering the employment of different parts and developmental stages in traditional uses.

Despite well documented records of the use of 7 *Adenosma* species in China, Vietnam and Laos, the other species are poorly explored. Therefore, further primary ethnobotanical field studies are necessary in other species and distribution regions of *Adenosma* that have been reported to have traditional uses.

Finally, although the current research into pharmacological activity has been based on traditional applications, there are still gaps worthy of in-depth discussion, because the biological activities presented in the research only explain a small part of the traditional uses. Furthermore, where *Adenosma* is mixed with other herbs, (for example, *A. bracteosum, A. caeruleum,* and *A. glutinosum* are used with other herbs in Vietnam (Dô, 1993; Chi et al., 2017), and *A. indianum* is one of the main compositions of Sanjin cold Tablet in China (Yao et al., 2020)), what exactly is the role the *Adenosma* in these mixtures?

In conclusion, this review provides background data for subsequent research into the genus *Adenosma*, and we believe that future research directions should include more study of the traditional uses, phytochemistry, and biological activities of compounds extracted from these plants.

Author contributions

All authors developed the concept for the study; C. Wang drafted the manuscript. H. Zhang, Q. Liu, J. Qi, H. Zhuang and Y. Gou participated in data mining, literature analysis, and manuscript editing. H. Wang and Y. Wang designed the study, revised the manuscript, and edited the final version. All authors reviewed and approved the final version of the manuscript.

Declaration of competing interest

The authors declare that there are no conflicts of interest.

Acknowledgements

This research was supported the Strategic Priority Research Program of Chinese Academy of Sciences (XDA20050204), National Natural Science Foundation of China (31670337), and Plant Germplasm Resources Innovation Project of Chinese Academy of Sciences (KFJ-BRP-007-002). We thank Dr. Wenyun Chen and Miss Zihong Lin for comments that greatly improved the manuscript.

References

Adam, G., Porzel, A., Sung, T., Schmidt, J., 1992. A monoterpenoid peroxide from. Adenosma Caeruleum. Phytochem. 31 (8), 2885–2887.
Alakurtti, S., Makela, T., Koskimies, S., Yli-Kauhaluoma, J., 2006. Pharmacological properties of the ubiquitous natural product betulin. Eur. J. Pharmaceut. Sci. 29 (1), 1–13.
Albach, D.C., Meudt, H.M., Oxelman, B., 2005. Piecing together the "new" Plantaginaceae. Am. J. Bot. 92 (2), 297–315.
Asia, Regional, 2011. Office for South-East. Traditional Herbal Remedies for Primary Health Care. World Health Organization, New Delhi.
Backer, C.A., Brink, R. C. Bakhuizen van den, 1965. Flora of Java, II. N.V.P. Noordhoff, Groningen, pp. 506–507.
Bailey, F. Manson, 1901. the Queensland Flora, IV. H. J. Diddams & Co., Queensland, pp. 1103–1104.
Bentham, George, 1869. Flora Australlensis: a description of the plants of the Australian territory, IV. L. Reeve & Co., London, pp. 484–485.
Bhuiyan, M.N.I., Akter, F., Chowdhury, J.U., Begum, J., 2010. Chemical constituents of essential oils from aerial parts of Adenosma capitatum and Limnophila aromatica. Bangladesh J. Pharmacol. 5 (1), 13–16.
Brown, R., 1810. Prodromus florae Novae Hollandiae et insulae Van-Diemen. Richard Taylor & Son London.
Burt, S., 2004. Essential oils: their antibacterial properties and potential applications in foods - a review. Int. J. Food Microbiol. 94 (3), 223–253.
Byng, J., Chase, M., Christenhusz, M., Fay, M., Judd, W., Mabberley, D., et al., 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot. J. Linn. Soc. 181, 1–20.
Châu, L.T., Van Hồng, L., 1992. Some study results of three *Adenosma* species, named "Nhân Trân," and their use in folk medicine for curing viral hepatitis. J. Pharmacol. 6–8.
Chen, B., Lin, Y., Ming, Y., Chen, B., Tong, Q., 2009. Inhibitory effect of three kinds of Chinese herbs on human hepatoma cell line SMMC7721 in vitro. J. Huaqiao Univ. Nat. Sci. 30, 425–428.
Chen, L.H., Qiu, l, Ming, Y.L., Zhong, x., Tong, Q.X., Cheng, q, 2008. The activation effect of medicine plants on the mushroom tyrosinase. Xiamen Daxue Xuebao/J. Xiamen Univ. (Nat. Sci.) 47 (s2), 110–114.
Chen, P., Zheng, F., Zhang, Y., Gao, F., Chen, Y., Shi, G., 2016. Ethnobotanical study of medicinal plants on arthritis used by Chaoshan in Guangdong, China. Med. Chem. 6, 715–723.
Chi, Tran Thi Kim, Clausen, Jesper H., Van, Phan Thi, Tersbøl, Britt, Anders, Dalsgaard, 2017. Use practices of antimicrobials and other compounds by shrimp and fish farmers in Northern Vietnam. Aquaculture Reports 7, 40–47.
Chibber, H.M., 1916. A list of the natural orders and genera of Bombay plants with derivations of the names. J. Bombay Nat. Hist. Soc. 24, 1.
China's State Administration of traditional Chinese medicine, 1998. t.C.M.M.e.b. Chinese Materia Medica. Shanghai Science and Technology Press.
Chowdhury, J., Bhuiyan, M., Begum, J., 2011. Constituents of volatile oils from *Limnophila aromatica* and *Adenosma capitatum*. Bangladesh J. Sci. Indus. Res. 46 (3), 385–388.
Clarke, C.B., 1900. Scrophulariaceae. Journal de botanique Botanisk Tidsskrift Bind 23, 346–347.
Craib, William Grant, 1912. Contributions to the Flora of Siam. University of Aberdeen, Aberdeen, p. 144.
Dai, D.N., Thang, T.D., Thai, T.H., Ogunwande, I.A., 2015. Chemical constituents of leaf essential oils of four Scrophulariaceae species grown in Vietnam. J. Essent. Oil Res. 27 (6), 481–486.
De Abreu, M.B., Malafronte, N., Van Kiem, P., Braca, A., 2009. A new iridoid from *Adenosma caeruleum* R. Br. Fitoterapia 80 (6), 358–360.
Dỏ, Tất Lợi, 1993. Medicinal Plants and Ingredients from Vietnam. Science and Technique Publisher, Hanoi.
Dũng, N.X., Van Hac, L., Leclercq, P.A., 1996. A new chemotype of *Adenosma glutinosum* (L.) Druce var. *caeruleum* (R.Br.) Tsoong from Vietnam. J. Essent. Oil Res. 8 (4), 359–362.
Ewart, Alfred J., Davies, Olive B., 1943. the Flora of the Northern Territory. Bird & Co., Melbourne, p. 246.
Fan, R., Gou, Y., Wang, C., Yang, N., Wang, Y., 2019. Ethnobotanical survey on mosquito-repellent plant used by Hani people in Xishuangbanna. Guangxi Zhiwu/Guihaia 39 (3), 359–374.
Fierascu, R.C., Ortan, A., Fierascu, I.C., Fierascu, I., 2018. In vitro and in vivo evaluation of antioxidant properties of wild-growing plants. A short review. Curr. Opin. Food Sci. 24, 1–8.
Figueiredo, A.C., Barroso, J.G., Pedro, L.G., Salgueiro, L., Miguel, M.G., Faleiro, M.L., 2008. Portuguese *Thymbra* and *Thymus* species volatiles: chemical composition and biological activities. Curr. Pharmaceut. Des. 14 (29), 3120–3140.
Franz, C., Baser, K.H.C., Windisch, W., 2010. Essential oils and aromatic plants in animal feeding - a European perspective. A review. Flavour Fragrance J. 25 (5), 327–340.
Gou, Y., Fan, R., Pei, S., Wang, Y., 2018. Before it disappeared: ethnobotanical study of fleagrass (*Adenosma buchneroides*), a traditional aromatic plant used by the Akha people. J. Ethnobiol. Ethnomed. 14, 79.
Grierson, A.J.C., Long, D.G., 2001. Flora of Bhutan, II. Royal Botanic Garden Edinburgh, Edinburgh, p. 1108.
Guidi, L., Landi, M., 2014. Aromatic plants: use and nutraceutical properties. John Wiley & Sons Ltd 305–345.
Guppy, Henry Brougham, 1887. The Solomon Islands and their natives. Swan Sonnenschein, Lowrey & Co., London, p. 299.
Gurib-Fakim, Ameenah, 2006. Medicinal plants: Traditions of yesterday and drugs of tomorrow. Molecular Aspects of Medicine Vol (27), 1–93.
Health, G.I.o.M.a., 1975. Preliminary study on the principle of Chinese herbal medicine inhibiting respiratory virus. Guangdong Med. J. 3, 12–13.
Henry, Trimen M.B., 1898. a hand-book to the Flora of Ceylon, III. Dulau & Co., London.
Herrera-Calderon, O., Yepes-Perez, A.F., Quintero-Saumeth, J., Pedro Rojas-Armas, J., Palomino-Pacheco, M., Manuel Ortiz-Sanchez, J., et al., 2020. Carvacrol: an in-silico approach of a candidate drug on HER2, PI3K alpha, mTOR, hER-alpha, PR, and EGFR Receptors in the Breast Cancer. *Evidence-Based Complementary and Alternative Medicine*, 2020.
Hong, D., Pan, K., 2006. Flora Yunnanica Tomus 16. Science Press, Beijing.
Hong, D., Yang, H., Jin, C., Holmgren, N., 1998. *Adenosma* R. Brown (Scrophulariaceae). In: flora of China (eds. Wu, Z & Raven, P). In: Science Press Missouri Botanical Garden Press Beijing. St.Louis, 24.
Hooker, Joseph Dalton, 1885. Flora of British India, lV. L. Reeve & Co., London, pp. 3–5.
Hou, K., 1956. Flora of Guangzhou. Science Press, Beijing.
Huang, J.-y., Lu, W.-j., Chen, J.-y., Tan, X., Lu, G.-s., Huang, Z.-f., 2013. Analysis of hydrophobic constituents from *Adenosma indianum*. Zhongguo Minzuminjian Yiyao/Chin. J. Ethnomedi. Ethnopharm. 22, 11–12.
Huang, Y., Wu, H.-e., Wei, Z.-y., Xiao, Y.-F., Yu, X.-l, 2011. Chemical constituents and anti-bacterial activity of essential oil from *Adenosma indianum*. Zhongguo Shiyan Fangjixue Zazhi/Chin. J. Exper. Tradit. Med. Form. 17 (12), 79–82.
Huu Du, N., Pham, A., Luong, Le, Vo, 2020. Potential antidiabetic activity of extracts and isolated compound from *Adenosma bracteosum* (Bonati). Biomolecules 10, 201.
Ikeda, Y., Murakami, A., Ohigashi, H., 2008. Ursolic acid: an anti- and pro-inflammatory, triterpenoid. Mol. Nutr. Food Res. 52 (1), 26–42.
Ji, X., Pu, Q., 1985. Studies on constituents in the essential oil from *Adenosma indianum* (Lour.) Merr. Zhiwu Xuebao/Acta Bot. Sin. 27 (1), 80–83.
King, George, 1907. Materials for a flora of the Malayan Peninsula, II. Baptist Mission Press, Singapore, pp. 344–345.
Le, T.C., 1977. Chemical composition of the essential oil from *Adenosma capitatum* Benth. (Scrophulariaceae). Tap Chi Hoa Hoc/J. Chem. (Vietnam) 15 (3), 25–32.
Liang, Q., Zhong, M., 2005. Chinese Zhuang pharmacy (Zhongguozhuangyaoxue). Guangxi nationalities publishing house, Nanning.
Lu, G.-s., Huang, Q.-j., Ye, Y., Lu, W., Ya, Q., Huang, W.-c., 2014. Separation and determination of betulinic acid in *Adenosma indianum* (Lour.) Merr. by HPLC. Zhongguo Shiyan Fangjixue Zazhi/Chin. J. Exper. Tradit. Med. Formulae 20.
Ludwiczuk, A., Skalicka-Woźniak, K., Georgiev, M.I., 2017. Chapter 11-Terpenoids. In: Badal, S., Delgoda, R. (Eds.), Pharmacognosy. Academic Press Boston, pp. 233–266.
Ma, Y., 2018. Chemical components from *Adenosma buchneroides* Bonati and its repellent activity against *Aedes albopictus*. Pharmaceutical Chemistry. University of Chinese academy of sciences Kunming.
Ma, Y., Li, M., Zhang, H., Sun, H., Su, H., Wang, Y., et al., 2019. Bioassay-guided isolation of active compounds from *Adenosma buchneroides* essential oil as mosquito repellent against Aedes albopictus. J. Ethnopharmacol. 231, 386–393.
Ma, Y., Zhang, H., Sun, G., Du, Z., 2018. Chemical constituents from *Adenosma buchneroides*. Tianran Chanwu Yanjiu Yu Kaifa/Nat. Prod. Res. Develop. 30 (8), 1376–1381, 1398.
Merrill, Elmer D., 1917. Notes on the flora of Kwangtung Province, China. The Philippine journal of science 12 (C), 99–112.
Merrill, Elmer D., 1921. A bibliographic enumeration of Bornean plants. Fraser & Neave, ltd., Singapore, p. 523.
Merrill, Elmer D., 1923. An enumeration of Philippine flowering plants, III. Bureau of Printing, Manila, pp. 434–435.
Morales-Lázaro, S.L., Rosenbaum, T., 2017. Chapter Five - Multiple Mechanisms of Regulation of Transient Receptor Potential Ion Channels by Cholesterol. In: Levitan, I. (Ed.), Current Topics in Membranes. Academic Press, pp. 139–161.
Muséum national d'histoire naturelle, 1909. Notulae systematicae. J. Dumoulin, Paris, pp. 331–332.

Nam, N., Jae, Y., 2009. NF-κB Inhibitory activities of the methanol extracts and some constituents therein of some Vietnamese medicinal plants. Sci. Pharm. 77 (2), 389–400.
Nam, N.H., Kim, H.M., Bae, K.H., Ahn, B.Z., 2003. Inhibitory effects of Vietnamese medicinal plants on tube-like formation of human umbilical venous cells. Phytother Res.: Int. J. Devoted Pharmacol. Toxicol. Eval. Nat. Prod. Deriv. 17 (2), 107–111.
Nguyễn, Xuân Dũng, Dô, Tất Lợi, 1991. Selection of traditional medicines for study. J. Ethnopharmacol. 32 (1), 57–70.
Nguyen, Van Duong, Doan, Thi Nhu, Pham, Kin Man, Le, Tung Chau, Do, Huy Bich, 1990. Medicinal plants in Vietnam. WHO Regional Publications, Western Pacific Series No. 3, WHO Regional Office for Western Pacific, Manila.
Nguyen, N.H., Luong, T.N.H., Pham, Q.T., 2018. Antioxidant activity and anti-hyperglycemic effect from *Adenosma bracteosum* Bonati. Acad. J. Biol. 40 (2).
Nguyen, N.H., Pham, Q.T., Luong, T.N.H., Le, H.K., Vo, V.G., 2020. Potential antidiabetic activity of extracts and isolated compound from *Adenosma bracteosum* (Bonati). Biomolecules 10 (2), 1–12.
Nguyên, T., 2017. Nghiên cứu thành phần hóa học và hoạt tính sinh học của loài nhân trần (*Adenosma cearuleum* R. Br.) Phân bố trên địa bàn tỉnh thái nguyên. Organic Chemistry. Thai Nguyen University, Thai Nguyen.
Nguyen, T.T., Nguyen, T.T., Tran, V.S., 2012. Chemical constituents of *Adenosma caeruleum* R. Br. Tap Chi Hoa Hoc/J. Chem. (Vietnam) 50 (5), 624–626.
Nikumbh, V.P., Tare, V.S., Mahulikar, P.P., 2003. Eco-friendly pest management using monoterpenoids-III: antibacterial efficacy of carvacrol derivatives. J. Sci. Ind. Res. 62 (11), 1086–1089.
Pandey, A.K., Kumar, P., Saxena, M.J., Maurya, P., 2020. Distribution of Aromatic Plants in the World and Their Properties. In: Florou-Paneri, P., Christaki, E., Giannenas, I. (Eds.), Feed Additives. Academic Press, pp. 89–114.
Parham, H.R., 1939. Fiji plants: their names and uses. Polynesian Society.
Peltzer, K., Nguyen Huu, T., Bach Ngoc, N., Pengpid, S., 2017. The use of herbal remedies and supplementary products among chronic disease patients in Vietnam. Stud. Ethno-Med. 11 (2), 137–145.
Peltzer, K., Sydara, K., Pengpid, S., 2016. Traditional, complementary and alternative medicine use in a community population in Lao PDR. Afr. J. Tradit., Complementary Altern. Med. 13 (3), 95–100.
Pennell, Francis W, 1943. A second summary of the Scrophulariaceae of New Guinea. Journal of the Arnold Arboretum XXIV, 243–274.
Phuong, Vu Xuan, 2005. Checklist of Plant Species of Vietnam (Danh luc CAC LOAI THUC VAT VIETNAM TAP III). Agriculture publishing house, Hanoi, p. 203.
Piccolella, S., Crescente, G., Pacifico, F., Pacifico, S., 2018. Wild aromatic plants bioactivity: a function of their (poly)phenol seasonality? A case study from Mediterranean area. Phytochemistry Rev. 17 (4), 785–799.
Quynh, N.N., Tin, D.C., Hung, T., 2013. Phytosterol and triterpene from petroleum ether extract of *Adenosma bracteosum* bonati (Ho Chi Minh City, Vietnam). Pharma Indochina 8th 923–927.
Sánchez, C., Aznar, R., Sánchez, G., 2015. The effect of carvacrol on enteric viruses. Int. J. Food Microbiol. 192, 72–76.
Schumann, K., Lauterbach, Karl, 1901. Die Flora der deutschen Schutzgebiete in der Südsee. verlag von Gebrüder Borntraeger, Leipzig, p. 537.
Shen, P.Q., Sun, H.D., Pei, S.J., 1991. Ethnobotany of fleagrass (*Adenosma buchneroides* Bonati), a traditional cultivated plant of the hani people, xishuangbanna, yunnan, China, In: The Museum. Belém: Ethnobiol.: Implicat. Appl.: Proc. First Int. Congr. Ethnobiol.; 1988 1, 305–309.
Silva, N.C.C., Fernandes, A., 2010. Biological properties of medicinal plants: a review of their antimicrobial activity. J. Venom. Anim. Toxins Incl. Trop. Dis. 16 (3), 402–413.
Singal, A.K., Jampana, S.C., Weinman, S.A., 2011. Antioxidants as therapeutic agents for liver disease. Liver Int.: Off. J. Int. Assoc. Stud. Liver 31 (10), 1432–1448.
Spiewak, R., Skorska, C., Dutkiewicz, J., 2001. Occupational airborne contact dermatitis caused by thyme dust. Contact Dermatitis 44 (4), 235–239.
Stevenson, P.C., Aslam, S.N., 2006. The Chemistry of the Genus *Cicer* L. In: Atta ur, R. (Ed.), Studies in Natural Products Chemistry. Elsevier, pp. 905–956.
Suntres, Z.E., Coccimiglio, J., Alipour, M., 2015. The bioactivity and toxicological actions of carvacrol. Crit. Rev. Food Sci. Nutr. 55 (3), 304–318.
Surburg, H., Panten, J., 2016. Common fragrance and flavor materials: preparation, properties and uses. 6 edn. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim.
Tan, B., 2017. The chemical constituents from the herb of *Adenosma glutinosum* (L.) Druce. Guangzhou Guangzhou Univ. Chin. Med. 1–90.
Tan, B., Peng, G., Yu, S., Xian, J., Liao, C., He, X., 2017. Chemical constituents of *Adenosma glutinosum*. Zhong Cao Yao/Chin. Tradit. Herbal Drugs 48 (10), 2024–2027.
Thu, N.B., Trung, T.N., Ha, D.T., Khoi, N.M., Hung, T.V., Hien, T.T., et al., 2010. Screening of Vietnamese medicinal plants for cytotoxic activity. Nat. Prod. Sci. 16 (1), 43–49.
Tran, V.S., 1997. Study on the chemical constituents of *Adenosma caeruleum* R.B.R. (Scrophulariaceae). Tap Chi Hoa Hoc/J. Chem. (Vietnam) 35 (2), 7–8.
Tsankova, E.T., Kuleva, L.V., Thanh, L.T., 1994. Composition of the essential oil of *Adenosma bracteosum* Bonati. J. Essent. Oil Res. 6 (3), 305–306.
Turner, I.M., 1993. the Names Used for Singapore Plants Since 1900. The Gardens' bulletin, Singapore Vol (45) (ser.4), 288.
Ueda, J.-y., Tezuka, Y., Banskota, A.H., Le Tran, Q., Tran, Q.K., Harimaya, Y., et al., 2002. Antiproliferative activity of Vietnamese medicinal plants. Biol. Pharm. Bull. 25 (6), 753–760.
Wu, C., Raven, P., Hong, D., 1998. Flora of China Vol. 18. Sciences Press and Missouri Botanic Garden Press, Beijing and St. Louis.
Wang, Cuncun, Wei, Gang, Li, Run-mei, 2008. GC-MS analysis of volatile oil in *Adenosma glutinosum* (Linn.) Druce [J]. Zhongguo Zhongyiyao Xinxi Zazhi/Chin. J. Informat. Tradit. Chin. Med. 15 (2), 36–37.
Wu, H., Liang, C., Li, Y., Huang, X., Zhu, X., 2010. GC-MS analysis of chemical constituents of the essential oil from *Adenosma indianum* (Lour.) Merr. by different extraction methods. Yaowu Fenxi Zazhi/Chin. J. Pharmaceut. Analys. 30 (10), 1941–1946.
Xiao, B., 2009. Ling Nan Cai Yao Lu. Guangdong science and technology press, guangzhou.
Xing, Fu-wu, 2007. Flora of Macao, II. Civic and Mnnicipal Affairs Burean of Macao Special Administrative Region, Guangzhou, p. 288.
Xu, Y., Cheng, B., Yu, Z., Ding, J., 2008. A preliminary study on the new perfume plant *Adenosma buchneroides* Bonati. In: the seventh China Flavor and Fragrance Conference. Hangzhou, China, p. 4.
Ya, Q., Lu, W., Chen, J., Tan, X., 2011a. GC-MS analysis of the chemical constituent of volatile oil from Zhuang drug *Adenosma indianum* (Lour.) Merr. Chin. J. Pharmaceut. Analys. 31 (3), 544–546.
Ya, Q., Lu, W., Chen, J., Tan, X., 2011b. Study on the chemical constituents of *Adenosma indianum*. Huaxi Yaoxue Zazhi/West Chin. J. Pharmaceut. Sci. 26 (6), 519–521.
Yamazaki, Takasi, 1985. Flore Du Cambodge Du Laos et Du Vietnam, XXI. French Association de Botanique Tropicale, Paris, p. 36.
Yang, D., Zhan, H., Shi, L., 2013. Chemical Constituents of the volatile oil from the leaves of *Adenosma glutinosum*. Xibeilin Xueyuan Xuebao/J. Northwest For. Coll. 28 (2), 164–167.
Yao, Q., Gao, Y., Lai, C., Wu, C., Zhao, C.-L., Wu, J.-L., et al., 2020. The phytochemistry, pharmacology and applications of *Melicope pteleifolia*: a review. J. Ethnopharmacol. 251, 112546.
Yu, H., Zhang, Z.L., Chen, J., Pei, A., Hua, F., Qian, X., et al., 2012. Carvacrol, a food-additive, provides neuroprotection on focal cerebral ischemia/reperfusion injury in mice. PloS One 7 (3), e33584.
Yu, S., Peng, G., Lei, Y., Xue, D., Xian, J., Zhang, C., et al., 2018. Chemical constituents of *Adenosma glutinosum* (II). Zhongshan Daxue Xuebao/Acta Sci. Natralium Univ. Sunyatseni 57 (3), 89–95.
Zeng, Z., Meng, C., Ye, X., Zeng, Z., 2013. Analysis of volatile components of *Adenosma indianum* (Lour.) Merr. by steam distillation and headspace Solid-phase Microextraction. J. Chem. 2013, 1–7.
Zhang, Q., Zhang, M., Shao, S., Peng, W., Wang, C., 2011. A preliminary study on the pharmacological and toxic effects of *Adenosma indianum* (Lour.) Merr. Shizhen Guoyi Guoyao/Lishizhen Med. Mater. Med. Res. 22 (5), 1293–1294.