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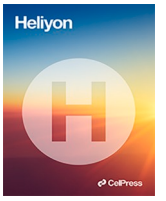

Review article

The genus *Polygonum*: An updated comprehensive review of its ethnomedicinal, phytochemical, pharmacological activities, toxicology, and phytopharmaceutical formulation

Sourour Idoudi [a,c], Audrey Tourrette [c], Jalloul Bouajila [b], Mehrez Romdhane [a], Walid Elfalleh [a,*]

[a] *Energy, Water, Environment and Process Laboratory, (LR18ES35), National Engineering School of Gabes, University of Gabes, Gabes, 6072, Tunisia*

[b] *Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INP, UPS, F-31062, Toulouse, France*

[c] *CIRIMAT, Université Toulouse 3 Paul Sabatier, Toulouse INP, CNRS, Université de Toulouse, 35 Chemin des Maraichers, 31062, Toulouse, Cedex 9, France*

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ABSTRACT

Polygonum is a plant genus that includes annual and perennial species and is found at various temperatures, from northern temperate regions to tropical and subtropical areas. The genus *Polygonum* has been used for centuries for various disorders, including hypertension, intestinal and stomach pain, dysuria, jaundice, toothaches, skin allergies, hemorrhoids, cardiac disorders, kidney stones, hemostasis, hyperglycemia, and others. Various databases, including Google Scholar, Scifinder, ScienceDirect, PubMed, Scopus, ResearchGate, and Web of Science, were utilized to collect pertinent scientific literature data. According to bibliographic studies, the *Polygonum* genus possesses various compounds from different families, including phenolic acids (gallic acid, caffeic acid, quinic acid, *p*-coumaric acid, ferulic acid, protocatechuic acid, chlorogenic acid, and many other compounds), flavonoids (quercetin, catechin, epicatechin, quercitrin, kaempferol, myricetin, etc.), tannins, stilbenes (polydatin and resveratrol), terpenes (α-pinene, β-caryophyllene and β-caryophyllene oxide, bisabolene, β-farnesene, etc.), fatty acids (decanoic acid, lauric acid, linoleic acid, oleic acid, palmitic acid, stearic acid, dodecanoic acid), polysaccharides, and others. Various chemical and biological activities (*in vitro* and *in vivo*), such as antioxidant, antimicrobial, anticancer, antitumor, anti-inflammatory, antidiabetic, antiparasitic, hepatoprotective, neuropharmacological, gastroprotective, diuretic, antipyretic, and others, have been described in several biological studies involving this species. An updated summary of *Polygonum* species and their ethnomedicinal, phytochemical, toxicological, pharmacological, and phytopharmaceutical formulations is necessary. Considering the numerous potentialities of the *Polygonum* species and their wide-ranging use, it is extremely essential to provide knowledge by compiling the accessible literature to identify the topics of intense investigation and the main gaps to better design future studies. The objective of this review is to give readers a better understanding, greater comprehension, and in-depth knowledge of the genus *Polygonum*'s traditional applications, phytochemistry, pharmacology, toxicological features, and galenic formulation. Several species of this genus have been detailed in this review, including those that

* Corresponding author.
E-mail addresses: sourour.idoudi@univ-tlse3.fr (S. Idoudi), audrey.tourrette@univ-tlse3.fr (A. Tourrette), jalloul.bouajila@univ-tlse3.fr (J. Bouajila), mehrez.romdhane@univgb.tn (M. Romdhane), walid.elfalleh@fst.rnu.tn (W. Elfalleh).

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were frequently used in traditional medicine (*P. minus, P. aviculare, P. hydropiper, P. cuspidatum, and P. multiflorum*) and many of the genus' therapeutic species, like *P. equisetiforme*, which do not get enough attention.

1. Introduction

Polygonum is a Polygonaceae medicinal genus with roughly 300 species found all over the world [1]. The genus *Polygonum* includes annual and perennial species and is found at various temperatures, from northern temperate regions to tropical and subtropical areas. For several centuries, people from different countries have used plants of the *Polygonum* genus for medicinal purposes. Among the most widely utilized plants in this genus, are the species *P. aviculare* and *P. hydropiper* L. *P. aviculare* was used in Africa, Asia, and Europe. In Morocco, this species is utilized for treating kidney stones, hemostasis, hyperglycemia, and digestive issues [2]. In India, the leaf powder has anti-inflammatory effects and is used against kidney diseases, burns, and urinary tract infections [3]. In Portugal, *P. aviculare* is known for its laxative, diuretic, sedative, anti-hemorrhoidal, and anti-hemorrhagic effects [4]. *P. hydropiper* L. was used in India for the treatment of a wide range of diseases, including hypertension, intestinal and stomach pain, dysuria, jaundice, toothaches, skin allergies, hemorrhoids, and cardiac disorders [5–7]. It was also used to treat dysentery, gynecological, and menstrual problems. *P. hydropiper* L decoction was used in Chinese traditional medicine to treat shoulder and neck pain, worm infestations, and snake bites [8]. Many other plants in the genus *Polygonum* have important traditional uses, including *P. barbatum* [9], *P. bellardii* [10], *P. bistorta* L [11], *P. capitatum* [12], *P. cognatum* [13], *P. equisetiforme* [14,15], *P. flaccidum* [16], *P. glabrum* [17], *P. multiflorum Thunb* [18–20], *P. orientale* Linn [21], *P. polystachyum* [22], *P. plebeium* [23], *P. tortuosum, P. viviparum* [22], and *P. hyrcanicum* [24]. Species belonging to the genus *Polygonum* showed biological properties, including antioxidant, anti-inflammatory, antimicrobial, neuropharmacological, anticancer, antitumor, antidiabetic, antiparasitic, hepatoprotective, and gastroprotective [25]. Bibliographic research indicates that the *Polygonum* genus includes a wide range of compounds from several groups, including phenolic acids (gallic acid, caffeic acid, quinic acid, *p*-coumaric acid, ferulic acid, protocatechuic acid, chlorogenic acid, etc.), flavonoids (quercetin, catechin, epicatechin, quercitrin, kaempferol, myricetin, etc.), tannins, stilbenes (polydatin and resveratrol), terpenes (α-pinene, β-caryophyllene and β-caryophyllene oxide, bisabolene, β-farnesene, etc.), fatty acid (decanoic acid, lauric acid, linoleic acid, oleic acid, palmitic acid, stearic acid, dodecanoic acid, etc.) and many other groups. Extracts from the *Polygonum* genus derive their pharmacological effects from several compounds, of which quercetin stands out as the predominant one. Quercetin has been shown to have a wide range of medicinal properties, including anticancer and antiviral effects, as well as treating conditions such as allergies, inflammatory, cardiovascular, arthritic, and ocular diseases [26]. Other abundant flavonoids, including catechin and epicatechin, were detected in the genus *Polygonum*. Regarding terpenes, sesquiterpenes are the most common terpenes in the *Polygonum* genus, closely followed by monoterpenes. Notably, three of the most prevalent sesquiterpenes are β-farnesene, β-caryophyllene, and β-caryophyllene oxide. For instance, β-caryophyllene and β-caryophyllene oxide exhibit strong anticancer properties that affect the proliferation and propagation of different cancer cells [27]. Certain species of the *Polygonum* genus have biological properties that are still not well understood, both *in vitro* and *in vivo*, while having many bioactive compounds. Other species with diverse biological activities have not been fully explored for their potential applications, especially in the pharmaceutical industry. Further investigation is necessary to fully exploit the industrial application of these *Polygonum* species. This review aims to provide an extensive understanding of the characteristics of the genus *Polygonum*, emphasizing phytochemical, pharmacological, ethnobotanical, toxicological, and phytopharmaceutical formulations. Our goal is to provide a comprehensive overview by providing an overview of the distribution, the botanical description, and the traditional usage. Furthermore, the phytochemical composition and biological activities will be examined in our review. The study will also offer future directions for the genus's research to evaluate the biological activities of understudied species, find new naturally occurring active components, and develop phytopharmaceutical formulations with active extracts or components.

2. Review methodology

Various databases, including Google Scholar, Scifinder, ScienceDirect, PubMed, Scopus, ResearchGate, and Web of Science, were utilized to collect pertinent scientific literature data regarding the phytochemical composition, ethnomedicinal uses, pharmacological activities, toxicology, and phytopharmaceutical formulation of the genus *Polygonum* between 1993 and 2023. Throughout the literature search, several terms were utilized, such as *Polygonum*, taxonomy, botanical description, traditional uses, phytochemistry, pharmacological activities, toxicity, and formulation. These keywords were used together with other terms regarding the review and were used interchangeably during the search process. The analysis of the research findings revealed that most of the papers discussed the phytochemical composition and biological properties of the species belonging to the genus *Polygonum*, with limited information on the botanical description and phytopharmaceutical formulations. Thus, we used the same keywords for each species belonging to the genus *Polygonum*, including *Polygonum minus*, *Polygonum aviculare*, *Polygonum equisetiforme*, *Polygonum bistorta*, *Polygonum capitatum*, *Polygonum divaricatum*, *Polygonum maritimum*, *Polygonum multiflorum*, *Polygonum orientale,* and others. The inclusion and exclusion criteria for this review are as follows: Studies focused mainly on the genus *Polygonum*, its taxonomy, botanical description, traditional uses, phytochemistry, pharmacological activities, toxicity, and formulation have been included. while reports on other related genus in the family *Polygonaceae* were excluded from this review. Select studies must be in English; we excluded studies in other languages apart from English. Articles with unreasonable study designs or unclear results were eliminated. *Polygonum* species combined effects with

other plant extracts belonging to another genus, and studies with or without proposing the mechanism of activity were included. Another important exclusion criteria were duplicated data, titles, and abstracts not meeting the inclusion criteria. After a preliminary analysis, the collected papers were grouped according to the review's general structure. Fig. 1 shows the schematic representation of the study methodology.

3. Taxonomical classification

The genus *Polygonum* belongs to the kingdom: Plantae Phylum: Angiospermae Class: Dicotyledoneae Order: Polygonales Family: Polygonaceae Genus: *Polygonum*.

4. Geographical distribution

The genus *Polygonum* consists of more than 300 species. The species of the genus *Polygonum* are distributed over Europe, North Africa, Asia, and America (north and south). They are also frequently found along slopes, roadsides, and cultivated areas [28].

5. Morphological and botanical description

The genus *Polygonum* varied greatly in size, from prostrate herbaceous biennial plants that are only 5 cm in height to upright herbaceous perennial plants between 3 and 4 m tall and perennial woody vines that are up to 20–30 m high in trees. The leaves are 1–30 cm long and can be oval, narrowly lanceolate, heart-shaped, broadly triangular, or arrowhead-shaped, depending on the species. The flowers of *Polygonum* are generally small; they can be green, pink, or white, and they emerge in dark clusters from the stem apices or leaf joints in the summer. The stems frequently have red specks or are reddish [29] (Fig. 2).

6. Ethnomedicinal/traditional properties

Polygonum plants have been used for therapeutic purposes for many years in several countries. Table 1 and Fig. 3 provide an overview of their traditional applications. In Chinese folk medicine, the leaves of *P. barbatum* have been used to treat ulcers. Furthermore, its roots have been consumed by the Chinese population due to their astringent and carminative properties [9]. The same region used the leaves of *P. hydropiper* L as a juice for the treatment of swelling, itching, and snake bites, and the decoction has been used for the pain of the neck and shoulder. The leaves have been employed for skin allergies and hair regeneration in India, as well as for the treatment of hypertension, dysuria, jaundice, stomach and intestinal discomfort, and toothaches; and in Japanese folk medicine, it's also used for treating insect bites [30]. In addition, combined with an equal quantity of ginger, a smashed aerial part of *P. hydropiper* L has been employed to treat food poisoning. *P. aviculare* has been used in many countries, both in Africa, Asia, and

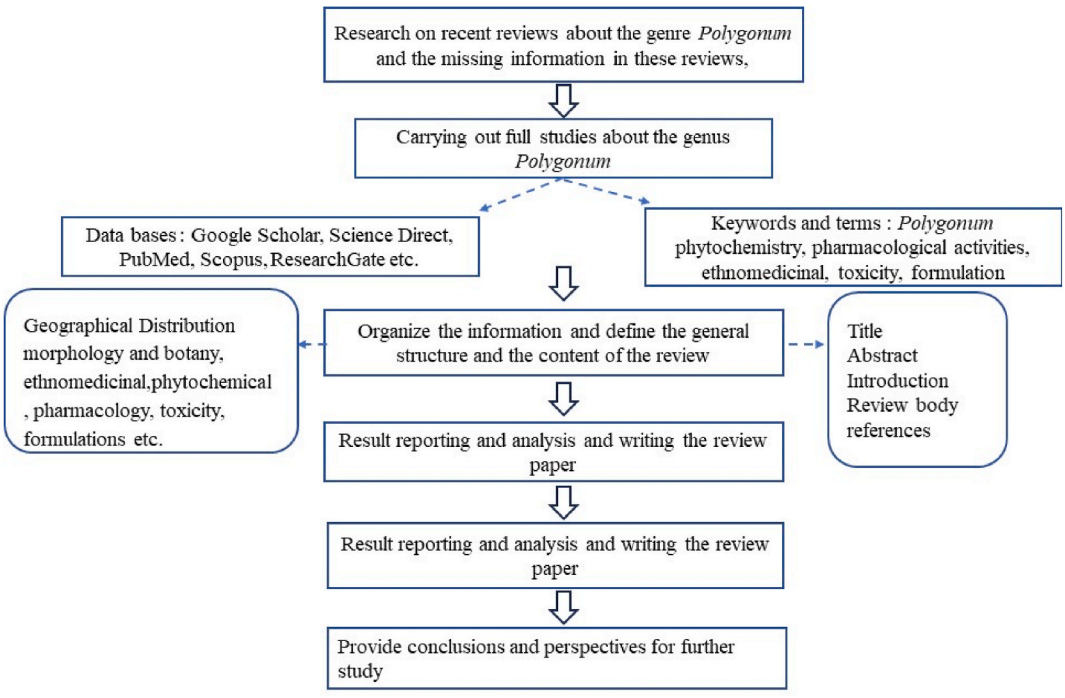

Fig. 1. Schematic representation of the study methodology.

Fig. 2. Morphological details of a *Polygonum* species: *P. equisetiforme*.

Europe. In the folk medicine of Morocco, the roots and leaves of the species have been administered as a treatment for kidney stones, hemostasis, and hyperglycemia; they are also used for digestive problems (astringent and laxative effects) [2]. Whereas, in India, the powder of the leaves has an anti-inflammatory effect and is also used to react against kidney diseases, burning, and urinary tract infections. In Portugal, *P. aviculare* has important ethnopharmacological reports; the juice of the leaves is used as a treatment for cellulite, diarrhea, and leucorrhoea and has been used for its laxative, diuretic, sedative, anti-haemorrhoidal, and anti-haemorrhagic effects [4]. In Turkey, the infusion of the leaves of *P. cognatum* has been administered for gastrointestinal and diabetes disorders [13]. Different parts of the species *P. glabrum* (the whole plant, leaves, and roots) are used in different countries (India, Pakistan, and Sudan) due to their therapeutic properties, such as the antimalarial and anthelminthic properties, the treatment of wounds, colic pain, fever, *pneumonia*, piles, and others [17]. The species *P. equisetiforme* is prevalent throughout the majority of Tunisia. In the desert of Tunisia, domesticated animals seem to enjoy grazing on and browsing on *P. equisetiforme*, which provides significant economic advantages to the rural areas. The plant is extensively utilized in the southern region of Tunisia for healing and disinfecting wood. Additionally, *P. equisetiforme* is employed in Egypt as a natural remedy for sore throats, colds, and coughs [15,31].

7. Phytochemical composition

7.1. Phenolic compounds

Phenolic compounds are substances that have one or more aromatic rings linked to one or more hydroxyl groups. With more than 8000 identified structures, they are the most abundant secondary plant metabolites. They range from simple elements like phenolic acids to complicated ones like tannins. These compounds help plants defend themselves against biotic and abiotic stress: pathogens, predators, and ultraviolet (UV) [32]. Phenolic compounds represent a crucial class of phytochemicals known for their established and diverse biological properties, including but not limited to antioxidative, anti-inflammatory, anticancer, and antimicrobial effects [33]. There are several groups of phenolic compounds in plants, such as phenolic acids, flavonoids, complex tannins, and lignans, etc [33]. *Polygonum* has a diverse range of phenolic compounds that belong to numerous groups (phenolic acids, flavonoids, tannins, etc.). Fig. 4 represents the major phenolic compounds in the genus *Polygonum*.

7.1.1. Phenolic acids

Phenolic acids are widely contained in plants and have been the focus of numerous studies spanning fields such as chemistry, biology, agriculture, and medicine. Two primary classes of phenolic acids may be distinguished in plant extracts: hydroxybenzoic acids, which come from benzoic acid, and hydroxycinnamic acids, which come from cinnamic acid. Derivatives of hydroxybenzoic acid are often found connected, and they have structural similarities with lignins and hydrolysable tannins. In contrast, hydroxycinnamic acid derivatives are mostly attached to the proteins, cellulose, and lignin, which make up the cell wall [34]. The genus *Polygonum* contains several compounds of phenolic acids (hydroxybenzoic and hydroxycinnamic acids). Phenolic acids are present in almost all parts of *Polygonum* plants; however, their identification is more prominent in the aerial part. Several species, including *P. maritimum, P. aviculare, P. bisorta, and P. equisetiforme*, contain an important number of phenolic acids. Among the phenolic compounds detected in *Polygonum* species, gallic acid, caffeic acid, quinic acid, *p*-coumaric acids, ferulic acid, protocatechuic acid, and chlorogenic acid are well-known phenolic acids with previously shown pharmacological and biological properties [33]. For instance, gallic acid, which is present in multiple plants of the *Polygonum* genus, has a variety of biological qualities, including antidiabetic, neuroprotective, antioxidant, anti-inflammatory, and wound healing effects [35]. Another example is chlorogenic acid, found in several plants of the genus *Polygonum*, such as *P. amphibium*, *P. angustifolium* [36], *P. aviculare* [36,37], *P. bistorta* [38–40], *P. chinese* [41], *P. odoratum* [42]

Table 1
Ethnobotanical use of the genus *Polygonum*.

Species	Region	Part used	Methods	Traditional uses	Reference
P. aviculare	–	Whole plant	Decoction	Treatment of the urinary canal, kidney stone and ascariasis.	[209]
		Aerial parts leaves, and flowers	–	Treatment of diarrhea, digestive infections, blooding, ulcers, cystitis, and worms.	[115]
	Marocco	Roots and leaves	Fumigation and external use	Astringent, laxative effect, diuretic, sudorific effect. Treatment of hyperglycemic, kidney stones and hemostatic.	[2]
	Tunisia	Aerial parts	–	Astringent effect and treatment of asthma, diarrhea, and gastric pains.	[210]
	Pakistan	Whole plant	–	Diuretic effect, treatment of diarrhea, coughs, wounds, and pulmonary complaints.	[211]
	India	Leaves	Powder	Anti-inflammatory effect. Treatment of kidney diseases and burning. Treatment of urine tract.	[3]
	Northen Irak	–	–	Treatment of piles, Helminthiasis, and dysentery.	[212]
	Mongolia	Roots and herbs	–	Fevers related with digestive problems, back pain after delivery.	[213]
	Northen of Portugal	Whole plant	Fresh juice	Laxative, diuretic, sedative, anti-haemorrhoidal, and anti-haemorrhagic effect. Treatment of cellulites, diarrhea and leucorrhoea.	[4]
	Lebanon	Aerial part	Infusion	Treatment of rheumatism.	[214]
P. barbatum	China	Leaves	–	Treatment of ulcer.	[9]
	China	Roots	–	Astringent and carminative effect.	
P. bellardii	–	Aerial part	Decoction	Treatment of kidney stone.	[10]
P. bistorta L.	China	Rhizomes	–	Anti-inflammatory, and astringent effect. Treatment of haemorroids, haematemesis and dermatitis.	[11]
P. capitatum	China	Aerial part	–	Treatment of diarrhea, infections, dysentery, rheumatalgia, urolithiasis, hematuria, urocystitis, pyelonephritis and urinary system.	[12]
P. cognatum	Turkey	Leaves	Infusion	Diuretic effect. Treatment of gastrointestinal and diabetes disorders.	[13]
P. equisetiforme	Egypt	Aerial part	–	Treatment of cold, cough and sore throat.	[14,15]
	Tunisia	–	–	Treatment of woods and healing.	
P. flaccidum	China	–	–	Treatment of snakebites, purgative, anti-inflammatory, analgesic, diuretic, and insecticidal effect.	[16]
P. glabrum	India	Whole plant	Decoction	Treatment of jaundice, headache, scorpion bites, burns, throat and colic pain, and fever.	[17]
			Juice	Bone setting.	
			Boiled paste	Treatment for wounds.	
		Leaves	Infusion	Treatment of colic pain.	
			Decoction	Treatment of fever.	
			Infusion	Treatment of fever	
			Juice	Treatment of *Pneumonia*.	
			Juice	Treatment of ectoparasites.	
		Roots	Decoction	Treatment of piles, constipation, consumption, and jaundice.	
		Roots	Juice	Treatment of jaundice.	
	Pakistan	Leaves	Infusion	Diuretic, astringent effect, treatment of rheumatism.	
	Sudan	Leaves	Juice	Antimalarial and anthelminthic properties.	
P. hydropiper L	Azerbaijan	Whole plant	–	Hemostatic, analgesic, and astringent effect. Treatment of edema, eczema, asthma, kidney stones, thyroid, ulcers, and gastric diseases.	[161]
	India and Bangladesh	Leaves	Juice	Insecticide, treatment of worms and snake bites, and antiseptic effect.	[159,216, 217]
	China	Leaves	Juice/Decoction	Treatment of swelling, itching and snake bites.	[8]
			Decoction	Pain of neck and shoulder.	
	India	Leaves	Decoction	Treatment of hemorrhoid.	[7]
			–	Treatment of hypertension, abdominal and intestinal pain, dysuria, jaundice, toothache, hair regeneration and skin allergies.	[6]
		Whole plant	–	Antiseptic, sedative, and antidote effect.	[218]
		–	–	Treatment of cardiac diseases, dysentery, gynecological, and menstrual problems.	[5]
	Japan	Aerial parts, leaves	Smashed	Treatment for food poisoning.	[30]
		Leaves	Juice	Treatment for the insect bites.	
		Whole plant	–	Treatment of heatstroke, beriberi, and rheumatism.	[8]
		Seeds	–	Treatment of swelling, stomachache, and gastroenteritis.	
	Nepal	Seeds	–	Treatment of stomachache.	
		Aerial parts	Decoction	Anthelmintic effect.	

(*continued on next page*)

Table 1 (*continued*)

Species	Region	Part used	Methods	Traditional uses	Reference
		Roots	Juice and decoction	kidney stones.	
		Whole plant	–	Anthelmintic effect.	
	Pakistan	Whole plant	–	Respiratory diseases.	
	Vietnam, Cambodia, Laos	Whole plant	–	Used for diuretic and homeostatic properties. Used in hypertension, edemas, and snake bites.	
P. multiflorum Thunb	China	–	–	Anti-inflammatory and antiatherosclerotic effect. Treatment of coronary disease, neurosis, hyoerlipidemia, premature graying, hair loss prevention, osteoarthritis, helminthic and bacterial infections.	[18–20]
P. orientale Linn	–	Whole plant	–	Treatment of menorrhagia and whooping cough.	[21]
		Fruits and leaves	Ash	Treatment of fever.	
P. polystachyum	–	Aerial part	Crushed	Treatment of mouth ulcer.	[22]
P. plebeium	–	Herb	–	Treatment of *Pneumonia*.	[23]
	–	Root	–	Treatment of bowel complaints.	
P. tortuosum	Himalaya	Aerial part	Powder	Treatment of stomach pain and jaundice.	[22]
P. viviparum		Seeds	Powder	Treatment of blood dysentery.	
		Seeds	Decoction	Reducing blood pressure and pain, treatment of wounds.	
P. hyrcanicum	Turkmen Sahra region	Aerial part	Decoction	Treatment of kidney stones, anemia, hemorrhoids, and liver problems.	[24]

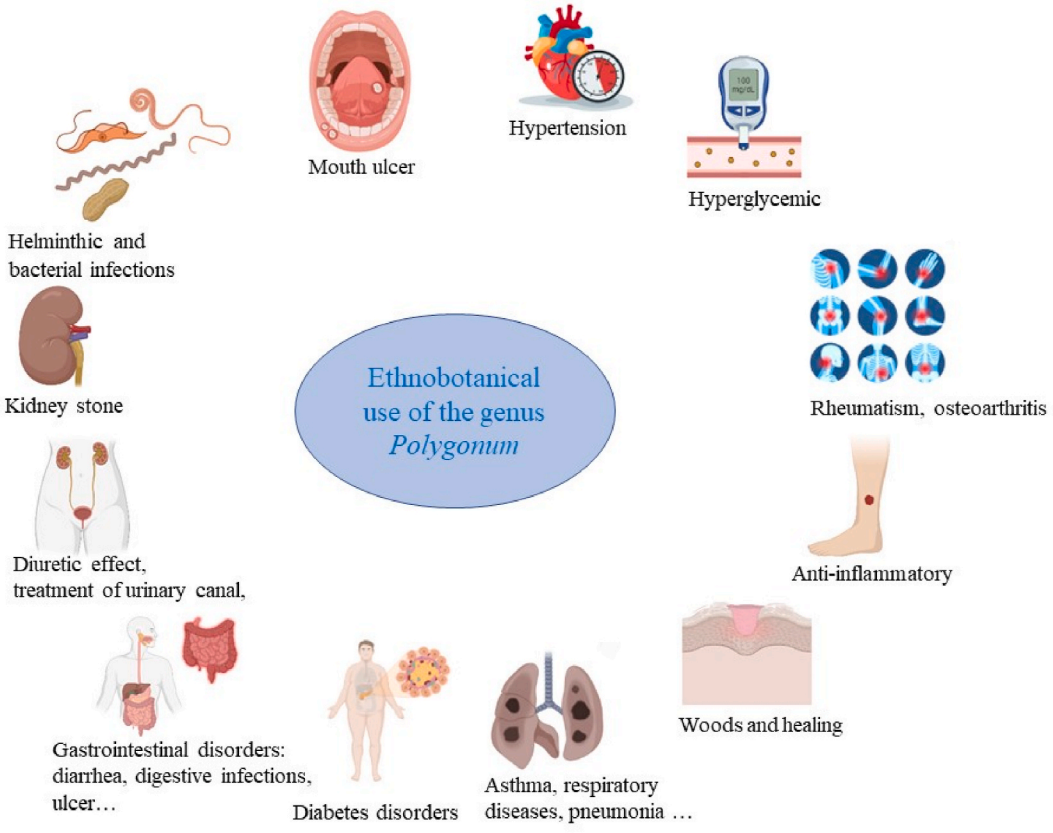

Fig. 3. Ethnobotanical use of the genus *Polygonum*.

and others. According to the literature review, this compound has several biological potentials, including cardioprotective, hepatoprotective, neuroprotective effects, antibacterial activity, antioxidant activity, antipyretic, anti-obesity, anti-inflammatory, antiviral, antihypertension, and antimicrobial [43]. Protocatechuic acid is another phenolic acid found in various plants of the genus *Polygonum*, such *as P. aviculare* [44], *P. angustifolium* [36], *P. amphibium* [36], *P. bistorta* [38,39], *P. capitatum* [45], *P. divaricatum* [36], *P. maritimum* [44], *P. equisetiforme* [15,46], *P. multiflorum* [47], *P. plebeium* [48], and *P. orientale* [45]. According to Ref. [49], this molecule has a multitude of biological functions, including powerful antioxidant capabilities *in vitro* and *in vivo*. In animal studies, it

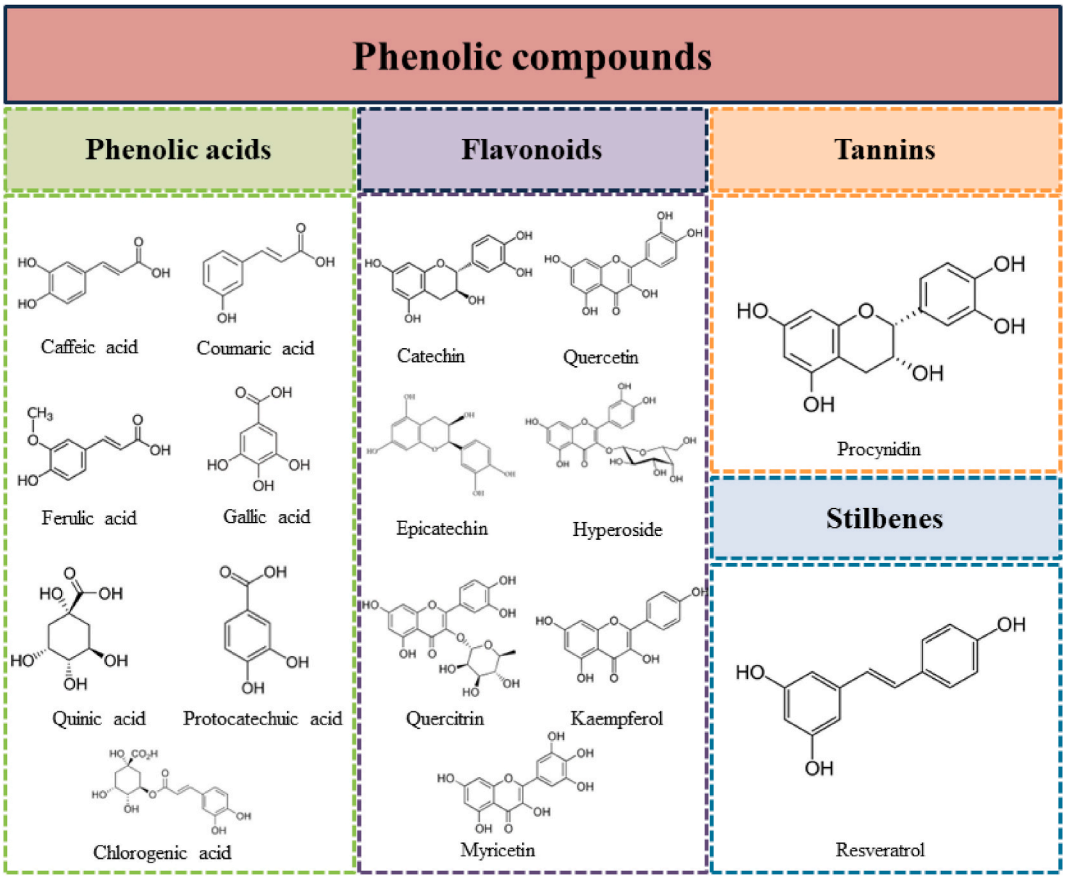

Fig. 4. The major phenolic compounds in the genus *Polygonum*.

has been shown to have anti-inflammatory, antihyperglycemic, and antiapoptotic properties. Protocatechuic acid has also been shown to suppress chemical carcinogenesis and to elicit antiproliferative and proapoptotic responses in tumors. Furthermore, *in vitro* tests have shown that protocatechuic acid has antibacterial characteristics and may function in conjunction with specific medicines to battle resistant microorganisms.

Ferulic acid (4-hydroxy-3-methoxycinnamic acid) is a hydroxycinnamic acid found in plant cell walls. Ferulic acid was known for its strong antimicrobial, antithrombotic, anti-inflammatory, antitumor, antioxidant, and neuroprotective effects. The antiviral effect has also been underlined. It has a broad spectrum of other attractive biological properties, including the ability to absorb UV rays and whiten skin, which highlights its importance for human health, nutrition, and well-being [50]. In the genus *Polygonum*, ferulic acid has been detected in the roots, stems, and leaves of *P. aviculare* [44], in the ethanolic extract from *P. odoratum* [42], and also in *P. amphibium* [36], *P. angustifolium* [36], *and P. maritimum* [44]. Mahmoudi et al. [15,46] demonstrated that this compound has been detected in the methanolic extract in the aerial part and seeds of *P. equisetiforme*. Table 2 and the **supplementary file** detail the phenolic compounds from the genus *Polygonum*.

7.1.2. Flavonoids

Plants produce a class of polyphenolic chemicals known as flavonoids. Fruits, vegetables, and other food crops contain flavonoids in large quantities. In addition to other bioactivities, flavonoids have many biological effects including anti-allergic, anti-carcinogenic, anti-inflammatory, antidiabetic, antiviral and anti-aging [51]. Flavonoid bioactivity is influenced by the structural changes that occur in their C6–C3–C6 rings [52]. Based on structure, flavonoids are classified into seven subclasses: flavonols, flavanols, flavones, flavanones, isoflavones, chalcones, and anthocyanidins [53]. Several flavonoids have been extracted from various *Polygonum* species. Most of the flavonoids in *Polygonum* have a flavonol structure, followed by the subclass flavone. Whereas the occurrence of flavonoid structures with flavanones and chalcone appears to be limited, there is only one compound from the chalcone group, phlorizin, that has been detected in the leaves of the plant *P. aviculare*. Quercetin is the most detected compound in the genus *Polygonum*. It is found in ten species, among them *P. aviculare* [37,54], *P. bistorta* [38], *P. equisetiforme* [15,46], *P. maritimum* [55], *P. multiflorum* [47], and other species. Quercetin is a highly important chemical found in plants. It has demonstrated a variety of medicinal properties, including being anticancer and antiviral, as well as treating allergies, inflammatory illnesses, cardiovascular diseases, arthritis, and ocular diseases. Additionally, it has shown a wide range of anticancer properties, and multiple studies support its effectiveness as a treatment

Table 2
The major phenolic compounds detected in the extracts of *Polygonum* species.

Compound Name	*Species*	Plant part	Extract	Analysis	Reference
Phenolic acid					
Caffeic Acid	*P. amphibium*	Aerial part	–	HPLC	[36]
	P. angustifolium	Aerial part	–	HPLC	[36]
	P. aviculare	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
	P. divaricatum	Aerial part	–	HPLC	[36]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[219]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
		–	EtOH	HPLC-ESI-MS	[55]
			Ac	HPLC-ESI-MS	[55]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
Ferulic Acid	*P. amphibium*	Aerial part	–	HPLC	[36]
	P. angustifolium	Aerial part	–	HPLC	[36]
	P. aviculare	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. maritimum	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
Gallic Acid	*P. amplexicaule*	Leaves	MeOH (80%)	LC-MS	[65]
	amplexicaule	Aerial part	–	HPLC	[36]
	P. amphibium	Aerial part	–	HPLC	[36]
	P. aviculare	Leaves	H_2O, EtOH (70%), EtOH (100%), and EtOAc/MeOH (80%)	HPLC-ESI-qTOF-MS/MS	[37,44,54]
		Aerial part	–	HPLC	[36]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
		Rhizome	MeOH (40%)	HPLC-DAD-ESI-MS	[39]
			MeOH (70%)	HPLC-QTOF MS	[40]
	P. chinense	–	H_2O	UHPLC-QTOF-MSMS	[41]
	P. capitatum	Whole plant	EtOH (70%)	UPLC–PDA–MS/MS	[45]
	P. divaricatum	Aerial part	–	HPLC	[36]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. glabrum	Leaves	Ac, EtOAc, MeOH, EtOH	HPLC-DAD	[220]
		Seed	MeOH, EtOH, H_2O, EtOAc: MeOH, Ac: MeOH, H_2O: Ac, H_2O: MeOH	HPLC-DAD	[220]
		Stem	EtOAc, MeOH, EtOH, H_2O, EtOAc: MeOH, Ac: MeOH, H_2O: Ac, H_2O: MeOH	HPLC-DAD	[220]
		Root	EtOAc, MeOH, EtOH, H_2O, EtOAc: MeOH, Ac: MeOH, H_2O: Ac, H_2O: MeOH	HPLC-DAD	[220]
	P. hydropiperoides	Aerial part	EtOAc	HPLC-DAD-ESI/MS	[221]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[219]
		–	Hex	HPLC-ESI-MS	[221]
			EtOH	HPLC-ESI-MS	[55]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
			MeOH	GC-MS	[97]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH	GC-MS	[97]
			MeOH (80%)	HPLC-ESI-MS	[44]
	P. minus	Leaves	EtOH (acetate:methanol (1:1) fraction)	HPLC	[222]
	P. plebeium	Aerial part	Ac	HPLC-ESI-MS	[223]
		Whole plant	MeOH	UHPLC/MS	[48]
	P. perfoliatum	Whole plant	MeOH (70%)	HPLC	[224]
	P. orientale	Whole plant	H_2O	HPLC-ESI-MS	[45]
	P. odoratum	Leaves	EtOH	HPLC-DAD	[58]

(*continued on next page*)

Table 2 (*continued*)

Compound Name	*Species*	Plant part	Extract	Analysis	Reference
	P. hydropiperoides	Aerial part	Hex	HPLC-DAD-ESI/MS	[221]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
		Stems	H_2O	HPLC	[225]
		Root	H_2O	HPLC	[225]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
Chlorogenic Acid	*P. amplexicaule*	Leaves	MeOH (80%)	LC-MS	[65]
	P. . amphibium	Aerial part	–	HPLC	[36]
	P. . angustifolium	Aerial part	–	HPLC	[36]
	P. aviculare L	Leaves	H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
		Aerial part	–	HPLC	[36]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
		Rhizome	MeOH (40%)	HPLC-DAD-ESI-MS	[39]
			MeOH (70%),	HPLC-QTOF MS	[40]
	P. chinense	–	H_2O	UHPLC-QTOF-MSMS	[41]
	P. cuspidatum	Leaves	EtOH (70%)	HPLC	[56]
		Stems	EtOH (70%)	HPLC	[56]
	P. . divaricatum	Aerial part	–	HPLC	[36]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
	P. perfoliatum	Whole plant	MeOH (70%)	HPLC	[224]
p-coumaric Acid	*P. aviculare*	Leaves	H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
			MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
		Aerial part	–	HPLC	[36]
	P. . amphibium	Aerial part	–	HPLC	[36]
	P. angustifolium	Aerial part	–	HPLC	[36]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
	P. divaricatum	Aerial part	–	HPLC	[36]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. maritimum	Aerial part	Ac	UPLC–QTOF-MS	[223]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[219]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. minus	Leaves	EtOH (acetate:methanol (1:1) fraction)	HPLC	[222]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
	P. perfoliatum	Whole plant	MeOH (70%)	HPLC	[1]
	P. capitatum	Whole plant	EtOH		[226]
Quinic Acid	*P. aviculare* L	Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. maritimum	Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
	P. plebeium	Whole plant	MeOH	UHPLC/MS	[48]
	P. amplexicaule	Leaves	MeOH (80%)	LC-MS	[65]
Protocatechuic Acid	*P. aviculare*	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. angustifolium	Aerial part	–	HPLC	[36]
	P. amphibium	Aerial part	–	HPLC	[1]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
		Rhizome	MeOH (40%)	HPLC-DAD-ESI-MS	[39]
	P. capitatum	Whole plant	EtOH (70%)	UPLC–PDA–MS/MS	[226]
	P. . divaricatum	Arial part	–	HPLC	[36]
	P. maritimum	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]

(*continued on next page*)

Table 2 (*continued*)

Compound Name	*Species*	Plant part	Extract	Analysis	Reference
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. multiflorum	Seeds	MeOH	HPLC	[1]
	P. plebeium	Whole plant	MeOH	UHPLC/MS	[48]
	P. orientale	Whole plant	H_2O	HPLC-ESI-MS	[45]
Flavonoids					
Catechin	*P. aviculare*	Leaves	MeOH (80)	HPLC-ESI-MS	[44]
		Stems	MeOH (80)	HPLC-ESI-MS	[48]
		Roots	MeOH (80)	HPLC-ESI-MS	[44]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
		Rhizome	MeOH (70%),	HPLC-QTOF MS	[40]
	P. cuspidatum	–	EtOH (70%)	HPLC	[56]
	P. cuspidatum	Rhizomes	Ac (70%)	HPLC	[127]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15,46]
		Seeds			
	P. odoratum	Leaves	EtOH	HPLC-DAD	[58]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[57]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. multiflorum	Stems	H_2O	HPLC	[225]
		Root	H_2O	HPLC	[225]
Epicatechin	*P. aviculare*	Leaves	MeOH (80%)	LC–ESI/MS	[44]
		Stems	MeOH (80%)	LC–ESI/MS	[44]
		Roots	MeOH (80%)	LC–ESI/MS	[44]
	P. cuspidatum	Rhizomes	Ac (70%)	HPLC	[227]
	P. cuspidatum	–	EtOH (70%)	HPLC	[56]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[219]
		Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. multiflorum	Stems	H_2O	HPLC	[225]
		Root	H_2O	HPLC	[225]
	P. paleaceum	Rhizome	EtOH (90%)	ESI-MS	[228]
Quercitrin (Quercetin-3-*O*-Rhamnoside)	*P. aviculaire*	Leaves	EtOH, MeOH (70%), MeOH (30%), and H_2O	HPLC	[54]
			H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
	P. chinense	–	H_2O	UHPLC-QTOF-MSMS	[41]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. hydropiper L	Leaves	H_2O	preparative HPLC	[140]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[219]
	P. minus	Leaves	MeOH	LCMS-IT-TOF	[165]
	P. multiforum	–	EtOH (80%) (EtOAc fraction)	HSCCC	[229]
	P. odoratum	Aerial part	EtOH (50%)	preparative HPLC, NMR	[197]
Quercetin	*P. aviculaire*	Leaves	EtOH, MeOH (70%), MeOH (30%), and H_2O	HPLC	[54]
			H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
	P. bistorta	Roots	Ac (70%), MeOH (70%), H_2O	LC-ESI/MS	[38]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15,46]
		Seeds	MeOH (80%)	LC–ESI/MS	[15,46]
	P. odoratum	Leaves	EtOH	HPLC-DAD	[58]
	P. perfoliatum	Whole plant	MeOH (30%)	HPLC	[224]
	P. hydropiper L	Leaves	H_2O	Prep-HPLC	[140]
	P. maritimum	–	Ac	HPLC-ESI-MS	[55]
	P. minus	Leaves	EtOH (acetate: methanol (1:1) fraction)	HPLC	[222]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
	P. cuspidatum	–	EtOH (70%)	HPLC	[56]
	P. viscosum	Root	TCM	NMR	[230]
Quercetin-3-*O*-Galactoside ((Hyperoside)	*P. aviculare* L	Leaves	H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
			MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. chinense	–	H_2O	UHPLC-QTOF-MSMS	[41]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15,46]
		Seeds	MeOH (80%)	LC–ESI/MS	[15,46]

(*continued on next page*)

Table 2 (*continued*)

Compound Name	*Species*	Plant part	Extract	Analysis	Reference
	P. maritimum	Leaves	MeOH (80%)	HPLC-ESI-MS	[44]
		Stems	MeOH (80%)	HPLC-ESI-MS	[44]
		Roots	MeOH (80%)	HPLC-ESI-MS	[44]
	P. minus	Leaves	MeOH	LCMS-IT-TOF	[231]
Kaempferol	*P. aviculaire*	Leaves	EtOH, MeOH, MeOH (70%), MeOH (30%), and H_2O	HPLC	[54]
			H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
	P. equisetiforme	Aerial part	MeOH (80%)	LC–ESI/MS	[15]
		Seeds	MeOH (80%)	LC–ESI/MS	[46]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. odoratum	Aerial part	EtOH	HPLC	[42]
	P. viscosum	Root	TCM	NMR	[230]
Myricetin	*P. aviculare*	Leaves	EtOH, MeOH (70%), MeOH (30%), and H_2O	HPLC	[54]
			H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
	P. maritimum	Aerial part	Ac	HPLC-ESI-MS	[223]
	P. multiflorum	Seeds	MeOH	HPLC	[47]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[57]
	P. viscosum	Root	TCM	NMR	[230]
Tannins					
Procyanidin	*P. . amplexicaule*	Leaves	MeOH (80%)	LC-MS	[65]
Procyanidin Dimer	*P. amplexicaule*	Leaves	MeOH (80%)	LC-MS	[65]
	P. cuspidatum	–	EtOH (70%)	HPLC	[56]
	P. maritimum	Aerial part	EtOAc, i-PrOH, EtOH, Ac, H_2O	LC-ESI-QTOF-MS	[57]
Stilbenes					
Polydatin	*P. aviculare*	Leaves	H_2O, EtOH (70%), EtOH (100%), and EtOAc	HPLC-ESI-qTOF-MS/MS	[37]
	P. cuspidatum	Roots	EtOH (70%)	HPLC	[56]
	P. plebeium	Whole plant	MeOH	UHPLC/MS	[48]
	P. cuspidatum	Rhizomes	Ac (70%)	HPLC	[227]
Resveratrol	*P. multiflorum*	Seeds	MeOH	HPLC	[47]
	P. cuspidatum	Roots	EtOH (70%), EtOAc	HPLC, NMR, HPLC-HRMS and NMR	[56] [232]
		Rhizomes	Ac (70%)	HPLC	[227]

Ac: Acetone; EtOAC: Ethyl Acetate; EtOH: Ethanol; MeOH: Methanol; H_2O: Water; i-PrOH: Isopropyl Alcohol; TCM: Trichloromethane = Chloroform.

for cancer prevention [26]. Catechin and epicatechin are two flavonoid compounds that were detected in various *Polygonum* species (*P. aviculare, P. cuspidatum, P. equisetiforme, P. maritimum, P. multiflorum,* and *P. paleaceum*) [15,38,40,46,55–59]. These compounds are two flavonoids stereoisomers that are highly prevalent in vegetable tissues and exhibit strong antioxidant properties in live organisms. Hyperoxide, kaempferol, and myricetin were also among the major compounds detected in the genus *Polygonum*. Details and references are presented in Table 2 and the **supplementary file**.

Among the flavonoids detected in the genus *Polygonum*, there are compounds with chemotaxonomic value that could help in the identification of species of this genus, for example, the two compound acacetin and afzelin. Acacetin is a flavone detected in a single species of the genus *Polygonum*, which is the species *P. equisetiforme* [46]. This compound is a mono-methoxy and di-hydroxy flavone identified in many plants, including *B. pendula*, *R. pseudoacacia,* and *T. diffusa*. Acacetin inhibits ischemia, myocardial reperfusion, and infarction-induced heart damage. It also has chemopreventive and cytotoxic effects on cancer cell lines. It also has an effect against rheumatoid arthritis, viral-mediated infections, collagen obesity, arthritis-induced arthritis, hepatic protection, and microbial growth inhibition [60]. Afzelin is a secondary metabolite found in many different plants [61]. In androgen-sensitive prostate cancer, afzelin's capacity to trigger the caspase cascade has also been shown. Afzelin also prevents prostate cancer cells that are androgen-sensitive or independent from proliferating and going through the cell cycle [61]. Afzelin was detected only in the leaf extract of *P. multiform* [62], and it can have a chemotaxonomic value and help in the identification of the species.

7.1.3. Tannins

Tannins have the potential to form bonds and establish a stable cross-linked connection inside various molecules, such as proteins or carbohydrates, due to the presence of several functional groups, such as hydroxyls, in their chemical structure. They may be distinguished from the common group of polyphenols thanks to their distinctive quality [63]. Plant tannins may be divided into two primary groups: condensed tannins and hydrolyzed tannins. Condensed tannins are polymeric or oligomeric flavonoids made up of flavane-3-ols (epigallocatechin, gallocatechin, epicatechin, and catechin). The range of their molecular weights is 1000 to 20,000 Da (Da); on the other hand, polyphenols with molecular weights ranging from 500 to 3000 Da make up hydrolyzed tannins [64]. Four tannins were found in the leaves of *P. amplexicaule*, according to Jabeen et al. [65], among them procyanidin and proanthocyanidin, which were also detected in the aerial parts of *P. maritimum* and *P. multiflorum*. The two classes of proanthocyanidin and procyanidin are the most abundant polyphenols in plants [66]. Thanks to their advantageous pharmacological effects, such as antiscavenging, antioxidative [67,68], anti-inflammatory [69], and antimicrobial effects [70], these valuable compounds attracted attention in the pharmaceutical industry. A new dimeric procyanidin glucoside, namely catechin 3-*O*-acetate-(4–8)-catechin

Table 3
The major volatile compounds detected in the essential oil of *Polygonum* species.

	Region	Part used	Methods	Traditional uses	Reference
Monoterpenes					
Camphene	*P. alpinum*	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
	P. persicaria L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
		Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
Cymene	*P. bistorta* L	Leaves	Essential oil (hydrodistillation)	GC/FID GC/MS	[11]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
Myrcene	*P. arenarium*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bistorta L	Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. minus	Leaves	SPME	GC–MS	[88]
	P. orientale	Flowers	Hex	GC-MS	[80]
Pinene	*P. alpinum All*	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. amphibium L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. hydropiper L	Leaves	Essential oil (SDE)	GC–MS	[233]
			DHS	GC–MS	[233]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			SPME	GC–MS	[88]
		Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. orientale	Flowers	Hex	GC-MS	[80]
	P. persicaria L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
Terpinene	*P. arenarium*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum.	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. alpinum All	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. amphibium L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. minus	Aerial part	Essential oil (hydrodistillation	GC-MS	[78]
	P. persicaria L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
Thujene	*P. alpinum All*	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. amphibium L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum.	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. minus	Leaves	SPME	GC-MS	[166]
		Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[1,78]
Monoterpenols					
Eucalyptol (1,8 Cyneole)	*P. alpinum All*	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. amphibium L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. minus	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. persicaria L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. bistorta L	Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. odoratum	–	–	–	[29]

(*continued on next page*)

Table 3 (*continued*)

	Region	Part used	Methods	Traditional uses	Reference
	P. viscosum	Leaves	Essential oil (microwave hydrodistillation)	GC-MS	[235]
Sesquiterpenes					
Aromadendrene	*P. arenarium*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. barbatum	Leaves	EtOH (70%)	GC-MS	[236]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. minus	Leaves	SPME	GC-MS	[166]
			Essential oil (hydrodistillation)	GC-MS	[166]
			SPME	GC-MS	[88]
	P. odoratum	Leaves	Essential oil (SDE)	GC-MS	[237]
Bisabolene	*P. arenarium*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. barbatum	Leaves	Hydroalcoholic extract	GC–MS	[236]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
				GC-MS/O	[89]
			SPME	GC-MS	[88,166]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. punctatum	Aerial part	Et_2O	GC-MS	[91]
Curcumene	*P. minus*	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			Essential oil (hydrodistillation)	GC-MS	[166]
			Essential oil (hydrodistillation)	GC-MS/O	[89]
		Stems	Essential oil (hydrodistillation)	GC-MS	[166]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. hyrcanicum	Leaves	Et_2O	GC-MS	[238]
B-Caryophyllene	*P. aviculare*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. hydropiper	Aerial part	MeOH	GC-MS	[239]
		Leaves	Essential oil (SDE)	GC-MS	[233]
			DHS	GC-MS	[233]
			DCM	GC-MS	[233]
		Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
		Leaves	Essential oil (hydrodistillation)	GC-MS	[240]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			Essential oil (hydrodistillation)	GC-MS/O	[89]
			SPME	GC-MS	[88]
		Roots	–	GC-MS	[241]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. punctatum	Aerial part	Et_2O	GC-MS	[91]
	P. viscosum	Leaves	Essential oil (microwave hydrodistillation)	GC-MS	[235]
B-Caryophyllene Oxide	*P. arenarium*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS/O	[89]
				GC-MS	[89]
			SPME	GC-MS	[86,88]
		Stems	SPME	GC-MS	[86]
			Essential oil (hydrodistillation)	GC-MS	[86]
		Roots	Essential oil (hydrodistillation)	GC-MS	[86]

(*continued on next page*)

Table 3 (*continued*)

	Region	Part used	Methods	Traditional uses	Reference
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. punctatum	Aerial part	Et_2O	GC-MS	[91]
Elemene	*P. aviculare,*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. minus	Leaves	SPME	GC-MS	[88]
		Stems	SPME	GC-MS	[86]
			Essential oil (hydrodistillation)	GC-MS	
	P. viscosum	Leaves	Essential oil (microwave hydrodistillation)	GC-MS	[235]
Farnesene	*P. aviculare*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. hydropiper	Leaves	Essential oil (SDE)	GC-MS	[233]
			DCM	GC-MS	[233]
		Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
		–	–	–	[158]
	P. hyrcanicum	Leaves	Et_2O	GC-MS	[238]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS/O	[89]
			Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			SPME	GC–MS	[241]
		Stems	SPME	GC–MS	[86]
		Roots	SPME	GC-MS	[86]
			–	GC-MS	[241]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. viscosum	Leaves	Essential oil (microwave hydrodistillation)	GC-MS	[235]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
Sesquiterpenols					
Drimenol	*P. acuminatum*	Leaves	DCM	GC/EM	[242]
	P. hydropiper	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS/O	[89]
				GC-MS	[86]
			Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			SPME	GC–MS	[88]
		Stems	Essential oil (hydrodistillation)	GC-MS	[86]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. odoratum	Leaves	Essential oil (hydrodistillation)	GC-MS	[240]
Nerolidol	*P. hydropiper*	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. hyrcanicum	Leaves	Et_2O	GC-MS	[238]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			SPME	GC–MS	[88]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
Trans-A-Bergamotol	*P. aviculare*	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC-MS/O	[89]
		–	Essential oil	GC–MS	[234]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
Aldehyde					
Hexanal	*P. bistorta*	Rhizome	MeOH (40%)	HPLC-DAD-ESI-MS	[99]
		Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. cuspidatum	Leaves	SDE	GC-MS	[243]
	P. hydropiper L	Leaves	Essential oil (SDE)	GC–MS	[233]

(*continued on next page*)

Table 3 (*continued*)

	Region	Part used	Methods	Traditional uses	Reference
			DHS	GC–MS	[233]
			DCM	GC–MS	[233]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			SPME	GC–MS	[88]
	P. odoratum	Leaves	Essential oil (SDE)	GC-MS	[237]
			MeOH	GC-MS	[244]
Nonanal	*P. bistorta* L	Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS/O	[89]
			Essential oil (hydrodistillation)	GC–MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			SPME	GC–MS	[88]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. orientale	Flowers	Hex	GC-FID	[80]
Tetradecanal	*P. minus*	Leaves	Essential oil (hydrodistillation	GC-MS	[87]
	P. minus	Leaves	Essential oil (hydrodistillation	GC × GC–TOF MS	[87]
				GC-MS/O	[89]
			SPME	GC–MS	[88]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. odoratum	Leaves	MeOH	GC-MS	[244]
			Essential oil (SDE)	GC-MS	[237]
Alcohol					
Decanol	*P. minus*	Leaves	Essential oil (hydrodistillation)	GC–MS	[87]
				GC × GC–TOF MS	[87]
			SPME	GC–MS	[88]
		Stems	SPME	GC-MS	[86]
			Essential oil (hydrodistillation)	GC-MS	[86]
		–	Essential oil (hydrodistillation)	GC–MS	[234]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. odoratum	Leaves	MeOH	GC-MS	[244]
			Essential oil (hydrodistillation)	GC-MS	[240]
	P. odoratum	Aerial part	Essential oil (hydrodistillation)	GC-MS	[90]
	P. hydropiper L	Leaves	Essential oil (SDE)	GC × GC–TOF MS	[233]
			DHS	GC × GC–TOF MS	[233]
Linalool	*P. alpinum All*	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. amphibium L	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bistorta L	Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. minus	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
	P. orientale	Flowers	Hex	GC-FID	[80]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	GC-MS	[78]
		Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. viscosum	Leaves	Essential oil (microwave hydrodistillation)	GC-MS	[235]
Phytol	*P. hydropiper*	Sprouts	Essential oil (hydrodistillation)	GC-MS	[81]
	P. minus	Leaves	Essential oil (hydrodistillation)	GC-MS	[87]
			Essential oil (hydrodistillation)	GC × GC–TOF MS	[87]
			Essential oil (hydrodistillation)	GC-MS	[86]
		Stems	Essential oil (hydrodistillation)	GC-MS	[86]
	P. maritimum	Leaves	MeOH	GC-MS	[245]
	P. orientale L	–	Essential oil	GC-MS	[101]
Terpineol	*P. bistorta* L	Leaves	Essential oil (hydrodistillation)	GC/FID and GC/MS	[11]
	P. arenarium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. arenastrum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. aviculare	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. bellardii	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. cognatum	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. lapathifolium	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]
	P. persicaria	Aerial part	Essential oil (hydrodistillation)	RI, MS	[28]

DCM: Dichloromethane; DHS: Dynamic Headspace Sampling; EtOH: Ethanol; Et_2O: Diethyl Ether; Hex: Hexane; SDE: Distillation and Solvent Extraction; SPME: Solide Phase Micrextraction

3-*O*-acetate-3′-*O*-D-glucopyranoside, was also effectively isolated by Cong et al. [71] in the aerial part of *P. aviculare* (Table 2 and supplementary file).

7.1.4. Stilbenes

The last two decades have seen a substantial increase in interest in stilbenes. Resveratrol is one of the naturally occurring stilbenes that has significant effects on health and illness. It's interesting to note that resveratrol exhibits a wide range of pharmacological effects, pointing to its potential for improving human health [72]. In the genus *Polygonum*, resveratrol was detected in *P. multiflorum* and *P. cuspidatum* extracts **(Table 2).**

7.2. Volatile compounds from the genus Polygonum

Essential oils are transparent substances that mostly consist of volatile and aromatic molecules found naturally in plant parts, including flowers, whole plants, seeds, peels, stems, and bark. They are extensively used as preservatives in food, cosmetics, medicines, and perfumes in many nations worldwide. Because of their flavor and odor, they were first utilized as medicine in the 19th century [73]. The distinctive properties of essential oils are attributed to their highly complicated mixes of monoterpenes and sesquiterpenes, which also contain biogenetically linked phenols, alcohols, aldehydes, ethers, carbohydrates, and ketones [74]. The essential oil compositions of many species in the *Polygonum* genus, including *P. hydropiper* [75] and *P. bistorta* [11], have been investigated.

Terpenoids, or terpenes, are the biggest, most functionally, chemically, and structurally diversified class of molecules in organisms, with more than 80, 000 substances now recognized [76]. Terpenes can be divided into monoterpene (two isoprene units), diterpene (four isoprene units), triterpene (six isoprene units), tetraterpene (eight isoprene units), and sesquiterpene (three isoprene units). They are chemical compounds that are typically present in plant essential oils. In plants, terpenes have a variety of purposes, including signaling, pigmentation, taste, and various therapeutic uses [77]. They have a wide range of medicinal advantages, including anti-cancer, antimicrobial, antiviral, antifungal, analgesic, antihyperglycemic, and antiparasitic effects. They are also utilized to enhance skin penetration, prevent inflammatory diseases, and are integral to various medicinal drugs [77]. Sesquiterpenes were the most detected groups in the genus *Polygonum,* followed by monoterpenes [28]. described the essential oils from seven species (*P. aviculare, P. arenastrum, P. arenarium, P. bellardii, P. cognatum, P. persicaria,* and *P. lapathifolium)* belonging to the genus *Polygonum*, which are widely eaten by people in many regions of the world. The author analyzed the composition of essential oils in the leaves of each species. The results showed that *Polygonum* species contained nineteen monoterpenes, eleven sesquiterpenes, and nine aliphatic acids. The most abundant compounds were the two sesquiterpenes (β-Caryophyllene and β-farnesene) and the aliphatic compound (dodecanal), with 15.92% in *P. aviculare,* 20.45% in *P. persicaria,* 25.65% in *P. lapathifolium,* 19.65% in *P. arenarium,* 16.23% in *P. bellardii,* 17.96% in *P. arenarium,* and 14.01% in *P. cognatum* extract.

Korulkin and Muzychkina. investigated the composition of essential oils from *P. amphibium* L, *P. minus, P. alpinum,* and *P. persicaria*. The main molecules of essential oil from *P. amphibium* were borneol (2.1%), γ-terpinene (2.1%), 1,8-cyneole (1.8%), piperitol (1.8%), linalool (1.6%), α-pinene (1.6%), terpinolene (1.3%), and sabinene (1.2%); for *P. alpinum*, sabinene (2.4%), *p*—cymol (2.2%), borneol (1.8%), camphere (1.7%), and 4-carene (1.7%); for *P. minu*, linalool (1.9%), terpinolene (1.8%), borneol (1.6%), camphere (1.6%), and 1,8-cyneole (1.3%); for *P. persicari*a, 4-terpineol (1.8%), 4-carene (1.6%), sabinene (1.5%), α-pinene (1.5%), and 1,8-cyneole (1.4%) [78].

Based on the bibliographic data presented in Table 3, the monoterpene camphene is found in most species in *Polygonum*: *P. alpinum, P. arenarium, P. arenastrum, P. aviculare, P. bellardii, P. cognatum, P. lapathifolium, P. minus,* and *P. persicaria* L. It is one of the primary compounds of many aromatic and medicinal plants' essential oils, particularly those in the genus *Thymus*, *Salvia*, and *Origanu*m [79]. The biological benefits of camphene, such as its antioxidant, antibacterial, antifungal, antiparasitic, anticancer, antiparasitic, anti-inflammatory, antidiabetic, and hypolipidemic capabilities, have been demonstrated by numerous *in vivo* and *in vitro* studies. Additionally, studies showed that camphene has hepatoprotective, anti-acetylcholinesterase, and anti-leishmanial inhibitory properties [79]. Myrcene is another major monoterpene detected in the essential oil of *Polygonum* plants *(P. arenarium, P. arenastrum, P. aviculare, P. bellardii, P. cognatum, P. lapathifolium, P. persicaria, P. bistorta* L, *P. hydropiper, P. minus,* and *P. orientale)* [28,80,81]. It's an acyclic, unsubstituted monoterpene with a pleasant aroma. Myrcene is found naturally in many species, particularly in the essential oils of plants like verbena, hops, and hemp and in citrus fruits and juices. Popular food additive myrcene is a flavor in food and drink production; additionally, commercial products like detergents, soaps, and cosmetics [82].

For centuries, γ-terpinene, a monoterpene, has been a significant constituent of essential oils derived from plants and fruit. It has strong antioxidant properties in several assay methods. In the *Polygonum* genus, terpinene was found in several species: *P. arenarium, P. arenastrum, P. aviculare, P. bellardii, P. cognatum, P. lapathifolium, P. persicaria, P. alpinum All, P. amphibium* L, *P. minus,* and *P. persicaria* L [28,78]. Cymene, α-pinene, and thujene are also among the major monoterpenes in essential oils of the *Polygonum* genus.

Commonly found in natural oils from plants, the sesquiterpene bisabolene is a bioactive molecule and the most basic monocyclic sesquiterpene. α-bisabolene, β-bisabolene, and γ -bisabolene are its three structure isomers. Multiple industries, including pharmaceutical, cosmetic, chemical, and nutraceutical, use bisabolene [83,84]. According to Ref. [85], β-bisabolene demonstrated specific cytotoxic effects on human tumor cells and mice cells. In the genus *Polygonum*, bisabolene is found in many species, including *P. arenastrum, P. aviculare, P. barbatum, P. bellardii, P. cognatum, P. hydropiper, P. lapathifolium, P. persicaria* [28], *P. minus* [86–89], *P. odoratum* [90], *and P. punctatum* [91].

β-caryophyllene and β-caryophyllene oxide are also substances with a powerful woody smell used as cosmetic and food additives. These two sesquiterpenes are detected in several species, such as the essential oil obtained from the aerial part of the plant *P. odoratum* [90], from the leaves of the species *P. minus* [89], and many other essential oils from different species. The European Food Safety

Authority (EFSA) and the Food and Drug Administration (FDA) have approved these natural chemicals as flavorings. Due to the low water solubility of these two chemicals, they cannot penetrate cell membranes in aqueous conditions like biological fluids. Both β-caryophyllene and β-caryophyllene oxide have strong anticancer effects on the development and proliferation of different cancer cells [27]. Among the other major sesquiterpenes in the *Polygonum* genus, we can also mention aromadendrene, curcumene, and elemene (Table 3).

7.3. Fatty acid

Carbon chains in fatty acids range in length from two to thirty-six carbon atoms and can be either unsaturated or saturated carboxylic acids [92]. Fatty acids were beneficial for nutrition and medicine and powered many biological and metabolic processes, including muscular contraction. They are crucial chemical components of cells. Natural fatty acids founded in medicinal plants include saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids (PUFA) [93]. It has been noticed that the *Polygonum* genus contains certain fatty acids, such as decanoic acid, lauric acid, linoleic acid, oleic acid, palmitic acid, stearic acid, dodecanoic acid, etc. The most abundant fatty acids in the genus *Polygonum* were palmitic acid, oleic acid, and stearic acid. The saturated fatty acid palmitic acid, which makes up 20–30% of all fatty acids in the human body, is frequently found in palm oil and coconut oil. It plays an essential role in the composition and structure of cell membranes as well as providing the body with energy. Despite its uses in industry, palmitic acid has drawn interest for its possible medicinal benefits [94]. In the genus *Polygonum*, palmitic acid was identified in *P. barbatum* leaves [95], *P. bistorta* rhizome [96], the seeds of *P. equisetiforme* [46], the leaves and roots of *P. maritimum* [97], the hexane extract from leaves and flowers of *P. orientale* [98], and the essential oil from the preceding plant seeds and other species. Oleic acid was detected in five species belonging to the genus *Polygonum* (*P. bistorta*, *P. equisetiforme, P. maritimum, P.* minus, and *P. orientale)*. Based on [46], the methanolic extract of *P. equisetiforme* contains 38% oleic acid, 30% linoleic acid, and 15% palmitic acid. On the other hand, the root extract prepared by SPME from *P. minus* only has a small amount of oleic acid, about 2.38%. Depending on the plant's provenance, Intisar et al. [99] indicate that the essential oil of *P. bistorta* rhizomes contains between 4.3% and 8.9% of this compound. Methanolic extract from the leaves of *P. maritimum* contains 4.13% of oleic acid, whereas dichloromethane extract from the roots contains 3.21% [97].

A vital fatty acid for the body is linoleic acid. It is an essential element to produce prostaglandins. It can enhance human growth and development, control bodily physiological processes, catabolize cholesterol in the body, and guard against cardiovascular disorders [100]. Linoleic acid was detected in *P. bistorta*, *P. equisetiforme, P. maritimum,* and *P. orientale* [46,80,96–98,101].

The primary utilization of the fatty acids obtained from plants was in the cosmetics industry. Palmitic, lauric, and myristic acids, detected in several *Polygonum* species, make up around 99% of the formulation of cosmetics, while stearic acids make up between 92% and 96% [102]. Fatty acids generally have several advantageous effects when included in cosmetic formulations, including hardening the soap, producing a rich lather, and improving the soap's velvety surface. Some fatty acids have occlusive qualities, which restrict or retard moisture loss from the skin's surface, assisting the skin in staying hydrated. Additionally, fatty acids can function as a surfactant/emulsifying agent, fragrance, emulsion stabilizer, and cleaning agent [102]. The **supplementary file** provides the fatty acid content of the genus *Polygonum.*

7.4. Polysaccharides from the genus Polygonum

One of the strongest components found in many traditional medicines is polysaccharide, which serves a variety of benefits, including anti-aging, lipid peroxidation inhibition, and antioxidant properties. In the genus *Polygonum*, polysaccharides were extracted from *P. multiflorum, P. cillinerve*, and *P. sibiricum.*

Two different polysaccharides (WPMPs), WPMP1 and WPMP2, were isolated from *P. multiflorum* for the research of [103]. They experienced many purification steps, including extraction by water, deproteination, the decolorization process, precipitation, and lyophilization. Polysaccharide's structure and immunomodulatory effects were studied. WPMP2 had been found to include arabinose, galactose, galacturonic acid, rhamnose, and just a small amount of glucose, while WPMP1 was recognized as a glucan. Using splenocyte proliferation tests, immunomodulation experiments demonstrated that WPMP1 and WPMP2 both have strong immunomodulatory actions. Compared to the normal control group, a dose-dependent increase in cell viability was observed within the 20–500 μg/mL concentration range. Moreover, WPMPs increased peritoneal macrophage phagocytosis. Interestingly, both WPMPs and WPMP2 markedly increased the absorption of neutral red at doses of 20 μg/mL. WPMP1 had a comparable result but needed 100 μg/mL of concentration. Moreover, WPMPs increased peritoneal macrophage phagocytosis and demonstrated immune cell defense against 5-fluorouracil-induced immunosuppression [103].

The ultrasonic-assisted extraction, structural characterization, and anticancer effectiveness of polysaccharide from *P. multiflorum* roots were examined in the study by Ref. [104]. By using gas chromatography, methylation analysis, nuclear resonance, and fourier-transform infrared spectroscopy, the structure of the main neutral polysaccharide was determined to be a linear (1 → 6)-α-D-glucan. The polysaccharides from *P. multiflorum* roots inhibited 38.58% and 53.35% of BGC-823 and HepG-2 cells, respectively, at 400 μg/mL. According to the findings, this polysaccharide may have natural anticancer properties [104].

The study by Refs. [94,105] showed that *P. sibiricum* polysaccharides successfully reversed the depressive-like behaviors caused by chronic, unexpected mild stress. There seem to be many pathways involved in the mediation of these antidepressant-like effects. First, injection of *P. sibiricum* polysaccharides (at 100 mg/kg, 200 mg/kg, and 400 mg/kg) reduced hypothalamic-pituitary adrenal axis dysfunction as shown by a reduction in blood levels of adrenocorticotropic hormone and corticosterone. In addition, *P. sibiricum* polysaccharides raised the hippocampal levels of neurotransmitters (5-hydroxytryptamine and norepinephrine) at 100 mg/kg, 200

mg/kg, and 400 mg/kg. Lastly, *P. sibiricum* polysaccharides seem to work by reducing neuroinflammation, controlling the structure of the gut microbiota, and raising the amounts of short-chain fatty acids needed to produce their antidepressant effects [105].

Second research by Ref. [106] conducted on the antidepressant effect of polysaccharides from *P. sibiricum*, demonstrated for the first time the antidepressant via the microbiota-gut-brain (MGB) axis. In mice exposed to chronic, unpredictably mild stress, transplantation of the feces microbiota from polysaccharide-treated mice successfully lowered hippocampal inflammation, decreased intestinal barrier damage, and reduced harmful metabolite penetration. *P. sibiricum* polysaccharides' antidepressant effects through the MGB axis were linked to certain signaling pathways, such as ERK/CREB/BDNF (extracellular signal-regulated kinase/cyclic AMP response element binding proteins/bbrain-nerved neurotrophic factor) and PI3K/AKT/TLR4/NF-κB (phosphatidylinositol 3-kinase/-protein kinase B/toll-like receptor/nuclear factor-kappa B).

[107] conducted a detailed characterization of *P. cillinerve* polysaccharide, indicating that it was predominantly composed of glucose and is classified as an α-D-glucan. Repeating units of (1 → 4)-α-D-glucose make up the structural basis of polysaccharides. Additionally, the study assessed polysaccharide's antioxidant capacity *in vitro*. The findings showed that *P. cillinerve* polysaccharide has strong hydroxyl radical scavenging capabilities, a moderate capacity to scavenge DPPH (2,2-diphenyl 1-pycrilhydrazyl), and an adequate capacity for lowering power. Furthermore, *P. cillinerve* polysaccharide significantly decreased the levels of malondialdehyde, myeloperoxidase, and xanthine oxidase (in macrophages) while significantly increasing those of glutathione peroxidase and superoxide dismutase at levels ranging from 15.62 to 0.97 μg/mL.

7.5. Bioactive compounds specific to the genus Polygonum

Polygonumins A, B, C, and D are compounds that are extracted only from the stems of *P. minus* and have demonstrated a range of bioactive properties. These substances have strong antioxidant properties. Moreover, polygonumins A, B, C, and D showed anti-acetylcholinesterase potential, which may support mental function. Polygonumins C and D are particularly interesting since they have the potential to inhibit HIV-1 and may have effects on antiviral treatment [108]. Another new compound extracted from *P. multiflorum* roots was polygonflavanol A [109]. In the meantime, the rhizomes of *P. bistorta* L. produce a specific compound, which is bistortaside A [110]. Furthermore, in a mouse model of breast cancer xenograft, amplexicaule A, which is derived from *P. amplexicaule* D rhizomes, has shown significant antitumor properties. Additionally, this compound causes breast cancer cell line apoptosis [111]. The structures of the bioactive compounds specific to the genus *Polygonum* are presented in Fig. 5.

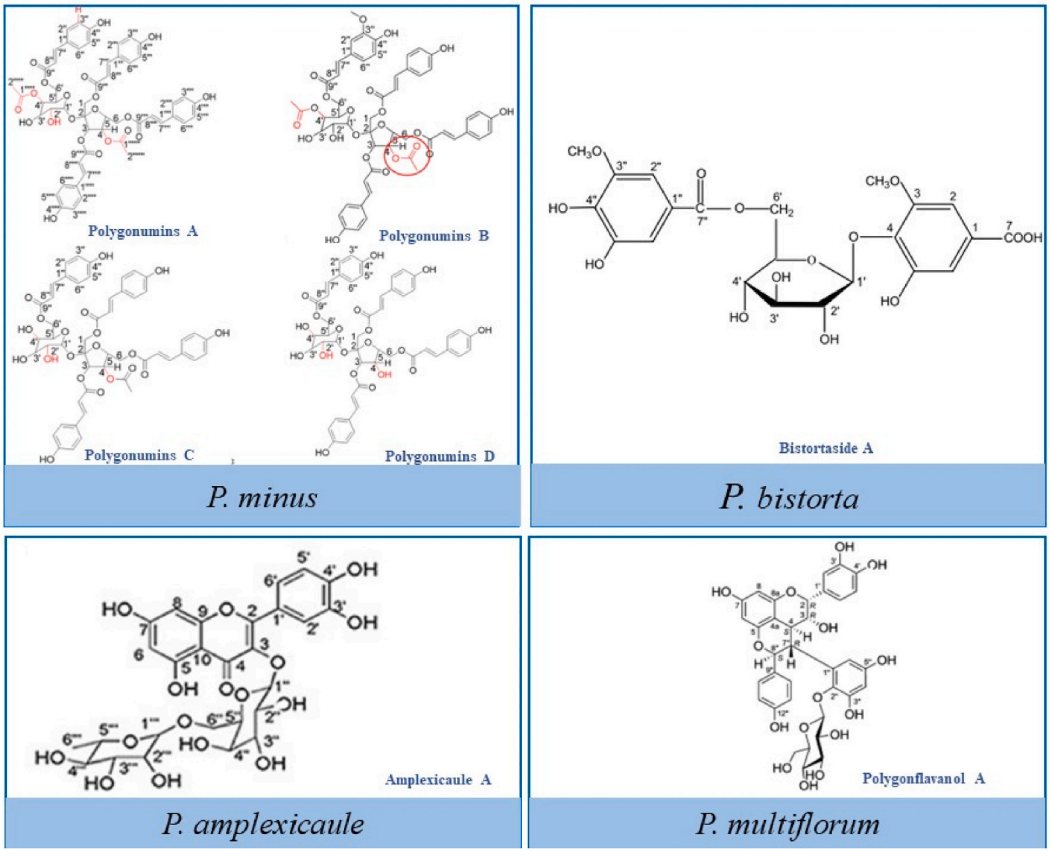

Fig. 5. Bioactive compounds specific to the genus *Polygonum*.

8. Pharmacological uses

Fig. 6 illustrates the biological activity of the genus *Polygonum*. The number of publications concentrating on the biological activities of each species is shown in **Figure (b).** In contrast, the number of articles focused on each biological activity is shown in **Figure (a).**

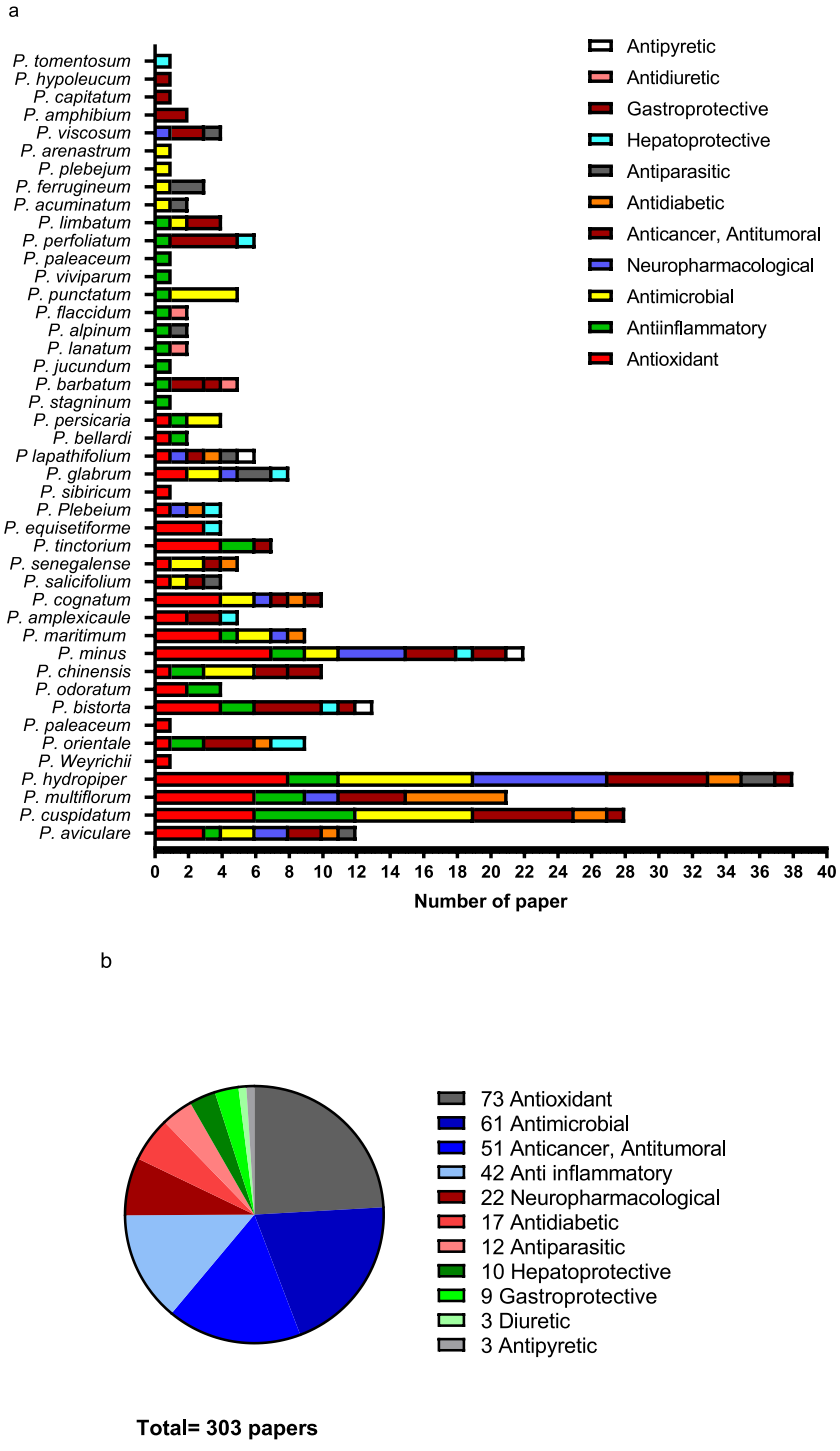

Fig. 6. Biological activities from the genus *Polygonum*. (**a**) Number of papers focusing on each biological activity. (**b**) Number of publications focusing on the biological activities of each specie.

8.1. Example of Polygonum species with multifaceted biological activities

8.1.1. Polygonum aviculare

8.1.1.1. Antioxidant activity. According to Hsu et al. [112], the *P. aviculare* L. ethanolic extract has an IC_{50} (half-maximal inhibitory concentration) value of 50 μg/mL for the DPPH test, 0.8 μg/mL for the SOR test (superoxide radical scavenging test), and 15 μg/mL for the LPO assay (lipid peroxidation assay). Additionally, *P. aviculare* L. extract protected DNA in tests that involved hydroxyl radicals that cause DNA strand scission. The extract had a total phenolic and flavonoid content of 677.4 μg/g and 112.7 μg/g, respectively. According to the results, *P. aviculare* L. extract exhibited an obvious antioxidant effect. The precedent study indicated that the high phenolic content of *P. aviculare* extract is likely connected to its efficiency as an antioxidant and that the hydroxyl groups in phenolics may be the cause of the extract's observed antioxidant activities. The antioxidant potential of eleven flavonol glucuronides obtained from the plant *P. aviculare*, of which eight were identified for the first time in the *Polygonum* species, was examined *in vitro* by Granica et al. [113]. According to the findings, all substances considerably reduced the formation of ROS (reactive oxygen species) at physiologically acceptable doses between 0.5 and 10 μM. At a concentration of 10 μM, compounds 10, 9, and 3 were shown to have an effect similar to quercetin, reference [113].

The antioxidant potential of four species (*P. aviculare, S. flavescens, D. superbus*, and *L. japonicum*) was compared by Ref. [114]. In accordance with the findings, *P. aviculare* extract showed the best antioxidant activity and the lowest half maximal effective concentration (EC_{50}) values, less than 0.1 mg/mL. The total phenol content of *P. aviculare* was substantially correlated with its capacity to eliminate free radicals (71.72–7.66 mg GAE/g).

8.1.1.2. Anti-inflammatory activity. Elastase is an enzyme generated by numerous kinds of inflammatory cells, including neutrophils, which are crucial in the human body's immunological response to inflammation. In excess, elastase may damage tissue and lead to chronic inflammation. The study by Ref. [113] demonstrated that eleven flavonol glucuronides obtained from *P. aviculare* extract affected neutrophils' ability to produce elastase in response to stimulation. The study's results demonstrated that quercetin, the positive control, had identical inhibitory efficacy to compounds 1, 2, 3, and 10. The *P. aviculare* plant is used to treat inflammation and burning in India, which makes it reasonable given its anti-inflammatory capacity [3]. The traditional utilization of *P. aviculare* in the treatment of digestive infections, diarrhea, bleeding, cystitis, and ulcers can also be attributed to its anti-inflammatory potential, as these gastrointestinal issues are frequently associated with inflammatory processes [115].

8.1.1.3. Antimicrobial activity. *P. aviculare* extracts were tested for their antibacterial properties against a variety of strains of Gram-positive (*S. aureus, B. subtilis,* and *S. pyogenes*) and Gram-negative (*E. coli, P. mirabilis, P. aeruginosa, S. typhi, S. paratyphi,* and *S. flexneri*) bacteria by Salama and Marraiki. With a 28-mm diameter of inhibition, the chloroform extract of *P. aviculare* stem exhibited the best efficacy against *P. mirabilis*. In comparison to the stem extracts, the leaf extracts often showed less efficacy against the tested organisms [116]. The antibacterial potential of *P. aviculare* was tested on a variety of bacteria by Gou et al. [114]. The pressure-assisted water extraction of *P. aviculare* produced an aqueous extract with a MIC_{99} (the minimal concentration that inhibits colony formation by 99%) value of 9.04 mg/mL that was effective against *S. Typhimurium*.

8.1.1.4. Neuroprotective activity. Using three groups: unstressed, stressed mice treated with a vehicle, and stressed mice treated with *P. aviculare* extract [117], evaluate the anti-inflammatory properties of *P. aviculare* extract. The treatment with *P. aviculare* lowered the levels of Cluster of Differentiation 68 (CD68), Ibal-1 (the microglial markers), the ionized binding calcium adaptor molecule, the pro-inflammatory cytokines IL-1 (interleukin-1), TNF-α (tumor necrosis factor-alpha), and IL-6 (interleukin-6), in the brain, as well as the expression of fatigue-related substances such as serotonin, corticosterone, and catecholamines in the brain and blood. This information showed that *P. aviculare* is both anti-inflammatory and reduces fatigued. The results were further supported by the histological tests, which showed that *P. aviculare* therapy corrected liver damage and atrophic volumes. *P. aviculare* extract may therefore be an innovative anti-inflammatory therapy for the treatment of chronic fatigue.

8.1.1.5. Anticancer and antitumor activity. The methanol extract, prepared with maceration, from the aerial part of *P. aviculare* was an interesting anticancer extract. The results of [118] demonstrated that *P. aviculare* extract caused cytotoxicity in the breast cancer cell line MCF-7 (michigan cancer foundation-7) at concentrations greater than 300 ng/μL, this was supported by the maximum level of cell death as determined by the MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) and Trypan Blue tests. Results from RT-PCR indicated that *P. aviculare* may induce mortality in MCF-7 cells and supported the hypothesis by showing up-regulation of Tumor protein P53 (P53) and reduced levels of Bcl-2 protein.

8.1.1.6. Antidiabetic activity. The ethanol extract of *P. aviculare* was examined for its antidiabetic properties by measuring the percentage of inhibition of α-glucosidase. The extract had good α-glucosidase inhibitory activity, with an IC_{50} (21.42 μg/mL) value that was noticeably lower than that of acarbose, the positive control (176.79 μg/mL). The anti-α-glucosidase activity assay demonstrated that polydatin, quercetin, and myricitrin represented the primary factors responsible for the *P. aviculare* extract's activity [37].

8.1.2. *Polygonum cuspidatum*

8.1.2.1. Antioxidant activity. [119] evaluated the antioxidant activity of the ethanolic extract of *P. cuspidatum* using the DPPH, SOD, LPO, and DNA strand scission tests that are brought on by hydroxyl radicals. The findings showed that, in LPO, SOD, and DPPH assays, the IC_{50} values of *P. cuspidatum* extract are 8 μg/mL, 3.2 μg/mL, and 110 μg/mL, respectively. *P. cuspidatum* shared a similar inhibitory potential with *A. confusa*, *U. btomentosa*, *A. cerefolium*, and *P. aviculare* L in terms of DPPH scavenging activity.

The aqueous ethanolic extract of *P. cuspidatum* was evaluated for its antioxidant properties by the DPPH and ABTS (2,2′-Azinobis-3-Ethylbenzthiazolin-6-Sulfonic Acid) assays. At a concentration of 100 μg/mL, the inhibition percentage for DPPH was 46.14%, whereas the results for ascorbic acid and BHA (butylhydroxyanisol) were 91.29% and 77.81% respectively. For ABTS, the values were 86.38% for the *P. cuspidatum* extract and 99.99% for the two positive controls.

Several other studies have demonstrated the antioxidant power of this plant, for example, the studies of Pen et al. [120,121] and others.

8.1.2.2. Anti-inflammatory activity. The study by Ref. [122] investigated the anti-inflammatory activity of the ethanol extract from *P. cuspidatum* and its fractions (HZE-30, HZE-60, and HZE-95). The UPLC-DAD technique was used for the quantification of the major compounds in the HZE-60 fraction, including compound number 6 (polydatin), compound number 7 (resveratrol), compound number 15 (emodin-1-*O*-β-*d*-glucoside), compound number 21 (emodin-8-*O*-β-*d*-glucoside), and compound number 31 (emodin). Resveratrol, emodin-1-*O*-d-glucoside, and emodin-8-*O*-d-glucoside demonstrated notable anti-inflammatory efficacy by inhibiting pro-inflammatory mediators, including IL-6, NO (nitric oxide), TNF, and MCP-1 (monocyte chemotactic protein-1). Compounds 7, 15, and 21 produced major improvements to the anti-inflammatory impact and may also be employed as possible indicators for the quality control of *P. cuspidatum*.

The work of Bralley et al. [123] showed the capacity of *P. cuspidatum* extract (PCE) to reduce mouse ear inflammation induced by 12-*O*-tetradecanoylphorbol-13-acetate (TPA) administration. In comparison to the TPA control, *P. cuspidatum* extract reduced ear edema at all dosages (0.07 mg PCE/ear, 0.15 mg PCE/ear, 0.3 mg PCE/ear, 1.25 mg PCE/ear, and 2.5 mg PCE/ear). As a result of the dose-dependent nature of the PCE response, 2.5 mg of PCE considerably suppressed all inflammatory indicators more than the reference indomethacin (0.5 mg). At *P. cuspidatum* dosages below 1.25 mg/ear, MPO activity was suppressed.

To test the anti-inflammatory potential of the ethyl acetate extract of *P. cuspidatum in vivo*, FCA (Freund's complete adjuvant)-induced adjuvant arthritis and serotonin-induced paw edema models were both employed by Ref. [124]. *P. cuspidatum* extract reduced swelling and inflammation within 12 min of serotonin administration. *P. cuspidatum* extract at 200 mg/kg significantly reduced FCA-induced joint swelling after 3 days, whereas *P. cuspidatum* extract at 100 mg/kg achieved the same outcome within 5 days [124].

Polygonum has strong anti-inflammatory properties, as demonstrated by studies conducted by Kim et al. [125], and Geng et al. [126].

8.1.2.3. Antimicrobial activity. The antibacterial potential of *P. cuspidatum* was tested on various bacterial strains by Kim et al. [125]. The results showed that the oral bacterium *S. mutans* was sensitive to the antibacterial effect of the *P. cuspidatum* ethanol extract. Within a single day, *P. cuspidatum* was showing antimicrobial effects at a dose of 1 mg/mL. At a concentration of 10 mg/mL, all bacterial activity was completely inhibited. Overall, Kim et al. [125] results suggest that *P. cuspidatum* ethanolic extract, at a non-toxic and safe dose, has antibacterial action against the bacterium *S. mutans* by decreasing the generation of inflammatory factors. These results suggest that *P. cuspidatum* extract can serve as an anti-inflammatory and antibacterial substance in oral products.

The antimicrobial properties of *P. cuspidatum* leaf ethanolic extract and their fractions were determined by Su et al. [127] using two methods: MIC (minimum inhibitory concentration) and disk diffusion. The findings demonstrated that the ethyl ether fraction, with MIC values ranging from 0.1 to 3.5 mg/mL, has a greater antibacterial spectrum and better antimicrobial activity against all the clinical drug-resistant isolates examined. The pathogen growth was completely stopped by this fraction, which also prevented the development of resistance to its active ingredients. The degradation and disruption of the cytoplasmic membrane and cell wall caused by the ethyl ether fraction also caused significant morphological alterations in the cells, which eventually culminated in cell death due to the compromised integrity of the cell membrane.

The antimicrobial activity of the methanol extract from *P. cuspidatum* root was tested. The results showed that this extract may be helpful for preventing the development of subsequent tooth decay and dental plaque due to its bactericidal or bacteriostatic activity at higher concentrations and its inhibitory impact on the factors that contribute to the virulence of *S. sobrinus* and *S. mutans* at lower concentrations [128].

The study of Li et al. [129] showed that *P. cuspidatum* extracts and emodin exhibited antibacterial activity against *H. parasuis in vitro*. Emodin has been suggested to have an antibacterial effect on *H. parasuis* by altering the physical structure of the bacterium and making cell membranes more permeable. According to this study, emodin may be a promising treatment for *H. parasuis* infection.

8.1.2.4. Anticancer and antitumor activity. *P. cuspidatum* extracts improved the immunological expression of TNF-α generated by the human acute monocytic leukemia cell line (THP-1) macrophage cell line. A375 and A375-S2 human skin melanoma cells demonstrated anti-proliferation in a dose-dependent manner, indicating that biological substances were used and had anticancer properties [130]. The proliferation of hepatocellular carcinoma in human cells was reported to be inhibited, *in vitro*, by resveratrol-4-*O*-d-(2′-galloyl)-glucopyranoside in a time- and dose-dependent way. Apoptosis was also generated by

resveratrol-4-*O*-d-(2′-galloyl)-glucopyranoside, and some proteins that are known to be associated with cell death were activated. In a mouse xenograft test for hepatic cancer, the previous compound demonstrated efficacy. These findings suggest that, by creating apoptosis via the ERK and JNK (c-Jun-N-terminal kinase) pathways, resveratrol-4-*O*-d-(2′-galloyl)-glucopyranoside may be a viable therapeutic treatment for hepatocellular cancer [131].

The purpose of the research by Alzahrani et al. [132] is the green production of SnO_2 nanoparticles embedded in Pluronic-F-127, utilizing *P. cuspidatum* root extract. Additionally, human hepatoma (HepG2) cell lines' anticancer efficacy is investigated. In HepG2 cells, the nanoparticle treatment developed oxidative stress and encouraged pro-apoptotic proteins. The PI3K/Akt/mTOR pathway, which causes death in HepG2 cells, was likewise downregulated by nanoparticles. Green pluronic-F-127-coated SnO_2 nanoparticles have the potential to be a powerful anticancer agent.

8.1.2.5. Antidiabetic activity. Diabetic nephropathy is initiated and progressed by platelet-derived growth factor-BB (PDGF-BB), which is abundantly present in the urinary tract of people who have the ailment. The purpose of Sohn et al. [133] was to investigate the potential protective effects of extract from the root of the *P. cuspidatum* plant against the early development of kidney glomerular proliferation in diabetic rats exposed to streptozotocin (STZ). The *P. cuspidatum* extract showed an IC_{50} value of 0.18 μg/mL, inhibiting the interaction between the PDGF-BB molecule and its receptor, PDGFR-β. Interestingly, *P. cuspidatum* extract dramatically decreased the amount of albumin found in the urine of diabetic rats, indicating a possible protective effect. Additionally, Sohn et al. [134] demonstrated that emodin, a physiologically active component from *P. cuspidatum* root extract, had a methylglyoxal-trapping action ($IC_{50} = 0.41$ mM lower than the reference aminoguanidine $IC_{50} = 1.05$ mM) and prevented the development of advanced glycation end products formed from methylglyoxal. These findings suggest that *P. cuspidatum* root extract can be given to STZ-induced diabetic rats in order to avoid proteinuria and podocyte damage, in part by preventing podocyte mortality and cleaved caspase-3 production and resetting the equilibrium between methylglyoxal expression and oxidative stress.

8.1.2.6. Antiparasitic activity. In the study of Zhou et al. [135], emodin, a *P. cuspidatum* compound with anti-*Ichthyophthirius multifiliis* action, was isolated and discovered. *In vitro* tests showed that emodin (at 1 mg/L) eliminated all *I. multifiliis* in 96 min. Furthermore, nonencysted and encysted tomonts' reproduction was successfully stopped by emodin at concentrations of 1 and 2 mg/L, respectively. When given continuously for 10 days, emodin at 0.5 mg/L effectively grass-covered carp and shielded uninfected fish against *I. multifiliis* infection, according to *in vivo* experiments.

8.1.2.7. Gastroprotective effect. At doses of 100 mg/kg and 300 mg/kg, *P. cuspidatum* root extract significantly decreased the stomach lesions caused by indomethacin and HCl/EtOH, 1.7 mm^2 for the second concentration and 14 mm^2 for the first. *P. cuspidatum* extract at 300 mg/kg effectively decreased stomach lesions in ulcers caused by acetic acid. The levels of SOD were noticeably greater in the stomach tissues of the HCl/EtOH-treated rats that were administered *P. cuspidatum* root extract at dosages of 100 mg/kg and 300 mg/kg compared to the control. *P. cuspidatum* extract did not change variables linked to stomach acid secretion, although it did raise glutathione (GSH) and prostaglandin E2 contents in the gastric tissue. The results showed that *P. cuspidatum* root extract improves acetic acid-induced ulcers' healing and gastroprotective properties against non-steroidal anti-inflammatory and HCl/EtOH drugs [136].

8.1.3. Polygonum hydropiper

8.1.3.1. Antioxidant activity. Using the FRAP (ferric reducing antioxidant power) and DPPH methods, Nasir et al. [137] investigated the antioxidant potential of extracts from *P. hydropiper* leaves and stems using water, ethanol, methanol, chloroform, acetone, and n-hexane. The research results indicated that the stem rather than the leaves had substantial antioxidant potential as determined by the DPPH and FRAP assays, with IC_{50} of 1.59 and 1.38 mg/mL, respectively.

P. hydropiper extracts (petroleum ether, chloroform, ethanol, n-hexane, and methanol), collected from Bangladesh, were tested for their *in vitro* antioxidant activity utilizing the DPPH, CUPRAC (Cupric Reducing Antioxidant Capacity), total antioxidant capacity (TAC), total polyphenol content (TPC), and total flavonoid content (TFC) determination tests. The results showed that plant extracts have considerable strong antioxidant activity; for example, the free radical-scavenging capacity of ethanol extract was significant with an IC_{50} of 12.21 μg/mL [138].

Three different techniques were used by Ayaz et al. [139] for antioxidant tests: ABTS, DPPH, and H_2O_2 free radical scavenging tests. The leaf and flower essential oils (Ph.LO and Ph.FO) had an IC_{50} of 20 and 200 μg/mL, respectively, in the DPPH test. The measured IC_{50} values for H_2O_2 and ABTS free radical scavenging were 60 μg/mL and 180 μg/mL for Ph.LO, and 50 μg/mL and 45 μg/mL for Ph.FO. The dual antioxidant potency of the essential oils highlights their potential utility in treating a variety of illnesses, even though their IC_{50} values were greater than those of medicines.

Peng et al. [140] isolated ten major flavonoids from *P. hydropiper* leaves, six of which belonged to flavone-3-ol and four belonged to flavone. The isolated flavonoids demonstrated strong antioxidant effects in both the ESR (electron spin resonance) and UV–visible (ultraviolet visible) assays; it should be mentioned that galloyl quercitrin gave the highest antioxidant activity.

The antioxidant activity of *P. hydropiper* extract was also evaluated and approved by Haraguchi et al. [141], Ayaz et al. [142], and Ren et al. [143].

8.1.3.2. Anti-inflammatory activity. The study by Ren et al. [143] demonstrated that the administration of the ethyl acetate fraction

from *P. hydropiper* induced an important decrease in inflammatory markers in an *in vitro* investigation using PCV2 (porcine circovirus type 2)-induced 3D4/2 cells (porcine alveolar macrophages). Decreased ROS production, reduced levels of inflammatory cytokines, modification of NF-κB p65, inhibition of NF-κB nuclear transfer, and suppression of PI3K/Akt signaling were all specifically induced by the plant extract. These results reveal that the ethyl acetate fraction from *P. hydropiper* has potent *in vitro* anti-inflammatory action. The results of [143] were confirmed by Yang et al. [144], who demonstrated that the methanolic extract from *P. hydropiper* showed strong anti-inflammatory properties by inhibiting the IRAK/AP-1/CREB (interleukin-1 receptor-associated kinase 1/activator protein-1/cAMP response element-binding) and Src/Syk/NF-κ pathways. Tao et al. [145] demonstrated that *P. hydropiper* extract reduced the levels of MDA (malondialdehyde), MPO (myeloperoxidase), and TNF-α and increased the levels of GSH, reducing the histopathological damage in mice exposed to lipopolysaccharide. *P. hydropiper* L extract improved phosphorylation of AMPKα (AMP-activated Protein Kinase α) that was reduced by lipopolysaccharide and decreased the generation of cytokines associated with inflammation, NO, and ROS protein expression of COX-2 (cyclooxygenase), iNOS (inducible nitric oxide synthase), and phosphorylation of c-JUN (N-terminal kinases), JNK, ERK, and MAPKs (mitogen-activated protein kinase). The anti-inflammatory activity of the *P. hydropiper* L plant may be due to the plant's rich quercetin content. This compound has been found as one of the active ingredients in the methanolic extract, [144]. This compound and its derivatives exhibit potent anti-inflammatory effects by suppressing the expression of pro-inflammatory cytokines through modulation of p38 MAPK and NF-κB. Studies, including those with a novel quercetin derivative, have demonstrated their efficacy in reducing inflammatory markers in mouse models, indicating potential therapeutic benefits in conditions such as atopic dermatitis. Key targets of quercetin include the pro-inflammatory cytokines RAGE (receptor for advanced glycation end products) and HMGB1 (high-mobility group protein 1) and the signaling proteins ERK1/2 and NF-κB, highlighting its role in attenuating inflammatory responses [146].

The ant-inflammatory effect of *P. hydropiper* clearly validates the traditional use of this herb for the treatment of snake bites in Bangladesh, China, India, and other countries. These snakebites are known to cause local and systemic inflammatory responses [147]. *P. hydropiper*'s anti-inflammatory qualities and the problems caused by snakebite present an intriguing opportunity for the creation of complementary and successful treatments.

8.1.3.3. Antimicrobial activity. The antibacterial properties of *P. hydropiper* extracts were examined by Ayaz et al. [148]. Chloroform (Ph.Chf), hexane (Ph.Hex), ethyl acetate (Ph.EtAc), and saponin crude (Ph.Sp) extracts showed the highest activity against *E. faecalis* in the disc diffusion test. Ph.Chf possessed MICs of 32.00 μg/mL against *E. faecalis*, 13.33 μg/mL against *K. pneumoniae*, 10.66 μg/mL against *E. coli*, 5.33 μg/mL against *P. mirabilis*, 64 μg/mL against *S. aureus*, 8.66 μg/mL against *S. typhi*, and 10.66 μg/mL against *P. aeruginosa*. The most powerful antibacterial agents against *T. castaneum* and *R. dominica* were Ph.EtAc, Ph.Sp, Ph.Chf, and Ph.Bt. Notably, Ph.Sp had an LC_{50} (lethal concentration) of less than 0.01 mg/mL and showed the maximum effectiveness against *A. punctatum*. The crude extract was subjected to a GC-MS study, which revealed one hundred twenty-four compounds, many of which were antibacterial, antifungal, and insecticidal substances.

The antifungal ability of *P. hydropiper* leaf extracts was also evaluated by Phatik et al. [149] against harmful pathogens, including *S. sclerotiorum, C. capsici, R. solani, and C. lunata*, known for inflicting major agricultural losses. Compared to an industrial fungicide in *in vitro* tests, *P. hydropiper* extract showed noteworthy efficiency against these infections. At a 2% concentration, *P. hydropiper* extracts generated maximal inhibition zones of 37.33 mm, 36.33 mm, and 30.66 mm against *S. sclerotiorum, C. lunata,* and *R. solani,* respectively. These results demonstrate the potential of this plant extract for controlling certain fungal diseases in agriculture.

The ability of *P. hydropiper* L. to fend off bacteria was investigated by Nasir et al. [137]. They used extracts from the leaves and stems of *P. hydropiper* in different solvents. They discovered that *P. hydropiper* L stem extracts had more potent antimicrobial effects, especially against bacterial strains of the 2 g-positive (*E. coli* and *S. aureus*) and 3 g-negative (*K. pneumoniae*, *M. morganii*, and *H. influenza*).

The disc diffusion technique was used in a study by Hasan et al. [150] to evaluate the antibacterial and antifungal properties of *P. hydropiper* root extract in chloroform. The findings showed substantial antibacterial activity against gram-positive (*B. subtilis*, *B. megaterium, S. aureus,* and *E. aerogenes*) and gram-negative (*E. coli, P. aeruginosa, S. typhi*, and *S. sonnei*) bacteria, with a MIC value varying from 16 μg/mL to 64 μg/mL. In addition, *A. fumigatus, A. niger, A. flavus, C. albicans, R. oryzae*, and *T. rubrum* were all strongly inhibited by the root extract antifungal effects. These results point to the potential uses of *P. hydropiper* root extract for the treatment of various illnesses, including fungal and bacterial infections, in traditional medicine throughout the world.

Other authors have also discussed *P. hydropiper's* antibacterial properties. The subject has been investigated by Duraipandiyan et al. [151], Hasan and Rahman [152], and Haraguchi et al. [141].

8.1.3.4. Neuropharmacological activity. *In vitro*, *in vivo*, and molecular docking investigations were conducted on β-sitosterol, which was isolated from *P. hydropiper*, as a possible anti-alzheimer's drug. Acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) enzymes were significantly inhibited by β-sitosterol in the *in vitro* investigation, with an IC_{50} of 55 and 50 μg/mL, respectively. Significant decreases in enzyme activity found in transgenic rat homogenates served as additional confirmation of these inhibitory effects. *In vitro* and *in vivo* results were confirmed by molecular docking studies, which also verified the binding affinity of β-sitosterol with its intended enzymes. At 31.25 μg/mL, the inhibition percentages for AChE and BChE were 43 and 39.50%, respectively, whereas at 1000 μg/mL, they were 83.5 and 89.16%. Galantamine, a positive control, showed inhibition percentages for AChE and BChE of 51.66 and 42.66% at 31.25 μg/mL and 91.10 and 94.16% at 1000 μg/mL, respectively, with an IC_{50} value of 10 and 8 μg/mL [142].

The previous anti-alzheimer's studies by Ayaz et al. [153] motivated them for further studies against beta amyloid cleaving enzyme 1 (BACE1) and monoamine oxidases (MAO-A) and (MAO-B) enzymes. Before conducting in-depth research on *P. hydropiper* using

immunohistochemistry and animal models, molecular docking studies were conducted to estimate the inhibitory potential of two compounds from *P. hydropiper* extract (β-sitosterol and stigmasterol) against three important enzymes related to several neurological illnesses, including Parkinson's disease (PD), Alzheimer's disease (AD), anxiety, and depression. Utilizing the triangular matching docking technique, both compounds were placed into the active sites of proteins. Following docking, molecular interactions in the anticipated ligand-protein complexes were examined. Comparing these compounds to MAO-A and MAO-B, the docking findings overall demonstrated that they interacted well with the BACE1 active site residues. Furthermore, β-sitosterol demonstrated better BACE1 interaction than stigmasterol.

8.1.3.5. Anticancer and antitumor activity. The study by Ayaz et al. [153] evaluated different solvent extracts from *P. hydropiper* and extracted saponins' cytotoxic, antitumor, and anti-angiogenic activities. Chloroform (Ph.Chf), saponin (Ph.Sp), ethyl acetate (Ph. EtAc), and the crude (Ph.Cr) extracts showed the maximum performance in the anti-angiogenic test, with IC_{50} values of 28.65, 19.21, 88.75, and 461.53 μg/mL, respectively. Ph.Sp was the most effective extract in the antitumor experiment, with IC_{50} values of 18.39 μg/mL. Ph.Chf was the most active extract in the MTT cell viability experiment, causing 79% cytotoxicity at 1000 μg/mL. Overall, Ph. Chf and Ph.Sp showed significant potential as sources of anticancer therapeutics.

Two biologically active compounds, 4-methyl-5-oxo-tetrahydrofuran-3-yl acetate (PH-1) and methyl 4-hydroxy3-methoxybenzoate (PH-2), were separated from the active fractions. The HeLA cell line was the primary compound's greatest cytotoxicity target, with an LD_{50} of 60 μg/mL and 87.50% mortality at 1 mg/mL. Similarly, methyl 4-hydroxy3-methoxy benzoate had an LD_{50} of 160 μg/mL and exhibited 82.33% cytotoxicity against HeLa cells. Additionally, LD_{50} values for PH-1 and PH-2 were 140 and 58 μg/L, respectively, and they were both potent cytotoxic agents against NIH/3T3 (mouse NIH/Swiss embryo) cells with 81.45 and 85.55% cytotoxicity at 1 mg/L concentration. The isolated substances demonstrated strong anti-angiogenic potentials, with IC_{50} values for 4-methyl-5-oxo-tetrahydrofuran-3-yl acetate and methyl 4-hydroxy3-methoxybenzoate of 340 μg/L and 500 μg/L, respectively. The isolated compounds showed 81.15% (PH-1) and 76.09% (PH-2) inhibitions in antitumor assays [154].

The study by Munira et al. [155] examined the effects of *P. hydropiper* leaves on mice with Ehrlich ascites carcinoma and the growth of their tumors. Tumor volume, packed cell volume, and the number of viable tumor cells both declined because of the *P. hydropiper* extract therapy. Additionally, it increased the mice's Ehrlich ascites carcinoma lifetime. The treated extract group's hematological and serum biochemical profiles stabilized at values comparable to those of the Ehrlich ascites carcinoma control group. According to these results, *P. hydropiper* leaves can prevent tumor growth, which may be because they strengthen our bodies' natural antioxidant defenses.

Several other studies have also confirmed the plant's effectiveness in combating tumors and its cytotoxic effects.

8.1.3.6. Antidiabetic activity. *P. hydropiper* L. aerial parts, leaves, and stems were obtained from Bangladesh; they were air-dried, powdered, and ethanol extracts prepared to demonstrate the antidiabetic effectiveness of the species, as described by Oany et al. [156]. In mice that had been given glucose, the injection of the leaf ethanol extract showed a dose-dependent and substantial decrease in blood glucose levels. Blood sugar levels in the tested mice were significantly reduced by 48.8, 51.5, 54.1, and 58.2%, respectively, as the extract dose (50, 100, 200, and 400 mg/kg of body weight), compared to the control group. In contrast, glibenclamide, a common antihyperglycemic drug, lowered blood glucose levels by 42.1% when given at a concentration of 10 mg/kg of body weight. However, in the examined animals, the stem extract only modestly reduced blood sugar levels by 1.5%, which was not considered statistically significant.

Moreover, Nasir et al. [137] confirmed *P. hydropiper* L.'s antidiabetic properties. Their findings showed that *P. hydropiper* has strong α-amylase inhibitory qualities, indicating that it may be a source for upcoming diabetic therapeutics. The leaf extracts were rated according to their capacity to inhibit α-amylase as follows: n-hexane has an IC_{50} of 1.03 mg/mL, followed by chloroform (IC_{50} = 1.53 mg/mL), methanol (IC_{50} = 2.32 mg/mL), acetone (IC_{50} = 4.70 mg/mL), water (IC_{50} = 4.85 mg/mL), and ethanol extract (IC_{50} = 13.89 mg/mL). The stem extracts, in contrast, showed the ordering of α-amylase inhibitory actions as follows: chloroform has an IC_{50} of 2.59 mg/mL, followed by methanol (IC_{50} = 3.52 mg/mL), ethanol (IC_{50} = 5.67 mg/mL), n-hexane (IC_{50} = 6.91 mg/mL), acetone (IC_{50} = 11.86 mg/mL), and finally water (IC_{50} = 13.12 mg/mL).

8.1.3.7. Antiparasitic activity. *P. hydropiper* aerial parts were collected in China, and the extraction was performed with ethanol (90%). Vanicoside F, (+)-ketopinoresinol, isorhamnetin, cardamomin, and pinosylvin all showed action against *T. brucei*, with IC_{50} values ranging from 0.49 to 7.77 μg/mL, using the Alamar blue test [157]. The study by Ayaz et al. [148] revealed the insecticidal properties of *P. hydropiper* saponins against *Tribolium castaneum* and *Rhyzopertha dominica*. Insecticidal compounds such as myristic acid, methyl palmitate, and farnesol were also found in *P. hydropiper* extract using GC-MS analysis. Kong et al. [158] evaluated the insecticide effect of the plant *P. hydropiper*. They demonstrated the insecticidal potential of *P. hydropiper* extracts against various insects, such as *Tetranychus cinnabarinus*, *Pieris rapae Linne*, and *Ectropisobliqua*. Kong et al. [158] suggested that the insecticide effect of this plant can be explained by its content of terpenoids. The significant content of phenolic bioactive compounds and terpenoids gives a reasonable explanation for the plant's traditional potency against mosquitoes and field insects [159].

8.1.3.8. Gastroprotective activity. In the finding of Ayaz et al. [160], *P. hydropiper* leaf oil, saponins, and extracts showed anti-Proteus and urease activity inhibition. In an animal model, the crude extract notably showed significant anti-ulcer and gastroprotective properties. Multiple substances that may oversee the gastroprotective activities of the plant essential oil and extracts were discovered using GC-MS analysis. The study carried out by Ayaz et al. [160] has clearly validated the traditional use of this herb as a

gastroprotective in different populations, such as India, Azerbaijan, Japan, and Nepal, and to treat different gastrointestinal problems (ulcers, abdominal and intestinal pain, stomachache, swelling, and gastroenteritis) [6,8,161].

8.1.4. *Polygonum minus*

8.1.4.1. Antioxidant activity. Herbs and spices such as kesum (*P. minus*), ginger (*Z. officinale*), and turmeric (*C. longa*) were extracted using a juice extractor. The extracts were examined for their total phenolic content (TPC) and antioxidant activity using FRAP and DPPH assays. The *P. minus* extract had the highest TPC and antioxidant potential. Notably, for all plant extracts, there was a significant and positive Pearson's correlation between the TPC and both the FRAP and DPPH assays ($r = 0.91$ and 0.86, respectively) which indicates that phenolic compounds were the main contributors to the antioxidant activity in these plants [162].

The Oxygen Radical Absorbance Capacity (ORAC) assay and the *in vivo* Cellular Antioxidant Protection of Erythrocytes (CAP-e) tests were used in the study by George et al. [163] to test an aqueous extract of *P. minus* for its antioxidant activity. A total ORAC value of 16.96 μmol TE/g was found in the extract, indicating *in vitro* antioxidant activity. Utilizing the CAP-e test, it was shown that cellular antioxidants prevented free radical damage with an IC_{50} of 0.58 g/L.

In their investigation, Hassim et al. [164] used the FRAP test and the DPPH assay to assess the antioxidant potential of *P. minus* extracts (water, methanol, and hexane). They also determined the total polyphenol content using the Folin-Ciocalteu assay. The methanol extract of the leaf part contained the most polyphenols (645.60 GAE/100 g). Additionally, it demonstrated the greatest antioxidant strength for the suppression of FRAP and DPPH radicals.

Using successive extractions with four solvents: hexane, ethyl acetate, methanol, and water, Abdullah et al. [165] examined the antioxidant potential of *P. minus* leaf extracts. TPC, TFC (total flavonoid content), and antioxidant assays (FRAP, ABTS, DPPH, nitric oxide scavenging, FIC, and CAA) were all measured to determine the antioxidant activity of the extracts. The methanol extract exhibited the highest values for TPC (174 mg GAE/g), TFC (53.19 mg GAE/g), FRAP (1728.33 μmol Fe^{2+}/g), ABTS (226.25 μmol TE/g), DPPH (1276.81 μmol TE/g), and nitric oxide scavenging assays (675 μg/mL). The *P. minus* methanol extract suppressed the peroxyl radical-induced oxidation of 2,7-dichlorodihydrofluorescein (DCFH2) to 2,7-dichlorofluorescein (DCF) in the CAA experiment with a dose-dependent inhibition and an EC*50* value of 263.92 μg/mL. The study by Abdullah et al. [165] demonstrated that *P. minus* is a rich source of flavonoids and tannins, including quercitrin, quercetin, hyperoside, astragalin, apigetrin, isoquercetin, and miquelianin. The significant antioxidant activity of *P. minus* methanolic extract may be partially explained by these compounds, which are known to have antioxidant and free radical-scavenging properties, and quercetin-3-*O*-rhamnoside (quercitrin) is one of the major bioactives.

Several other studies have also confirmed the plant's effectiveness in combating antioxidant effects.

8.1.4.2. Antimicrobial activity. In the study of Hassim et al. [164], *P. minus* extracts were tested for their antibacterial abilities against *E. coli, B. subtilis, and S. aureus*. Only the distilled water and methanol extracts have antimicrobial properties. The distilled water extract showed less effective antibacterial activity (inhibition zones ranging from 8 mm to 9 mm), while the methanol extracts from the leaf and the whole plant revealed moderate antibacterial activity (inhibition zones ranging from 10 mm to 14.5 mm) against all tested bacteria. The effect of diverse chemicals found in the various solvent extracts is likely to be responsible for the variation in bacterial inhibition.

The results of Ahmad et al. [166] demonstrated that the n-hexane extract of *P. mins* showed the highest antimicrobial properties against methicillin-resistant *S. aureus* compared to other extracts. Aliphatic decanal and dodecanal compounds [166,167], dodecanol [168], α-pinene [169], limonene [170], β-caryophyllene [171], and hexadecenoic acid [172] are some of the compounds that may be responsible for this antimicrobial property against Methicillin-resistant *S. aureus*.

8.1.4.3. Anti-inflammatory activity. The research of George et al. [173] evaluated the anti-inflammatory effect of *P. minus*. Significant 5-lipoxygenase (5-LOX) and COX-1 activity inhibition was seen in the ethanolic extract of *P. minus*, with particularly strong 5-LOX inhibition seen at 30 μg/mL. However, it had only a mild inhibitory impact on COX-2, and it had no effect on secretory phospholipase A2 (sPLA2) activity. The inhibitory effect of the aqueous extract was assessed using a rat model in which the injection of carrageenan caused inflammation in the paws. In the experimental model, paw edema caused by carrageenan was considerably decreased by the aqueous extracts from *P. minus* provided at dosages of 100 and 300 mg/kg b.w. at 4 h when compared to the control. In addition, 100 or 300 mg/kg of b.w. given 4 h after the injection absolutely decreased paw inflammation.

Christapher et al. [174] additionally investigated the anti-inflammatory properties of aqueous and methanol extracts from *P. minus* using rat models of carrageenan-induced paw edema. Only the aqueous extract demonstrated anti-inflammatory activity in the acute model, and this impact was equivalent to that of a typical drug. The chemical analysis of *P. minus*

has shown the presence of flavonoids, and the anti-inflammatory effect of this plant could be due to these flavonoids. These flavonoids include quercetin, isoquercitrin, and hyperoside [175,176].

8.1.4.4. Neuropharmacological activity. The chronic unpredictable stress (CUS) zebrafish model was used to evaluate the antidepressant effects of *P. minus* standardized extract at doses of 1 mg/L and 100 mg/L using four separate behavioral tests: the exploratory, the open field, the social interaction, and the light and dark tests. A whole-body cortisol analysis was done following four days of therapy. The extract showed an ameliorating impact at both doses, although this effect was more pronounced in the exploratory test. This improvement is thought to be a result of the plant's anti-inflammatory effects. The exploratory test revealed a significant

difference after *P. minus* therapy. Although the difference was not statistically significant, cortisol analysis revealed a reduction in levels after treatment with the extract and fluoxetine [177].

The primary objective of Bashir et al. [178] study was to assess the effects of the aqueous extract of *P. minus* on a mouse model of depression brought on by chronic ultra-mild stress (CUMS). The results suggest that *P. minus* aqueous extract has antidepressant properties, including an improvement in spatial memory, a reduction in immobility time, an increase in brain-derived neurotrophic factor (BDNF), a decrease in corticosterone levels, and a reduction in MAO-A enzyme levels along with an increase in norepinephrine and serotonin levels, in the hippocampus.

The neuroprotective abilities of *P. minus* ethanolic extract (PMEE) in protecting SH-SY5Y cells from H_2O_2-induced neurotoxicity are examined in the study by Sayuti et al. [179]. Their research showed that PMEE has neuroprotective properties against H_2O_2-induced oxidative damage. In differentiated SH-SY5Y cells (human neuroblastoma cells) administered with PMEE, important signaling pathways such as Nrf2/ARE (nuclear erythroid 2-related factor 2/antioxidant response element), NF-κB/IκB, and MAPK were activated in order to produce the neuroprotective effect. To evaluate the identified compounds from *P. minus* ethanolic extract binding affinity to AChE enzyme residues, molecular docking research was carried out. The results demonstrated that quercetin had the highest docking score compared to the other chemicals.

The neuropharmacological effect of the plant *P. minus* was confirmed by Bashir et al. [180]. The principal objective of the study was to assess the way *P. minus* extract affected chronic ultra-mild stress-induced anhedonia and anorexia. The results indicated that *P. minus* aqueous extract significantly reduced chronic ultra-mild stress-induced anhedonia and anorexia at its highest doses (100 and 200 mg).

8.1.4.5. Anticancer and antitumor activity. A new molecule named polygonumin A was discovered by Ahmad et al. [166] in the stem of *P. minus*. A cell viability experiment using MTT evaluated its cytotoxicity against different cancer cell lines. Interestingly, the treatment with the compound extracted from *P. minus* showed the strongest antiproliferative effects against the human leukemia cell line K562, the human breast adenocarcinoma cell line MCF7, and the colon cancer cell line HCT116. According to Abdullah et al. [165] research, *P. minus* extracts in hexane and ethyl acetate selectively inhibited the HCT116 cell line with IC_{50}s of 40.00 μg/mL and 43.18 μg/mL, respectively.

Several other studies have also confirmed the plant's effectiveness in combating antitumor effects.

8.1.4.6. Hepatoprotective effect. According to Abd Rashid et al. [181], cisplatin increased pro-inflammatory cytokine levels in the hepatic tissues (TNF-α, IL-1β, IL-1α, and IL-6) despite reducing levels of the anti-inflammatory cytokine IL-10. However, the liver inflammation brought on by cisplatin was successfully reduced when *P. minus* essential oil was administered at a dose of 100 mg/kg, which also reduced the levels of IL-6, IL-1α, IL-1β, and TNF-α while raising the level of IL-10. Sesquiterpenes, which can inhibit complement activation and decrease inflammatory cell adhering to endothelial cells, may be responsible for the capacity to diminish this inflammatory response in *P. minus* essential oil.

8.1.4.7. Gastroprotective effect. According to a study by Qader et al. [182], the methanol: ethyl acetate fraction (1:1) had a high gastroprotective effect against oxidative stress caused by an ethanol induction model. The high phenolic content of the extract from *P. minus*, especially *p*-coumaric acid and gallic acid, which support mucus barrier function, antioxidant activity, and the maintenance of SOD and prostaglandin E2 (PGE2) levels, is crucial for the extract's efficacy. *P. minus*'s main active constituents may be its high phenolic component content, including gallic and *p*-coumaric acids, which have demonstrated potential benefits in preventing stomach ulcers [182].

8.2. Example of Polygonum species with limited biological activities

Within the *Polygonum* genus, certain species, such as *P. amphibium, P. equisetiforme, P. jucundum, P. odoratum,* and *P. capitatum*, have received limited attention from researchers. In this section, we will highlight a few examples of these less-studied plants to encourage further research.

8.2.1. Polygonum equisetiforme

8.2.1.1. Antioxidant activity. The antioxidant capabilities of eleven different *P. equisetiforme* populations, which were collected from various bioclimatic zones in Tunisia, are discussed by Mahmoudi et al. [15]. The total phenolic content, flavonoid content, and condensed tannins of the plants varied between the different populations. Strong antioxidant activity was shown between the eleven populations, with significant variations in reducing power (ranging between 68 μg/mL and 210 μg/mL) and DPPH scavenging activity (ranging from 12 mM TRE/g dw to 51 mM TRE/g dw). The highest levels of phytochemical and antioxidant activity were found in plants from the Saharan region [15]. Some of the compounds that may be responsible for this antioxidant property are quinic acid [183], gallic acid [184], protocatechuic acid [185], 4-*O*-caffeoylquinic acid [186], *trans*-ferulic acid [187], catechin [188], and quercetin [189].

Mahmoudi et al. [46] also conducted research that demonstrated the antioxidant capability of *P. equisetiforme* seed methanolic extracts using two different techniques: the DPPH assay to quantify free radical scavenging activity and the phosphomolybdenum method to estimate total antioxidant capacity. The results indicated that the seed extracts had significant antioxidant activity. The mean TAC value was 30.57 mg GAE/g DW, with a range of 21.17–46.02 mg GAE/g DW. All seed extracts also showed strong free

radical scavenging capacities, with average values of 19.82 mM TRE/g DW and values ranging from 14.33 to 35.37 mM TRE/g DW.

The studies of El-Toumy et al. [190] and Elgudayem et al. [192] also confirmed the antioxidant activity of the plant *P. equisetiforme.* The antioxidant properties of the plant *P. equisetiforme* may explain why this plant has long been used to treat heal wounds. The antioxidant compounds found in the plant may be particularly important in lowering oxidative damage and creating an atmosphere that is favorable for tissue repair and regeneration [193].

8.2.1.2. Hepatoprotective effect. The finding by El-Toumy et al. [194] showed that the methanolic extract of *P. equisetiforme* aerial parts was tested for its ability to protect Sprague-Dawley rats' livers from damage brought on by carbon tetrachloride (CCl4). By examining hepatic marker enzymes like aspartate aminotransferase (AST) and alanine aminotransferase (ALT), as well as oxidative stress markers like MDA, NO, glutathione peroxidase (GPx), glutathione (GSH), and superoxide dismutase (SOD), the extract's hepatoprotective effects were determined. The findings showed that administering the extract at doses of 100 and 200 mg/kg considerably decreased blood levels of AST and ALT and successfully suppressed oxidative stress indicators, including MDA and NO. The quantities of antioxidant enzymes, including GSH, GPx, and SOD, were also increased. Histopathological analysis of the liver tissue confirmed these biochemical results. Syringic acid may be the source of *P. equisetiforme* hepatoprotective activity by suppressing oxidative damage, particularly liver fibrosis produced by repeated CCl4 injections [195].

8.2.2. Polygonum odoratum

8.2.2.1. Antioxidant activity. The analysis of the ethanolic extract of *P. odoratum* Lour., collected from India, was the primary objective of the study conducted by Ahongshangbam et al. [42]. The findings showed that there was a significant amount of bioactive chemicals in the plant extract. According to the analysis, the TPC was 13.03 mg GAE/g of DW, showing a considerable number of phenolic compounds. Furthermore, the flavonoid content was found to be 4.92 mg/g of DW. The researchers used the DPPH test to evaluate the extract's antioxidant activity. The IC_{50} was calculated to be 190.19 μg/mL. The main bioactive substances found in the plant extract, according to the analysis, were gallic acid, ferulic acid, apigenin, ellagic acid, quercetin, and *p*-coumaric acid, and they may be responsible for the extract's antioxidant activity.

The methanol extracts from the leaves and stem of *P. odoratum* showed a high level of antioxidant potential that might be due to the important levels of polyphenols [196].

8.2.2.2. Anti-inflammatory activity. The study by Chansiw et al. [196] showed that the most effective anti-inflammatory effect was the dichloromethane extract from *P. odoratum* leaves, which inhibited nitric oxide synthesis in a concentration-dependent manner (IC_{50} = 53.75 μg/mL). Okonogi et al. [197] evaluated *P. odoratum*'s potential as an anti-inflammatory. The key fractions responsible for this activity were also isolated and characterized as part of the investigation. As part of the research, extracts from *P. odoratum*'s aerial parts were tested for their ability to reduce inflammation. Specifically, their effects on the release of cytokines by lipopolysaccharide-stimulated macrophages were studied. Following the extraction procedure and component separation using HPLC, the anti-inflammatory potential of the various fractions was evaluated. The findings showed that *P. odoratum*'s ethanolic extract significantly reduced IL-6 production, with an IC_{50} of 25 μg/mL, demonstrating substantial anti-inflammatory activity. The synthesis of IL-6 was significantly decreased by two important fractions, identified as fractions 5 and 7, with IC_{50} values of 102 and 77 μM, respectively. These two fractions were identified as quercitrin (fraction 7) and scutellarein-7-glucoside (fraction 5).

8.2.3. Polygonum amphibium

8.2.3.1. Anticancer and antitumor activity. Three new flavonoid glucuronides were extracted and identified from the plant *P. amphibium* L. in a study by Smolarz et al. [198].The two compounds quercetin-3-*O*-rhamnosyl-(1, 2)-glucuronide and quercetin-3-*O*-glucuronide were studied to better understand the possible biological effects of these flavonoids on human leukemia cells. The findings suggest that these quercetin glucuronides may induce apoptosis in the examined human leukemia cells. The studies showed that these substances could enter the cellular nucleus through the cytoplasm of cultivated cells. They significantly increased the number of apoptotic reactions in the activated leukemia cells once they were within the nucleus. The amount of apoptosis that was seen was associated with the chemical concentration and exposure time.

8.2.4. Polygonum jucundum

8.2.4.1. Anti-inflammatory activity. Using a variety of inflammatory models, Zhang et al. [199] examined the effects of the *P. juncundum* ethyl acetate extract at dosages of 200 and 500 mg/kg. The results showed that the plant extract had dose-dependent anti-inflammatory effects in mice, especially in the models of vascular permeability caused by xylene-induced and acetic acid-induced edema. Crucially, even at a high dosage of 3000 mg/kg, the extract did not show signs of acute toxicity. Moreover, the ethyl acetate extract was shown to be active in decreasing the release of inflammatory cytokines, including IL-6 and TNF-α, in lipopolysaccharide (LPS)-activated RAW264.7 cells.

9. Toxicity

Compared to other extracts (H_2O, EtOH 30%, EtOH 50%, EtOH 95%, MeOH, and acetone), the toxicity of the 70% EtOH extract from *P. multiflorum* is significantly higher. Second, a gradient of water and EtOH (95% EtOH, 40% EtOH, 25% EtOH, and H_2O) was used to elute the 70% EtOH extract using macroporous resin to provide four components (A–D). Component D's toxicity was found to be higher than that of components A through C. As a result, component D received more study focus. Zebrafish embryos were used to identify and evaluate twenty-seven substances that were identified in the chemical components of compound D. These compounds included seven anthraquinones from 1 to 7, eight stilbenes from 8 to 15, seven anthrones from 16 to 22, three cinnamic acid amides from 23, 24, and 25, and two naphthols from 26 to 27. Compounds 1 through 3 (Emodin, Rhein, Physcion), 16 through 22 ((Cis)-emodin-emodin dianthrones, (Trans)-emodin-emodin dianthrones, Polygonumnolide C1, C2, C3, and C4), 1,3,8-Trihydroxy-6-methyl-10H-anthracen-9-one), and 26 through 27 (Torachrysone-8-*O*-β-D-glucopyranoside and Torachrysone-8-*O*-(6′-*O*-acetyl)-β-D-glucopyransoide) demonstrated significant toxicity against the zebrafish embryos. Other compounds, like stilbenes, did not exhibit any obvious toxicity [200].

The findings of the investigation by Lv et al. [201] demonstrated that the ethanolic extract of *P. multiflorum* was damaging to LO2 cells in a human hepatocyte at 1 mg/mL and that this toxic effect increased with greater doses. The water and solvent extracts, on the other hand, had no harmful effects. Furthermore, MTT test findings demonstrated that ethanol extracts at concentrations of 100–400 μg/mL substantially ignored LO2 cell growth at both 12 and 24 h. Additionally, when treated with 200–400 μg/mL ethanol extract for 24 h, the cell viability of LO2 cells decreased below 50%. Water extract, on the other hand, showed no hepatotoxicity when administered at a concentration of 800 μg/mL for 24 h. Water extracts at concentrations of 100–200 μg/mL was shown to enhance the growth of LO2 cells. The finding demonstrated that emodin, physcion, emodin-8-*O*–D-glucopyranoside, and physcion-8-*O*–D-glucopyranoside were all shown to be almost hepatotoxic.

To determine the safety of methanol extract from *P. minus* leaves in Sprague-Dawley rats, acute and subchronic toxicity experiments were performed. In animals examined up to 2000 mg/kg, general symptoms and behavior were determined to be normal. Similarly, there was no change in the biochemistry and blood parameter values of the control animals, or the extract treated in the 28-day repeated dosage subchronic toxicity trial. Based on these results, the methanol extract is judged safe in Sprague-Dawley rats at doses up to 2000 mg/kg [202].

The acude toxicity of *P. equisetiforme* methanolic extract was terminated by El-Toumy et al. [190]. The rats received oral doses of *P. equisetiforme* extract at 100, 200 and 1000 mg/kg b.wt. All rats were tested for mortality throughout a 24-72-h period. After 24 h, just one dead animal was seen at a dosage of 1000 mg/kg b.wt.

10. Phytopharmaceutical Formulations

Research on formulations, especially galenic formulations, seems to be quite limited in the context of *Polygonum* species. There are just six papers that particularly cover this topic, according to the literature (Fig. 7).

According to the study by Haris et al. [203] herbal cream prepared from the aqueous extract of *P. minus* has promising anti-aging activity. The results showed that *P. minus* cream extract has beneficial anti-wrinkle qualities for cosmetic use. These qualities were seen by the research participants following two months of daily usage, in addition to being confirmed by objective evaluations such as the

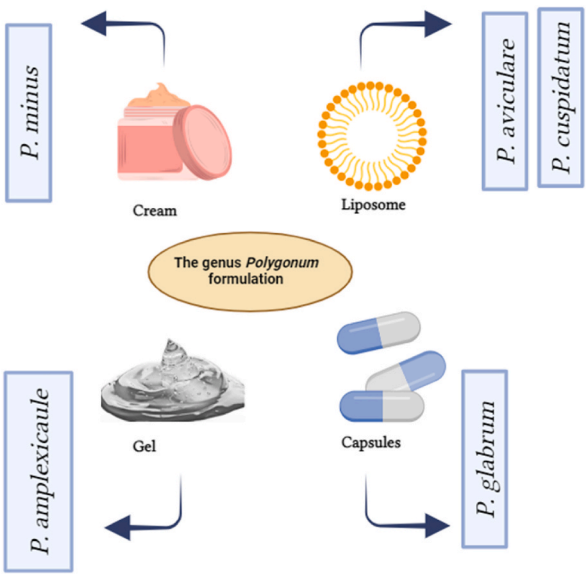

Fig. 7. Different galenic formulation from *Polygonum* species.

examination of silicone replicas. These findings highlight the fact that *P. minus* plant extract has a significant clinical anti-wrinkle impact, significantly reducing the appearance of crow's feet wrinkles, thanks to its antioxidant properties.

The anti-arthritic capsule formulation of *P. glabrum, C. dicoccum, O. obtusata*, and *A. nervosa* (2:1:1:1) was evaluated by Satyanarayana et al. [204]. Results showed that the polyherbal extract formulations decreased joint and paw edema; after 15 days, the paw varied from 25.7 to 4.85 and significantly improved body weight, hematological profile, and parameters in the full Freund's adjuvant-induced arthritis model.

The aim of the study by Ref. [205] was to create an herbal gel with *P. amplexicaule* methanol extract and assess its various physical characteristics, antityrosinase activity, and antioxidant capacity. Using chitosan gel base as the gelling agent, several gel formulations were created by varying the extract and polymer concentrations. A stable gel formulation with acceptable homogeneity, appearance, easy spreadability, and outstanding extrudability was created using a 5% plant extract and 1% chitosan gel basis. The tyrosinase inhibition assay and the DPPH free radical scavenging assay were used to assess the skin-whitening. This herbal gel formulation has a strong potential for usage in cosmetics, as evidenced by the DPPH scavenging activity (IC_{50} = 0.45 mg/mL) and tyrosinase inhibitory activity (IC_{50} = 0.80 mg/mL).

Liposomes are thought to be a promising and adaptable kind of drug vehicle. Liposomes have greater qualities than standard drug delivery methods, such as site-specificity, regulated or prolonged release, protecting medications from clearance and degradation, better therapeutic benefits, and fewer harmful side effects. Over the past few decades, a number of liposomal medicinal items have been licensed and effectively utilized in clinics due to their benefits [206]. The purpose of the study by Mureşan et al. [207] is to assess how the liposome made of *P. aviculare* extract and quercetin affects the doxorubicin-induced toxicity in human umbilical vein endothelial cells (HUVECs). Less so than quercetin and the liposomes containing quercetin, the *P. aviculare* extract and liposomes loaded with it showed antioxidant and anti-inflammatory properties, reduced the DNA lesions, and prevented the activation of transcription factors. and extrinsic apoptosis.

Kwon et al. [208] showed that cell-penetrating peptide-conjugated liposomes containing the plant extract work well for transdermal administration of anti-aging and antioxidant drugs. As shown in Table 4, the *P. aviculare* extract was incorporated into both liposomes with an approximate 83% efficiency. The conjugated liposomes had a greater level of skin penetration than ordinary liposomes. Furthermore, *in vivo* research showed that CPP-conjugated liposomes outperformed conventional liposomes in anti-wrinkle and depigmentation investigations.

11. Conclusions

Plants of the *Polygonum* genus have been used for medicinal purposes by people from different countries for many centuries. Several diseases have been treated using *Polygonum*, such as hypertension, kidney stones, intestinal and stomach pain, dysuria, jaundice, toothaches, skin allergies, hemorrhoids, cardiac problems, hemostasis, hyperglycemia, and others. These uses in traditional medicine make the genus interesting for its phytochemical composition. The results of various studies have shown that the *Polygonum* genus possesses various compounds from different families, including phenolic acids, flavonoids, tannins, stilbenes, fatty acids, polysaccharides, and others. The chemical composition of the genus *Polygonum* is responsible for its numerous biological activities, including antioxidant, antimicrobial, anticancer, antitumor, anti-inflammatory, antidiabetic, antiparasitic, hepatoprotective, neuropharmacological, and gastroprotective. Of the 300 recognized species in the *Polygonum* genus, only a few have been the subject of detailed reports on their phytochemistry and biological activity, while several other species in the *Polygonum* genus remain unexplored. Research on previously unstudied species, which belong to the genus *Polygonum*, offers promise for the isolation of biologically active molecules with greater pharmacological activity and possible leads, indicating a viable path toward the development of novel medications with a wide range of effects. Documented toxicological studies of the *Polygonum* species are also addressed in this paper. The results showed that the tested extract was safe to use in a range of *in vitro* and *in vivo* studies; however, as the safety of many plants in the genus *Polygonum* has not been evaluated, further research on the subject may be necessary. In addition to the phytocomposition, biological activities, and toxicity of the *Polygonum* genus, the application in the galenic industry, or the phytopharmaceutical application of the species belonging to this genus, was evaluated. It was found that, despite the large number of species characterized by the presence of several active molecules and possessing various biological activities, their application in the galenic industry is not very well evaluated.

Data availability statement

No data was used for the research described in the article.

CRediT authorship contribution statement

Sourour Idoudi: Writing – original draft, Investigation. **Audrey Tourrette:** Validation, Supervision. **Jalloul Bouajila:** Writing – review & editing, Data curation, Conceptualization. **Mehrez Romdhane:** Validation, Resources. **Walid Elfalleh:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

Table 4
Different galenic formulation from *Polygonum* species.

Plant	Organ	Extract	Formulation	Results	Reference
P. minus	Leaves	H_2O	Anti-ageing cream	- A notable decrease in the "number of wrinkles" (−17.6% and −20.1%, after one and two months, respectively). - An important decrease in "total length of wrinkles" (−15.9% and −25.7% respectively after one and two months). - A substantial decrease in "mean length of wrinkles" (−8.6%, $p < 0.05$) after two months.	[203]
P. amplexicaule	Rhizome	MeOH	Antityrosinase and antioxidant gel	- $IC_{50} = 0.45$ mg/mL for the DPPH scavenging activity - $IC_{50} = 0.80$ mg/mL for the tyrosinase inhibition activity.	[205]
P. glabrum,	–	EtOH	Anti-arthritic capsule	- The ethanolic extract of a polyherbal mixture including various quantities of *P. glabrum, C. dicoccum, O. obtusata*, and *A. nervosa* (2:1:1:1) in a capsule has demonstrated strong *in vivo* antiarthritis action.	[204]
P. aviculare	–	EtOH (70%)	Liposomes	- The purpose of the study is to assess how the liposome made of plant extract and quercetin affects the doxorubicin-induced toxicity in HUVECs. Less so than quercetin and the liposomes containing quercetin, the *P. aviculare* extract and liposomes loaded with it showed antioxidant and anti-inflammatory properties, reduced the DNA lesions, and prevented the activation of transcription factors. and extrinsic apoptosis.	[207]
	–	EtOH (50%)	Liposomes linked with a cell-penetrating peptide.	- CPP-conjugated liposomes had a zeta potential of +42 mV, compared to the normal liposomes (−45 mV). - It was determined that the *P. aviculare* extract incorporated into both liposomes with an approximate 83% efficiency. - CPP-conjugated liposomes, as opposed to regular liposomes, enhanced cellular absorption of the fluorescent dye. - conjugated liposomes had a greater level of skin penetration than ordinary liposomes. - The *in vivo* research showed that CPP-conjugated liposomes outperformed conventional liposomes in anti-wrinkle and depigmentation investigations.	[208]
P. cuspidatum	Root	EtOH (80%)	*P. cuspidatum Solid Dispersions*	- Dissolution test: results show a significant increase in resveratrol solubility when employing *P. cuspidatum* Solid Dispersions, from 46.75% to 130.06%. - The AUC0-t of RES significantly increased, going from 111,471.22% to 160,458.968%. - PCE-SD screw rotation speed is lower than RES-SD screw rotation speed. - PCE-SD has a slightly higher bioavailability than RES-SD. - RES-SD is less hygroscopic, than PCE-SD. - PCE-SD improved RES's oral bioavailability and solubility.	[246]

AUC0-t: the extrapolated area under the concentration-time curve; CPP: cell-penetrating peptide; EtOH: ethanol; HUVECs: human umbilical vein endothelial cells; H_2O: water; IC50: half-maximal inhibitory concentration; MeOH: methanol; RES: resveratrol; SD: solid dispersion.

influence the work reported in this paper. Walid Elfalleh is currently serving as associate editor in Heliyon Food Science and Nutrition.

Appendix ASupplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28947.

References

[1] X. Dong, J. Fu, X. Yin, X. Li, B. Wang, S. Cao, J. Zhang, H. Zhang, Y. Zhao, J. Ni, Pharmacological and other bioactivities of the genus polygonum-A review, Trop. J. Pharmaceut. Res. 13 (2014).
[2] M. Bnouham, A. Legssyer, H. Mekhfi, A. Ziyyat, Medicinal plants used in the treatment of diabetes in Morocco, Dubai Diabetes Endocrinol J. 10 (2002) 33–50.
[3] B. Ballabh, O.P. Chaurasia, Z. Ahmed, S.B. Singh, Traditional medicinal plants of cold desert Ladakh—used against kidney and urinary disorders, J. Ethnopharmacol. 118 (2008) 331–339.
[4] J.M. Neves, C. Matos, C. Moutinho, G. Queiroz, L.R. Gomes, Ethnopharmacological notes about ancient uses of medicinal plants in Trás-os-Montes (northern of Portugal), J. Ethnopharmacol. 124 (2009) 270–283.
[5] R.K. Choudhary, S. Oh, J. Lee, An ethnomedicinal inventory of knotweeds of Indian Himalaya, J. Med. Plants Res. 5 (2011) 2095–2103.
[6] S. Gairola, J. Sharma, Y.S. Bedi, A cross-cultural analysis of Jammu, Kashmir and Ladakh (India) medicinal plant use, J. Ethnopharmacol. 155 (2014) 925–986.
[7] S.S. Ningthoujam, A. Das Talukdar, K.S. Potsangbam, M.D. Choudhury, Traditional uses of herbal vapour therapy in Manipur, North East India: an ethnobotanical survey, J. Ethnopharmacol. 147 (2013) 136–147.
[8] M. Ayaz, I. Ahmad, A. Sadiq, F. Ullah, M. Ovais, A.T. Khalil, H.P. Devkota, Persicaria hydropiper (L.) Delarbre: a review on traditional uses, bioactive chemical constituents and pharmacological and toxicological activities, J. Ethnopharmacol. 251 (2020) 112516.

[9] U. Farooq, S. Naz, A. Shams, Y. Raza, A. Ahmed, U. Rashid, A. Sadiq, Isolation of dihydrobenzofuran derivatives from ethnomedicinal species Polygonum barbatum as anticancer compounds, Biol. Res. 52 (2019) 1–12.
[10] B. Gürdal, Ş. Kültür, An ethnobotanical study of medicinal plants in Marmaris (Muğla, Turkey), J. Ethnopharmacol. 146 (2013) 113–126.
[11] R. Cecotti, E. Carpana, L. Falchero, R. Paoletti, A. Tava, Determination of the volatile fraction of Polygonum bistorta L. at different growing stages and evaluation of its antimicrobial activity against two major honeybee (Apis mellifera) pathogens, Chem. Biodivers. 9 (2012) 359–369.
[12] Y. Yang, Q. Hong, B. Zhu, Z. Zhou, J. Yang, Polygonum capitatum Buch.-Ham. ex D. Don: a review of its phytochemistry, Food Sci. Technol. 42 (2022).
[13] U. Cakilcioglu, I. Turkoglu, An ethnobotanical survey of medicinal plants in Sivrice (Elazığ-Turkey), J. Ethnopharmacol. 132 (2010) 165–175.
[14] I.K. Khafagi, A. Dewedar, The efficiency of random versus ethno-directed research in the evaluation of Sinai medicinal plants for bioactive compounds, J. Ethnopharmacol. 71 (2000) 365–376.
[15] M. Mahmoudi, F. Boughalleb, M. Mabrouk, N. Tlili, D. Potter, R. Abdellaoui, N. Nasri, Chemical analysis of the antioxidants from the aerial parts of wild Polygonum equisetiforme from Tunisia, Food Biosci. 29 (2019) 24–29.
[16] P.R. Dash, M.H. Sohrab, M.S. Rana, Polygonum flaccidum (polygonaceae): a review, Int. J. Libr. Sci. Res. 2 (2016) 109–113.
[17] D.N.S. Gautam, Ethnopharmacology, phytochemistry, and pharmacology of Polygonum glabrum Willd, Int. J. Green Pharm. 11 (2017).
[18] S. Henamayee, K. Banik, B.L. Sailo, B. Shabnam, C. Harsha, S. Srilakshmi, N. Vgm, S.H. Baek, K.S. Ahn, A.B. Kunnumakkara, Therapeutic emergence of rhein as a potential anticancer drug: a review of its molecular targets and anticancer properties, Molecules 25 (2020) 2278.
[19] J. Yang, H. Sun, J. Ma, Y. Song, Y. Liu, Q. Wang, S. Ma, X. Cheng, F. Wei, New phenolic constituents obtained from Polygonum multiflorum, Chinese Herbal Medicines 12 (2020) 342–346.
[20] Y.-Z. Zhang, J.-F. Shen, J.-Y. Xu, J.-H. Xiao, J.-L. Wang, Inhibitory effects of 2, 3, 5, 4′-tetrahydroxystilbene-2-O-β-D-glucoside on experimental inflammation and cyclooxygenase 2 activity, J. Asian Nat. Prod. Res. 9 (2007) 355–363.
[21] V. Nigam, Antihyperglycaemic activity on flower of Polygonum orientale Linn. using steptozotocin induced diabetic mice model, Int. J. Pharm. Teach. Pract. 4 (2013) 1–7.
[22] K.N. Singh, Traditional knowledge on ethnobotanical uses of plant biodiversity: a detailed study from the Indian western Himalaya, Biodivers. Res. Conserv. 28 (2013) 63–77.
[23] A.N. Hasan, P. Roy, N.J. Bristy, S.K. Paul, T.B. Wahed, M.N. Alam, Evaluation of in vitro antioxidant and brine shrimp lethality bioassay of different extracts of Polygonum plebeium R. Br, Int. J. 3 (2015) 97–107.
[24] F. Moradi-Afrapoli, B. Asghari, S. Saeidnia, Y. Ajani, M. Mirjani, M. Malmir, R. Dolatabadi Bazaz, A. Hadjiakhoondi, P. Salehi, M. Hamburger, In vitro α-glucosidase inhibitory activity of phenolic constituents from aerial parts of Polygonum hyrcanicum, Daru 20 (2012) 1–6.
[25] S. Cherian, K.M. Hacisayidli, R. Kurian, A. Mathews, Therapeutically important bioactive compounds of the genus Polygonum L. and their possible interventions in clinical medicine, J. Pharm. Pharmacol. 75 (2023) 301–327.
[26] G.E.-S. Batiha, A.M. Beshbishy, M. Ikram, Z.S. Mulla, M.E.A. El-Hack, A.E. Taha, A.M. Algammal, Y.H.A. Elewa, The pharmacological activity, biochemical properties, and pharmacokinetics of the major natural polyphenolic flavonoid: quercetin, Foods 9 (2020) 374.
[27] K. Fidyt, A. Fiedorowicz, L. Strządała, A. Szumny, β-caryophyllene and β-caryophyllene oxide—natural compounds of anticancer and analgesic properties, Cancer Med. 5 (2016) 3007–3017.
[28] A. Demirpolat, Chemical composition of essential oils of seven polygonum species from Turkey: a chemotaxonomic approach, Molecules 27 (2022) 9053.
[29] G. Narasimhulu, K.K. Reddy, J. Mohamed, The genus polygonum (Polygonaceae): an ethnopharmacological and phytochemical perspectives-review, J. Pharm. Pharmaceut. Sci. 6 (2014) 21–45.
[30] M. Watanabe, H.P. Devkota, K. Sugimura, T. Watanabe, A Guidebook of Medicinal Plant Park, School of Pharmacy, Kumamoto University, Kumamoto, 2018.
[31] H. Hamrouni, S. Idoudi, M. Romdhane, W. Elfalleh, Ethnobotanical study of medicinal plants used in southern Tunisia, Euro-Mediterranean Journal for Environmental Integration (2023) 1–15.
[32] O.R. Alara, N.H. Abdurahman, C.I. Ukaegbu, Extraction of phenolic compounds: a review, Curr. Res. Food Sci. 4 (2021) 200–214.
[33] R. Bahramsoltani, M. Kalkhorani, S.M.A. Zaidi, M.H. Farzaei, R. Rahimi, The genus Tamarix: traditional uses, phytochemistry, and pharmacology, J. Ethnopharmacol. 246 (2020) 112245.
[34] F. Çayan, E. Deveci, G. Tel-Çayan, M.E. Duru, Identification and quantification of phenolic acid compounds of twenty-six mushrooms by HPLC–DAD, J. Food Meas. Char. 14 (2020) 1690–1698.
[35] S.M. Pal, G. Avneet, S.S. Siddhraj, Gallic acid: pharmacogical promising lead molecule: a review, Int. J. Pharmacogn. Phytochem. Res 10 (2018) 132–138.
[36] G. Nikolaeva, M. Lavrent'Eva, I. Nikolaeva, Phenolic compounds from several Polygonum species, Chem. Nat. Compd. 45 (2009) 735–736.
[37] Y. Cai, L. Wu, X. Lin, X. Hu, L. Wang, Phenolic profiles and screening of potential α-glucosidase inhibitors from Polygonum aviculare L. leaves using ultra-filtration combined with HPLC-ESI-qTOF-MS/MS and molecular docking analysis, Ind. Crop. Prod. 154 (2020) 112673.
[38] S. Demiray, M.E. Pintado, P.M.L. Castro, Evaluation of phenolic profiles and antioxidant activities of Turkish medicinal plants: tiliaargentea, Crataegi folium leaves and Polygonum bistorta roots, International Journal of Pharmacological and Pharmaceutical Sciences 3 (2009) 74–79.
[39] A. Intisar, L. Zhang, H. Luo, J.B. Kiazolu, R. Zhang, W. Zhang, Anticancer constituents and cytotoxic activity of methanol-water extract of Polygonum bistorta L., African Journal of Traditional, Complementary and Alternative Medicines 10 (2013) 53–59.
[40] S.-T. Wang, W. Gao, Y.-X. Fan, X.-G. Liu, K. Liu, Y. Du, L.-L. Wang, H.-J. Li, P. Li, H. Yang, Phenol profiles and antioxidant capacities of Bistort Rhizoma (Polygonum bistorta L.) extracts, RSC Adv. 6 (2016) 27320–27328.
[41] Y. Wu, Z. Zhang, T. Chen, C. Cheng, Z. Zhang, H. Zhou, P. Luo, Comparison of two Polygonum chinense varieties used in Chinese cool tea in terms of chemical profiles and antioxidant/anti-inflammatory activities, Food Chem. 310 (2020) 125840.
[42] S.K. Ahongshangbam, S. Guruaribam, S. Chattopadhhyay, Bioactive compounds and antioxidant activity of Polygonum odoratum Lour, Int. J. Basic Appl. Biol 2 (2014) 94–97.
[43] M. Naveed, V. Hejazi, M. Abbas, A.A. Kamboh, G.J. Khan, M. Shumzaid, F. Ahmad, D. Babazadeh, X. FangFang, F. Modarresi-Ghazani, Chlorogenic acid (CGA): a pharmacological review and call for further research, Biomed. Pharmacother. 97 (2018) 67–74.
[44] M. Mahmoudi, R. Abdellaoui, E. Feki, F. Boughalleb, S. Zaidi, N. Nasri, Analysis of polygonum aviculare and polygonum maritimum for minerals by flame atomic absorption spectrometry (FAAS), polyphenolics by high-performance liquid chromatography-electrospray ionization–mass spectrometry (HPLC-ESI-MS), and antioxidant propertie, Anal. Lett. 54 (2021) 2940–2955.
[45] S. Liao, Y. Li, L. Zhang, Z. Wang, T. Chen, Y. Huang, J. Li, A. Wang, Y. Li, Y. Lan, UPLC–PDA–ESI–MS/MS analysis of compounds extracted by cardiac h9c2 cell from Polygonum orientale, Phytochem. Anal. 24 (2013) 25–35.
[46] M. Mahmoudi, F. Boughalleb, T. Bouhamda, R. Abdellaoui, N. Nasri, Unexploited Polygonum equisetiforme seeds: potential source of useful natural bioactive products, Ind. Crop. Prod. 122 (2018) 349–357.
[47] M. Thiruvengadam, N. Praveen, E.-H. Kim, S.-H. Kim, I.-M. Chung, Production of anthraquinones, phenolic compounds and biological activities from hairy root cultures of Polygonum multiflorum Thunb, Protoplasma 251 (2014) 555–566.
[48] M. Saleem, N. Shazmeen, M. Nazir, N. Riaz, G. Zengin, H.M. Ataullah, F. Nisar, M. Mukhtar, M.I. Tousif, Investigation on the phytochemical composition, antioxidant and enzyme inhibition potential of Polygonum Plebeium R. Br: a comprehensive approach to disclose new nutraceutical and functional food ingredients, Chem. Biodivers. 18 (2021) e2100706.
[49] Y. Semaming, P. Pannengpetch, S.C. Chattipakorn, N. Chattipakorn, Pharmacological properties of protocatechuic acid and its potential roles as complementary medicine, Evid. base Compl. Alternative Med. 2015 (2015).
[50] I. Antonopoulou, E. Sapountzaki, U. Rova, P. Christakopoulos, Ferulic acid from plant biomass: a phytochemical with promising antiviral properties, Front. Nutr. 8 (2022) 777576.
[51] H. Guven, A. Arici, O. Simsek, Flavonoids in our foods: a short review, Journal of Basic and Clinical Health Sciences 3 (2019) 96–106.
[52] N. Shen, T. Wang, Q. Gan, S. Liu, L. Wang, B. Jin, Plant flavonoids: classification, distribution, biosynthesis, and antioxidant activity, Food Chem. 383 (2022) 132531.

[53] K.M. Brodowska, Natural flavonoids: classification, potential role, and application of flavonoid analogues, European Journal of Biological Research 7 (2017) 108–123.
[54] A. Nugroho, E.J. Kim, J.S. Choi, H.-J. Park, Simultaneous quantification and peroxynitrite-scavenging activities of flavonoids in Polygonum aviculare L. herb, J. Pharmaceut. Biomed. Anal. 89 (2014) 93–98.
[55] I. Rukavina, M.J. Rodrigues, C.G. Pereira, I. Mansinhos, A. Romano, S. Ślusarczyk, A. Matkowski, L. Custódio, Greener is better: first approach for the use of natural deep eutectic solvents (NADES) to extract antioxidants from the medicinal halophyte polygonum maritimum L, Molecules 26 (2021) 6136.
[56] A. Kirino, Y. Takasuka, A. Nishi, S. Kawabe, H. Yamashita, M. Kimoto, H. Ito, H. Tsuji, Analysis and functionality of major polyphenolic components of Polygonum cuspidatum (itadori), J. Nutr. Sci. Vitaminol. 58 (2012) 278–286.
[57] M.J. Rodrigues, A. Matkowski, S. Ślusarczyk, C. Magne, T. Poleze, C. Pereira, L. Custodio, Sea knotgrass (Polygonum maritimum L.) as a potential source of innovative industrial products for skincare applications, Ind. Crop. Prod. 128 (2019) 391–398.
[58] N. Chansiw, S. Champakam, P. Chusri, K. Pangjit, S. Srichairatanakool, Quercetin-rich ethanolic extract of Polygonum odoratum var pakphai leaves decreased gene expression and secretion of pro-inflammatory mediators in lipopolysaccharide-induced murine RAW264. 7 macrophages, Molecules 27 (2022) 3657.
[59] D.Q. Han, J. Zhao, J. Xu, H.S. Peng, X.J. Chen, S.P. Li, Quality evaluation of Polygonum multiflorum in China based on HPLC analysis of hydrophilic bioactive compounds and chemometrics, J. Pharmaceut. Biomed. Anal. 72 (2013) 223–230.
[60] S. Singh, P. Gupta, A. Meena, S. Luqman, Acacetin, a flavone with diverse therapeutic potential in cancer, inflammation, infections and other metabolic disorders, Food Chem. Toxicol. 145 (2020) 111708.
[61] E. Rachmi, B.B. Purnomo, A.T. Endharti, L.E. Fitri, Afzelin inhibits migration of MDA-MB-231 cells by suppressing FAK expression and Rac1 activation, J. Appl. Pharmaceut. Sci. 10 (2020) 77–82.
[62] M. Cao, J. Wu, L. Wu, Z. Gu, C. Xie, L. Wu, J. Hu, G. Xu, Separation of three flavonoid glycosides from Polygonum multiflorum Thunb. leaves using HSCCC and their antioxidant activities, Eur. Food Res. Technol. (2022) 1–11.
[63] M. Fraga-Corral, P. García-Oliveira, A.G. Pereira, C. Lourenço-Lopes, C. Jimenez-Lopez, M.A. Prieto, J. Simal-Gandara, Technological application of tannin-based extracts, Molecules 25 (2020) 614.
[64] Z. Tong, W. He, X. Fan, A. Guo, Biological function of plant tannin and its application in animal health, Front. Vet. Sci. 8 (2022) 803657.
[65] Z. Jabeen, A. Riaz, F. Naz, M.S. Ahmed, A. Raheel, Evaluation of antifungal potential of indigenous plant extracts against grey mould and HPLC and LC-MS based identification of phytochemical compounds in polygonum amplexicaule D. Don extracts, International Journal of Phytopathology 11 (2022) 287–299.
[66] C. Da Porto, D. Decorti, A. Natolino, Water and ethanol as co-solvent in supercritical fluid extraction of proanthocyanidins from grape marc: a comparison and a proposal, J. Supercrit. Fluids 87 (2014) 1–8.
[67] Y. Adachi, B.C.-Y. Lu, Supercritical fluid extraction with carbon dioxide and ethylene, Fluid Phase Equil. 14 (1983) 147–156.
[68] D. Bagchi, M. Bagchi, S.J. Stohs, D.K. Das, S.D. Ray, C.A. Kuszynski, S.S. Joshi, H.G. Pruess, Free radicals and grape seed proanthocyanidin extract: importance in human health and disease prevention, Toxicology 148 (2000) 187–197.
[69] W. Liu, S. Zhao, J. Wang, J. Shi, Y. Sun, W. Wang, G. Ning, J. Hong, R. Liu, Grape seed proanthocyanidin extract ameliorates inflammation and adiposity by modulating gut microbiota in high-fat diet mice, Mol. Nutr. Food Res. 61 (2017) 1601082.
[70] A.M. Balde, L. Van Hoof, L.A. Pieters, D.A. Vanden Berghe, A.J. Vlietinck, Plant antiviral agents. VII. Antiviral and antibacterial proanthocyanidins from the bark of Pavetta owariensis, Phytother Res. 4 (1990) 182–188.
[71] H.J. Cong, S.W. Zhang, C. Zhang, Y.J. Huang, L.J. Xuan, A novel dimeric procyanidin glucoside from Polygonum aviculare, Chin. Chem. Lett. 23 (2012) 820–822.
[72] P. Jeandet, E. Sobarzo-Sánchez, C. Clément, S.F. Nabavi, S. Habtemariam, S.M. Nabavi, S. Cordelier, Engineering stilbene metabolic pathways in microbial cells, Biotechnol. Adv. 36 (2018) 2264–2283.
[73] S. Bhavaniramya, S. Vishnupriya, M.S. Al-Aboody, R. Vijayakumar, D. Baskaran, Role of essential oils in food safety: antimicrobial and antioxidant applications, Grain & Oil Science and Technology 2 (2019) 49–55.
[74] M. Moghaddam, L. Mehdizadeh, Chemistry of essential oils and factors influencing their constituents, in: Soft Chemistry and Food Fermentation, Elsevier, 2017, pp. 379–419.
[75] J. Bairagi, P.J. Saikia, F. Boro, A. Hazarika, A review on the ethnopharmacology, phytochemistry and pharmacology of Polygonum hydropiper Linn, J. Pharm. Pharmacol. 74 (2022) 619–645.
[76] F. Zhou, E. Pichersky, More is better: the diversity of terpene metabolism in plants, Curr. Opin. Plant Biol. 55 (2020) 1–10.
[77] M.H. Roaa, A review article: the importance of the major groups of plants secondary metabolism phenols, alkaloids, and terpenes, International Journal for Research in Applied Sciences and Biotechnology (IJRASB) 7 (2020) 354–358.
[78] D.Y. Korulkin, R.A. Muzychkina, Essential oils of polygonum L. Plants growing in Kazakhstan and their antibacterial and antifungal activity, Int. J. Biol. Life Sci. 9 (2015) 757–760.
[79] N.E.L. Hachlafi, T. Aanniz, N. El Menyiy, A. El Baaboua, N. El Omari, A. Balahbib, M.A. Shariati, G. Zengin, K. Fikri-Benbrahim, A. Bouyahya, In vitro and in vivo biological investigations of camphene and its mechanism insights: a review, Food Rev. Int. 39 (2023) 1799–1826.
[80] U. Malik, A. Barik, Volatiles and surface wax long-chain alkanes and free fatty acids from Polygonum orientale L.(Polygonaceae) flowers, Botany Letters 163 (2016) 453–460.
[81] M. Miyazawa, N. Tamura, Inhibitory compound of tyrosinase activity from the sprout of Polygonum hydropiper L.(Benitade), Biol. Pharm. Bull. 30 (2007) 595–597.
[82] S. Surendran, F. Qassadi, G. Surendran, D. Lilley, M. Heinrich, Myrcene—what are the potential health benefits of this flavouring and aroma agent? Front. Nutr. 8 (2021) 699666 https://doi.org/10.3389/fnut.2021.699666.
[83] D. Bekele, Z. Asfaw, B. Petros, H. Tekie, Ethnobotanical study of plants used for protection against insect bite and for the treatment of livestock health problems in rural areas of Akaki District, Eastern Shewa, Ethiopia, Topclass Journal of Herbal Medicine 1 (2012) 12–24.
[84] P.P. Peralta-Yahya, M. Ouellet, R. Chan, A. Mukhopadhyay, J.D. Keasling, T.S. Lee, Identification and microbial production of a terpene-based advanced biofuel, Nat. Commun. 2 (2011) 483.
[85] S.K. Yeo, A.Y. Ali, O.A. Hayward, D. Turnham, T. Jackson, I.D. Bowen, R. Clarkson, β-Bisabolene, a sesquiterpene from the essential oil extract of opoponax (Commiphora guidottii), exhibits cytotoxicity in breast cancer cell lines, Phytother Res. 30 (2016) 418–425.
[86] R. Ahmad, S.N. Baharum, H. Bunawan, M. Lee, N. Mohd Noor, E.R. Rohani, N. Ilias, N.M. Zin, Volatile profiling of aromatic traditional medicinal plant, Polygonum minus in different tissues and its biological activities, Molecules 19 (2014) 19220–19242.
[87] S.N. Baharum, H. Bunawan, M.A. Ghani, W.A.W. Mustapha, N.M. Noor, Analysis of the chemical composition of the essential oil of Polygonum minus Huds. using two-dimensional gas chromatography-time-of-flight mass spectrometry (GC-TOF MS), Molecules 15 (2010) 7006–7015.
[88] R. Rahnamaie-Tajadod, H.-H. Goh, N.M. Noor, Methyl jasmonate-induced compositional changes of volatile organic compounds in Polygonum minus leaves, J. Plant Physiol. 240 (2019) 152994.
[89] N.A. Rusdi, H.-H. Goh, S.N. Baharum, GC-MS/Olfactometric characterisation and aroma extraction dilution analysis of aroma active compounds in'Polygonum minus' essential oil, Plant Omics 9 (2016) 289–294.
[90] K. Řebíčková, T. Bajer, D. Šilha, M. Houdková, K. Ventura, P. Bajerová, Chemical composition and determination of the antibacterial activity of essential oils in liquid and vapor phases extracted from two different southeast Asian herbs—houttuynia cordata (saururaceae) and Persicaria odorata (polygonaceae), Molecules 25 (2020) 2432.
[91] M. Gilabert, E. Cartagena, G. Escobar, A. Bardón, M. Arena, Volatile terpenoids from water pepper (Polygonum punctatum) against Pseudomonas aeruginosa and Staphylococcus aureus virulence strategies, Global Journal of Agricultural Innovation, Research & Development 1 (2014) 3–10.
[92] E. Tvrzicka, L.-S. Kremmyda, B. Stankova, A. Zak, Fatty acids as biocompounds: their role in human metabolism, health and disease-a review. part 1: classification, dietary sources and biological functions, Biomedical Papers of the Medical Faculty of Palacky University in Olomouc 155 (2011).

[93] K.A. Akinyede, G.D. Hughes, O.E. Ekpo, O.O. Oguntibeju, Comparative study of the antioxidant constituents, activities and the GC-MS quantification and identification of fatty acids of four selected Helichrysum species, Plants 11 (2022) 998.
[94] X. Wang, C. Zhang, N. Bao, Molecular mechanism of palmitic acid and its derivatives in tumor progression, Front. Oncol. 13 (2023) 1224125.
[95] V. Kumar, A. Sharma, H. Kaur, A.K. Thukral, R. Bhardwaj, Phytochemical profiling of the leaves of Chenopodium and Polygonum using GC-MS, Res. J. Pharm. Technol. 8 (2015) 1629–1632.
[96] A. Intisar, L. Zhang, H. Luo, J.B. Kiazolu, R. Zhang, W. Zhang, Anticancer constituents and cytotoxic activity of methanol-water extract of Polygonum bistorta L., African Journal of Traditional, Complementary and Alternative Medicines 10 (2013) 53–59.
[97] M.J. Rodrigues, L. Custódio, A. Lopes, M. Oliveira, N.R. Neng, J.M.F. Nogueira, A. Martins, A.P. Rauter, J. Varela, L. Barreira, Unlocking the in vitro anti-inflammatory and antidiabetic potential of Polygonum maritimum, Pharmaceut. Biol. 55 (2017) 1348–1357.
[98] U. Malik, A. Barik, Free fatty acids from the weed, Polygonum orientale leaves for attraction of the potential biocontrol agent, Galerucella placida (Coleoptera: chrysomelidae), Biocontrol Sci. Technol. 25 (2015) 593–607.
[99] A. Intisar, L. Zhang, H. Luo, R. Zhang, Z. Wu, W. Zhang, Difference in essential oil composition of rhizome of Polygonum bistorta L. from different Asian regions and evaluation of its antibacterial activity, Journal of Essential Oil Bearing Plants 15 (2012) 964–971.
[100] S. Zhang, P. Li, Z. Wei, Y. Cheng, J. Liu, Y. Yang, Y. Wang, Z. Mu, Cyperus (Cyperus esculentus L.): a review of its compositions, medical efficacy, antibacterial activity and allelopathic potentials, Plants 11 (2022) 1127.
[101] J. Cai, S. Wang, Y. Gao, Q. Wang, Antibacterial activity and mechanism of Polygonum orientale L. essential oil against Pectobacterium carotovorum subsp. carotovorum, Foods 11 (2022) 1585.
[102] A.A. Aziz, F.N.M. Nordin, Z. Zakaria, N.K. Abu Bakar, A systematic literature review on the current detection tools for authentication analysis of cosmetic ingredients, J. Cosmet. Dermatol. 21 (2022) 71–84.
[103] Q. Zhang, Y. Xu, J. Lv, M. Cheng, Y. Wu, K. Cao, X. Zhang, X. Mou, Q. Fan, Structure characterization of two functional polysaccharides from Polygonum multiflorum and its immunomodulatory, Int. J. Biol. Macromol. 113 (2018) 195–204.
[104] W. Zhu, X. Xue, Z. Zhang, Ultrasonic-assisted extraction, structure and antitumor activity of polysaccharide from Polygonum multiflorum, Int. J. Biol. Macromol. 91 (2016) 132–142.
[105] Y. Zhang, Y. Sun, Y. Liu, J. Liu, J. Sun, Y. Bai, B. Fan, C. Lu, F. Wang, Polygonum sibiricum polysaccharides alleviate chronic unpredictable mild stress-induced depressive-like behaviors by regulating the gut microbiota composition and SCFAs levels, J. Funct.Foods 101 (2023) 105411.
[106] Y. Zhang, Y. Sun, Y. Liu, J. Liu, J. Sun, X. Liu, B. Fan, C. Lu, F. Wang, Polygonum sibiricum polysaccharides exert the antidepressant-like effects in chronic unpredictable mild stress-induced depressive mice by modulating microbiota-gut-brain axis, Phytother Res. 37 (2023) 3408–3423.
[107] Y. Zhou, W. Ma, L. Wang, W. Sun, M. Li, W. Zhang, Y. Liu, X. Song, Y. Fan, Characterization and antioxidant activity of the oligo-maltose fraction from Polygonum Cillinerve, Carbohydr. Polym. 226 (2019) 115307.
[108] R. Ahmad, A.R. Rosandy, I. Sahidin, N.S. Ab Ghani, N.M. Noor, S.N. Baharum, Bioassay analysis and molecular docking study revealed the potential medicinal activities of active compounds polygonumins B, C and D from polygonum minus (persicaria minor), Plants 12 (2022) 59.
[109] L.-L. Chen, X.-J. Huang, M.-M. Li, G.-M. Ou, B.-X. Zhao, M.-F. Chen, Q.-W. Zhang, Y. Wang, W.-C. Ye, Polygonflavanol A, a novel flavonostilbene glycoside from the roots of Polygonum multiflorum, Phytochem. Lett. 5 (2012) 756–760.
[110] X.-Q. Liu, H.-M. Hua, J. Liu, F.-K. Chen, L.-J. Wu, A new tannin-related compound from the rhizome of Polygonum bistorta L, J. Asian Nat. Prod. Res. 8 (2006) 299–302.
[111] M. Xiang, H. Su, G. Shu, D. Wan, F. He, M. Loaec, Y. Ding, J. Li, S. Dovat, G. Yang, Amplexicaule A exerts anti-tumor effects by inducing apoptosis in human breast cancer, Oncotarget 7 (2016) 18521.
[112] C.-Y. Hsu, Antioxidant activity of extract from Polygonum aviculare L, Biol. Res. 39 (2006) 281–288.
[113] S. Granica, M.E. Czerwińska, B. Żyżyńska-Granica, A.K. Kiss, Antioxidant and anti-inflammatory flavonol glucuronides from Polygonum aviculare L, Fitoterapia 91 (2013) 180–188.
[114] J. Gou, Y. Zou, J. Ahn, Enhancement of antioxidant and antimicrobial activities of Dianthus superbus, Polygonum aviculare, Sophora flavescens, and Lygodium japonicum by pressure-assisted water extraction, Food Sci. Biotechnol. 20 (2011) 283–287.
[115] D. Egamberdieva, N. Mamadalieva, O. Khodjimatov, A. Tiezzi, Medicinal plants from Chatkal Biosphere Reserve used for folk medicine in Uzbekistan, Med. Aromat. Plant Sci. Biotechnol. 7 (2013) 56–64.
[116] H.M.H. Salama, N. Marraiki, Antimicrobial activity and phytochemical analyses of Polygonum aviculare L.(Polygonaceae), naturally growing in Egypt, Saudi J. Biol. Sci. 17 (2010) 57–63.
[117] S.H. Park, S. Jang, E. Son, S.W. Lee, S.D. Park, Y.-Y. Sung, H.K. Kim, Polygonum aviculare L. extract reduces fatigue by inhibiting neuroinflammation in restraint-stressed mice, Phytomedicine 42 (2018) 180–189.
[118] R.M. Habibi, R.A. Mohammadi, A. Delazar, R. Halabian, R.J. Soleimani, A. Mehdipour, M. Bagheri, A. Jahanian-Najafabadi, Effects of Polygonum Aviculare Herbal Extract on Proliferation and Apoptotic Gene Expression of MCF-7, Daru, vol. 19, Journal of Faculty of Pharmacy, Tehran University of Medical Sciences, 2011, p. 326.
[119] C.-Y. Hsu, Y.-P. Chan, J. Chang, Antioxidant activity of extract from Polygonum cuspidatum, Biol. Res. 40 (2007) 13–21.
[120] Y. Pan, X. Zhang, H. Wang, Y. Liang, J. Zhu, H. Li, Z. Zhang, Q. Wu, Antioxidant potential of ethanolic extract of Polygonum cuspidatum and application in peanut oil, Food Chem. 105 (2007) 1518–1524.
[121] M.-H. Lee, L. Kao, C.-C. Lin, Comparison of the antioxidant and transmembrane permeative activities of the different Polygonum cuspidatum extracts in phospholipid-based microemulsions, J. Agric. Food Chem. 59 (2011) 9135–9141.
[122] M. Yu, T.-T. Chen, T. Zhang, H.-M. Jia, J.-J. Li, H.-W. Zhang, Z.-M. Zou, Anti-inflammatory constituents in the root and rhizome of Polygonum cuspidatum by UPLC-PDA-QTOF/MS and lipopolysaccharide-activated RAW264. 7 macrophages, J. Pharmaceut. Biomed. Anal. 195 (2021) 113839.
[123] E.E. Bralley, P. Greenspan, J.L. Hargrove, L. Wicker, D.K. Hartle, Topical anti-inflammatory activity of Polygonum cuspidatum extract in the TPA model of mouse ear inflammation, J. Inflamm. 5 (2008) 1–7.
[124] J.-H. Han, W. Koh, H.-J. Lee, H.-J. Lee, E.-O. Lee, S.J. Lee, J.-H. Khil, J.T. Kim, S.-J. Jeong, S.-H. Kim, Analgesic and anti-inflammatory effects of ethyl acetate fraction of Polygonum cuspidatum in experimental animals, Immunopharmacol. Immunotoxicol. 34 (2012) 191–195.
[125] E.-H. Kim, J.-C. Kim, H.K. Kim, Y.-A. Jang, Antimicrobial and anti-inflammatory effects of the ethanol extract of polygonum cuspidatum as a mouthwash component, Nat. Prod. Commun. 16 (2021), 1934578X211005255.
[126] Q. Geng, Q. Wei, S. Wang, H. Qi, Q. Zhu, X. Liu, X. Shi, S. Wen, Physcion 8-O-β-glucopyranoside extracted from Polygonum cuspidatum exhibits anti-proliferative and anti-inflammatory effects on MH7A rheumatoid arthritis-derived fibroblast-like synoviocytes through the TGF-β/MAPK pathway, Int. J. Mol. Med. 42 (2018) 745–754.
[127] P.-W. Su, C.-H. Yang, J.-F. Yang, P.-Y. Su, L.-Y. Chuang, Antibacterial activities and antibacterial mechanism of Polygonum cuspidatum extracts against nosocomial drug-resistant pathogens, Molecules 20 (2015) 11119–11130.
[128] J.-H. Song, S.-K. Kim, K.-W. Chang, S.-K. Han, H.-K. Yi, J.-G. Jeon, In vitro inhibitory effects of Polygonum cuspidatum on bacterial viability and virulence factors of Streptococcus mutans and Streptococcus sobrinus, Arch. Oral Biol. 51 (2006) 1131–1140.
[129] L. Li, X. Song, Z. Yin, R. Jia, Z. Li, X. Zhou, Y. Zou, L. Li, L. Yin, G. Yue, The antibacterial activity and action mechanism of emodin from Polygonum cuspidatum against Haemophilus parasuis in vitro, Microbiol. Res. 186 (2016) 139–145.
[130] C.-C. Lee, Y.-T. Chen, C.-C. Chiu, W.-T. Liao, Y.-C. Liu, H.-M.D. Wang, Polygonum cuspidatum extracts as bioactive antioxidaion, anti-tyrosinase, immune stimulation and anticancer agents, J. Biosci. Bioeng. 119 (2015) 464–469.
[131] Q. Xie, Y. Yang, Z. Wang, F. Chen, A. Zhang, C. Liu, Resveratrol-4-O-D-(2'-galloyl)-glucopyranoside isolated from polygonum cuspidatum exhibits anti-hepatocellular carcinoma viability by inducing apoptosis via the JNK and ERK pathway, Molecules 19 (2014) 1592–1602.
[132] B. Alzahrani, A.Y. Elderdery, N.A.N. Alzerwi, A. Alsrhani, A. Alsultan, M. Rayzah, B. Idrees, F. Rayzah, Y. Baksh, A.M. Alzahrani, Pluronic-F-127-Passivated SnO2 nanoparticles derived by using polygonum cuspidatum root extract: synthesis, characterization, and anticancer properties, Plants 12 (2023) 1760.

[133] E. Sohn, J. Kim, C.-S. Kim, K. Jo, Y.M. Lee, J.S. Kim, Root of Polygonum cuspidatum extract reduces progression of diabetes-induced mesangial cell dysfunction via inhibition of platelet-derived growth factor-BB (PDGF-BB) and interaction with its receptor in streptozotocin-induced diabetic rats, BMC Compl. Alternative Med. 14 (2014) 1–9.
[134] E. Sohn, J. Kim, C.S. Kim, K. Jo, J.S. Kim, Extract of Rhizoma Polygonum cuspidatum reduces early renal podocyte injury in streptozotocin-induced diabetic rats and its active compound emodin inhibits methylglyoxal-mediated glycation of proteins, Mol. Med. Rep. 12 (2015) 5837–5845.
[135] S.-Y. Zhou, Y.-M. Liu, Q.-Z. Zhang, Y.-W. Fu, D.-J. Lin, Evaluation of an antiparasitic compound extracted from Polygonum cuspidatum against Ichthyophthirius multifiliis in grass carp, Vet. Parasitol. 253 (2018) 22–25.
[136] Y.-S. Kim, Y. Nam, J. Song, H. Kim, Gastroprotective and healing effects of polygonum cuspidatum root on experimentally induced gastric ulcers in rats, Nutrients 12 (2020) 2241.
[137] A. Nasir, M. Khan, Z. Rehman, A.A.K. Khalil, S. Farman, N. Begum, M. Irfan, W. Sajjad, Z. Parveen, Evaluation of alpha-amylase inhibitory, antioxidant, and antimicrobial potential and phytochemical contents of polygonum hydropiper L, Plants 9 (2020) 852.
[138] S. Sharif, M. Shahriar, M.A. Haque, Z. Chowdhury, M.R. Islam, M.A. Bhuiyan, In-vitro antioxidant activities, anti-nociceptive and neuropharmacological activities of Polygonum hydropiper, In Vitro 3 (2013).
[139] M. Ayaz, M. Junaid, F. Ullah, A. Sadiq, M.A. Khan, W. Ahmad, M.R. Shah, M. Imran, S. Ahmad, Comparative chemical profiling, cholinesterase inhibitions and anti-radicals properties of essential oils from Polygonum hydropiper L: a Preliminary anti-Alzheimer's study, Lipids Health Dis. 14 (2015) 1–12.
[140] Z.F. Peng, D. Strack, A. Baumert, R. Subramaniam, N.K. Goh, T.F. Chia, S.N. Tan, L.S. Chia, Antioxidant flavonoids from leaves of Polygonum hydropiper L, Phytochemistry 62 (2003) 219–228.
[141] H. Haraguchi, R. Matsuda, K. Hashimoto, High-performance liquid chromatographic determination of sesquiterpene dialdehydes and antifungal activity from Polygonum hydropiper, J. Agric. Food Chem. 41 (1993) 5–7.
[142] M. Ayaz, M. Junaid, F. Ullah, F. Subhan, A. Sadiq, G. Ali, M. Ovais, M. Shahid, A. Ahmad, A. Wadood, Anti-Alzheimer's studies on β-sitosterol isolated from Polygonum hydropiper L, Front. Pharmacol. 8 (2017) 697.
[143] C.-Z. Ren, W.-Y. Hu, M. Song, Y.-Y. Wei, T.-J. Hu, An ethyl acetate fraction of flavonoids from Polygonum hydropiper L. exhibits an anti-inflammatory activity in PCV2-infected porcine alveolar macrophages via PI3K/Akt and NF-κB pathways, in: Veterinary Research Forum, Faculty of Veterinary Medicine, Urmia University, Urmia, Iran, 2022, p. 339.
[144] Y. Yang, T. Yu, H.-J. Jang, S.E. Byeon, S.-Y. Song, B.-H. Lee, M.H. Rhee, T.W. Kim, J. Lee, S. Hong, In vitro and in vivo anti-inflammatory activities of Polygonum hydropiper methanol extract, J. Ethnopharmacol. 139 (2012) 616–625.
[145] J. Tao, Y. Wei, T. Hu, Flavonoids of Polygonum hydropiper L. attenuates lipopolysaccharide-induced inflammatory injury via suppressing phosphorylation in MAPKs pathways, BMC Compl. Alternative Med. 16 (2015) 1–15.
[146] V. Karuppagounder, S. Arumugam, R.A. Thandavarayan, R. Sreedhar, V.V. Giridharan, K. Watanabe, Molecular targets of quercetin with anti-inflammatory properties in atopic dermatitis, Drug Discov. Today 21 (2016) 632–639.
[147] D. Resiere, H. Mehdaoui, R. Neviere, Inflammation and oxidative stress in snakebite envenomation: a brief descriptive review and clinical implications, Toxins 14 (2022) 802.
[148] M. Ayaz, M. Junaid, F. Ullah, A. Sadiq, M. Ovais, W. Ahmad, S. Ahmad, A. Zeb, Chemical profiling, antimicrobial and insecticidal evaluations of Polygonum hydropiper L, BMC Compl. Alternative Med. 16 (2016) 1–14.
[149] T. Phatik, J. Das, P. Boruah, Antifungal activity of Polygonum hydropiper and Solanum melongena against plant pathogenic fungi, Plant Arch 14 (2014) 15–17.
[150] M. Hasan, R. Das, A. Khan, M. Hossain, M. Rahman, The determination of antibacterial and antifungal activities of Polygonum hydropiper (L.) root extract, Adv. Biol. Res. 3 (2009) 53–56.
[151] V. Duraipandiyan, F. Indwar, S. Ignacimuthu, Antimicrobial activity of confertifolin from Polygonum hydropiper, Pharmaceut. Biol. 48 (2010) 187–190.
[152] M.F. Hasan, M. Rahman, Screening of antibacterial, antifungal and cytotoxic activities of Polygonum hydropiper L. stem extracts, Int. J. Biosci. 1 (2011) 47–53.
[153] M. Ayaz, A. Wadood, A. Sadiq, F. Ullah, O. Anichkina, M. Ghufran, In-silico evaluations of the isolated phytosterols from polygonum hydropiper L against BACE1 and MAO drug targets, J. Biomol. Struct. Dyn. 40 (2022) 10230–10238.
[154] M.H. Mahnashi, Y.S. Alqahtani, B.A. Alyami, A.O. Alqarni, F. Ullah, A. Wadood, A. Sadiq, A. Shareef, M. Ayaz, Cytotoxicity, anti-angiogenic, anti-tumor and molecular docking studies on phytochemicals isolated from Polygonum hydropiper L, BMC Complementary Medicine and Therapies 21 (2021) 1–14.
[155] S. Munira, F. Sultana, S. Mollika, L. Nesa, J. Ria, M.M. Islam, Anti-neoplastic activities of Polygonum hydropiper Linn. against Ehrlich ascites carcinoma in Swiss Albino mice, Adv. Biol. Res. 7 (2013) 9–14.
[156] A.R. Oany, A.A. Siddikey, M.U. Hossain, R. Islam, A.-A. Emran, A preliminary evaluation of cytotoxicity, antihyperglycemic and antinociceptive activity of Polygonum hydropiper L. ethanolic leaf extract, Clinical Phytoscience 2 (2017) 1–6.
[157] H. Xiao, R. Rao Ravu, B.L. Tekwani, W. Li, W.-B. Liu, M.R. Jacob, S.I. Khan, X. Cai, C.-Y. Peng, I.A. Khan, Biological evaluation of phytoconstituents from Polygonum hydropiper, Nat. Prod. Res. 31 (2017) 2053–2057.
[158] Y.-D. Kong, Y. Qi, N. Cui, Z.-H. Zhang, N. Wei, C.-F. Wang, Y.-N. Zeng, Y.-P. Sun, H.-X. Kuang, Q.-H. Wang, The traditional herb Polygonum hydropiper from China: a comprehensive review on phytochemistry, pharmacological activities and applications, Pharmaceut. Biol. 61 (2023) 799–814.
[159] M. Jena, M. Annamalai, G. Basana-Gowda, C. Muthiah, N. Patil, P.C. Rath, T. Adak, Toxicity of water pepper, Persicaria hydropiper (L.) extracts against Nilaparvata lugens (Stål) and non-targeted effect on earthworm, Ind. Crop. Prod. 187 (2022) 115309.
[160] M. Ayaz, M. Junaid, F. Ullah, A. Sadiq, M. Shahid, W. Ahmad, I. Ullah, A. Ahmad, N.-H. Syed, GC-MS analysis and gastroprotective evaluations of crude extracts, isolated saponins, and essential oil from Polygonum hydropiper L, Front. Chem. 5 (2017) 58.
[161] G. Shiraliyeva, Persicaria species in flora of Azerbaijan and etnobiology of their use, Int J Curr Microbiol App Sci 1 (2017) 527–531.
[162] M. Maizura, A. Aminah, W.M. Wan Aida, Total phenolic content and antioxidant activity of kesum (Polygonum minus), ginger (Zingiber officinale) and turmeric (Curcuma longa) extract, Int. Food Res. J. 18 (2011).
[163] A. George, C.P. Ng, M. O'Callaghan, G.S. Jensen, H.J. Wong, In vitro and ex-vivo cellular antioxidant protection and cognitive enhancing effects of an extract of Polygonum minus Huds (Lineminus™) demonstrated in a Barnes Maze animal model for memory and learning, BMC Compl. Alternative Med. 14 (2014) 1–10.
[164] N. Hassim, M. Markom, N. Anuar, K.H. Dewi, S.N. Baharum, N. Mohd Noor, Antioxidant and antibacterial assays on polygonum minus extracts: different extraction methods, Int. J. Chem. Eng. 2015 (2015).
[165] M.Z. Abdullah, J. Mohd Ali, M. Abolmaesoomi, P.S. Abdul-Rahman, O.H. Hashim, Anti-proliferative, in vitro antioxidant, and cellular antioxidant activities of the leaf extracts from Polygonum minus Huds: effects of solvent polarity, Int. J. Food Prop. 20 (2017) 846–862.
[166] R. Ahmad, S.N. Baharum, H. Bunawan, M. Lee, N. Mohd Noor, E.R. Rohani, N. Ilias, N.M. Zin, Volatile profiling of aromatic traditional medicinal plant, Polygonum minus in different tissues and its biological activities, Molecules 19 (2014) 19220–19242.
[167] M. Mahboubi, M.M. Feizabadi, Antimicrobial activity of Ducrosia anethifolia essential oil and main component, decanal against methicillin-resistant and methicillin-susceptible Staphylococcus aureus, Journal of Essential Oil Bearing Plants 12 (2009) 574–579.
[168] F. de Sousa Ferreira, J.B. de Araújo Neto, C.D. de Morais Oliveira-Tintino, A.C.J. de Araújo, J. Ribeiro-Filho, P.R. Freitas, I.M. Araújo, M.A. Lima, F.R. de Azevedo, S.R. Tintino, Chemical composition and antibacterial effects of Etlingera elatior (Jack) RM Smith against Staphylococcus aureus efflux pumps, Chem. Biol. Interact. 386 (2023) 110751.
[169] A.C. da Silva Rivas, P.M. Lopes, M.M. de Azevedo Barros, D.C. Costa Machado, C.S. Alviano, D.S. Alviano, Biological activities of α-pinene and β-pinene enantiomers, Molecules 17 (2012) 6305–6316.
[170] Y. Han, W. Chen, Z. Sun, Antimicrobial activity and mechanism of limonene against Staphylococcus aureus, J. Food Saf. 41 (2021) e12918.
[171] S.S. Dahham, Y.M. Tabana, M.A. Iqbal, M.B. Ahamed, M.O. Ezzat, A.S. Majid, A.M. Majid, The anticancer, antioxidant and antimicrobial properties of the sesquiterpene β-caryophyllene from the essential oil of Aquilaria crassna, Molecules 20 (2015) 11808–11829.
[172] Z.-H. Pu, Y. Zhang, Z. Yin, X. Jiao, R. Jia, L. Yang, Y. Fan, Antibacterial activity of 9-octadecanoic acid-hexadecanoic acid-tetrahydrofuran-3, 4-diyl ester from neem oil, Agric. Sci. China 9 (2010) 1236–1240.

[173] A. George, S. Chinnappan, M. Chintamaneni, V. Kotak C, Y. Choudhary, T. Kueper, A.K. Radhakrishnan, Anti-inflammatory effects of Polygonum minus (Huds) extract (Lineminus™) in in-vitro enzyme assays and carrageenan induced paw edema, BMC Compl. Alternative Med. 14 (2014) 1–7.
[174] P.V. Christapher, T.Y. Xin, C.F. Kiun, L.C. Leng, N.G. Fu, G.L. Yuan, S. Parasuraman, M. Vikneswaran, Evaluation of analgesic, anti-inflammatory, antipyretic and antiulcer effect of aqueous and methanol extracts of leaves of Polygonum minus Huds.(Polygonaceae) in rodents, Archives of Medicine and Health Sciences 3 (2015) 12–17.
[175] S. Mansour, N. Djebli, E.E. Ozkan, A. Mat, In vivo antiinflammatory activity and chemical composition of Hypericum scabroides, Asian Pac. J. Tropical Med. 7 (2014) S514–S520.
[176] M.-J. Sheu, P.-Y. Chou, H.-C. Cheng, C.-H. Wu, G.-J. Huang, B.-S. Wang, J.-S. Chen, Y.-C. Chien, M.-H. Huang, Analgesic and anti-inflammatory activities of a water extract of Trachelospermum jasminoides (Apocynaceae), J. Ethnopharmacol. 126 (2009) 332–338.
[177] N.A. Rahim, N. Nordin, N.I.S.A. Rasedi, F.S.M. Kauli, W.N.W. Ibrahim, F. Zakaria, Behavioral and cortisol analysis of the anti-stress effect of Polygonum minus (Huds) extracts in chronic unpredictable stress (CUS) zebrafish model, Comp. Biochem. Physiol. C Toxicol. Pharmacol. 256 (2022) 109303.
[178] M.I. Bashir, N.H.K. Abdul Aziz, D.A.M. Noor, Antidepressant-like effects of polygonum minus aqueous extract in chronic ultra-mild stress-induced depressive mice model, Behav. Sci. 12 (2022) 196.
[179] N.H. Sayuti, N. Zulkefli, J.K. Tan, N. Saad, S.N. Baharum, H.S. Hamezah, H. Bunawan, Q.U. Ahmed, H. Parveen, S. Mukhtar, Ethanolic extract of polygonum minus protects differentiated human neuroblastoma cells (SH-SY5Y) against H2O2-induced oxidative stress, Molecules 28 (2023) 6726.
[180] M.I. Bashir, N.H.K.A. Aziz, D.A.M. Noor, Polygonum Minus Aqueous Extract Supplement Reduces Stress-Induced Anorexia and Anhedonia in Mice, (n.d.)..
[181] N. Abd Rashid, F. Hussan, A. Hamid, N.R.A. Ridzuan, S.A.S. Abd Halim, N.A.A. Jalil, N.H.M. Najib, S.L. Teoh, S.B. Budin, Polygonum minus essential oil modulates cisplatin-induced hepatotoxicity through inflammatory and apoptotic pathways, EXCLI Journal 19 (2020) 1246.
[182] S.W. Qader, M.A. Abdulla, L.S. Chua, H.M. Sirat, S. Hamdan, Pharmacological mechanisms underlying gastroprotective activities of the fractions obtained from Polygonum minus in Sprague Dawley rats, Int. J. Mol. Sci. 13 (2012) 1481–1496.
[183] T. Benali, S. Bakrim, R. Ghchime, N. Benkhaira, N. El Omari, A. Balahbib, D. Taha, G. Zengin, M.M. Hasan, S. Bibi, Pharmacological insights into the multifaceted biological properties of quinic acid, Biotechnol. Genet. Eng. Rev. (2022) 1–30.
[184] S. Shabani, Z. Rabiei, H. Amini-Khoei, Exploring the multifaceted neuroprotective actions of gallic acid: a review, Int. J. Food Prop. 23 (2020) 736–752.
[185] S. Zhang, Z. Gai, T. Gui, J. Chen, Q. Chen, Y. Li, Antioxidant effects of protocatechuic acid and protocatechuic aldehyde: old wine in a new bottle, Evid. base Compl. Alternative Med. 2021 (2021).
[186] A. Tajner-Czopek, M. Gertchen, E. Rytel, A. Kita, A.Z. Kucharska, A. Sokół-Łętowska, Study of antioxidant activity of some medicinal plants having high content of caffeic acid derivatives, Antioxidants 9 (2020) 412.
[187] M. Stompor-Gorący, M. Machaczka, Recent advances in biological activity, new formulations and prodrugs of ferulic acid, Int. J. Mol. Sci. 22 (2021) 12889.
[188] J. Bae, N. Kim, Y. Shin, S.-Y. Kim, Y.-J. Kim, Activity of catechins and their applications, Biomedical Dermatology 4 (2020) 1–10.
[189] H.G. Ulusoy, N. Sanlier, A minireview of quercetin: from its metabolism to possible mechanisms of its biological activities, Crit. Rev. Food Sci. Nutr. 60 (2020) 3290–3303.
[190] S.A. El-Toumy, J.Y. Salib, N.H. Shafik, A.S. Elkarim, A.A. Farag, New flavonoids from the aerial parts of Polygonum equisetiforme SM (Polygonaceae), Int. J. Pharm. Pharmaceut. Sci. 9 (2017) 166–170.
[192] F. Elgudayem, A. Aldiyab, M.A. Albalawi, A. Omran, N.E. Kafkas, H. Saghrouchni, I. Var, M.A. Rahman, A. El Sabagh, M. Sakran, Box-Behnken design based optimization of phenolic extractions from Polygonum equisetiforme roots linked to its antioxidant and antibacterial efficiencies, Front. Sustain. Food Syst. 7 (2023) 1141207.
[193] N. Kahkeshani, B. Farahanikia, P. Mahdaviani, A. Abdolghaffari, G. Hassanzadeh, M. Abdollahi, M. Khanavi, Antioxidant and burn healing potential of Galium odoratum extracts, Research in Pharmaceutical Sciences 8 (2013) 197.
[194] S.A.H. El-Toumy, J.Y. Salib, N.H. Shafik, A.S. Abd Elkarim, A. Salama, E.A.A. Omara, J. Micky, Evaluation of hepatoprotective activity of Polygonum equisetiforme methanolic extract, J. Appl. Pharmaceut. Sci. 9 (2019) 54–59.
[195] A. Itoh, K. Isoda, M. Kondoh, M. Kawase, A. Watari, M. Kobayashi, M. Tamesada, K. Yagi, Hepatoprotective effect of syringic acid and vanillic acid on CCl4-induced liver injury, Biol. Pharm. Bull. 33 (2010) 983–987.
[196] N. Chansiw, K. Chotinantakul, S. Srichairatanakool, Anti-inflammatory and antioxidant activities of the extracts from leaves and stems of Polygonum odoratum Lour, Anti-Inflammatory Anti-Allergy Agents Med. Chem. 18 (2019) 45–54.
[197] S. Okonogi, K. Kheawfu, W. Holzer, F.M. Unger, H. Viernstein, M. Mueller, Anti-inflammatory effects of compounds from Polygonum odoratum, Nat. Prod. Commun. 11 (2016), 1934578X1601101107.
[198] H.D. Smolarz, J. Budzianowski, A. Bogucka-Kocka, J. Kocki, E. Mendyk, Flavonoid glucuronides with anti-leukaemic activity from Polygonum amphibium L, Phytochem. Anal. 19 (2008) 506–513.
[199] C.F. Zhang, Y. Hu, Y. Lin, F. Huang, M. Zhang, Anti-inflammatory activities of ethyl acetate extract of Polygonum jucundum and its phytochemical study, J. Med. Plants Res. 6 (2012) 1505–1511.
[200] J.-B. Yang, W.-F. Li, Y. Liu, Q. Wang, X.-L. Cheng, F. Wei, A.-G. Wang, H.-T. Jin, S.-C. Ma, Acute toxicity screening of different extractions, components and constituents of Polygonum multiflorum Thunb. on zebrafish (Danio rerio) embryos in vivo, Biomed. Pharmacother. 99 (2018) 205–213.
[201] G.P. Lv, L.Z. Meng, D.Q. Han, H.Y. Li, J. Zhao, S.P. Li, Effect of sample preparation on components and liver toxicity of Polygonum multiflorum, J. Pharmaceut. Biomed. Anal. 109 (2015) 105–111.
[202] P.V. Christapher, S. Parasuraman, M.Z. Asmawi, V. Murugaiyah, Acute and subchronic toxicity studies of methanol extract of Polygonum minus leaves in Sprague Dawley rats, Regul. Toxicol. Pharmacol. 86 (2017) 33–41.
[203] H.H.B. Haris, Y.K. Ming, F. Perin, C. Blanche, N. Jinapong, Split-face placebo controlled evaluation of the in vivo anti-ageing efficacy of lineminustm cream (Polygonum minus extract) in healthy asian skin type female subjects, Asian J. Pharmaceut. Clin. Res. 7 (2014) 7–13.
[204] V. Satyanarayana, Evaluation of in vivo rheumatoid arthritis activity of formulated capsule with different portions polyherbal ethanolic extract from selected potential Indian herbs, Int. J. Green Pharm. 13 (2019).
[205] N. Aziz, A. Sami, A. Jabeen, M. Gulfraz, R. Qureshi, T. Ibrahim, A.A. Farooqi, S.M. Naqvi, M.S. Ahmad, Formulation and evaluation of antioxidant and antityrosinase activity of Polygonum amplexicaule herbal gel, Pak. J. Pharm. Sci. 33 (2020).
[206] P. Liu, G. Chen, J. Zhang, A review of liposomes as a drug delivery system: current status of approved products, regulatory environments, and future perspectives, Molecules 27 (2022) 1372.
[207] M. Mureşan, D. Olteanu, G.A. Filip, S. Clichici, I. Baldea, T. Jurca, A. Pallag, E. Marian, A. Frum, F.G. Gligor, Comparative study of the pharmacological properties and biological effects of polygonum aviculare L. Herba extract-entrapped liposomes versus quercetin-entrapped liposomes on doxorubicin-induced toxicity on HUVECs, Pharmaceutics 13 (2021) 1418.
[208] S.S. Kwon, S.Y. Kim, B.J. Kong, K.J. Kim, G.Y. Noh, N.R. Im, J.W. Lim, J.H. Ha, J. Kim, S.N. Park, Cell penetrating peptide conjugated liposomes as transdermal delivery system of Polygonum aviculare L. extract, Int. J. Pharm. 483 (2015) 26–37.
[209] K. Benrahou, M. Driouech, O. El Guourrami, H.N. Mrabti, Y. Cherrah, M. El Abbes Faouzi, Medicinal uses, phytochemistry, pharmacology, and taxonomy of Poygonum aviculare L.: a comprehensive review, Med. Chem. Res. (2023) 1–15.
[210] A. Ben Sassi, F. Harzallah-Skhiri, M. Aouni, Investigation of some medicinal plants from Tunisia for antimicrobial activities, Pharmaceut. Biol. 45 (2007) 421–428.
[211] S. Kayani, M. Ahmad, S. Sultana, Z.K. Shinwari, M. Zafar, G. Yaseen, M. Hussain, T. Bibi, Ethnobotany of medicinal plants among the communities of Alpine and Sub-alpine regions of Pakistan, J. Ethnopharmacol. 164 (2015) 186–202.
[212] A.-L. Molan, A.M. Faraj, A.S. Mahdy, Antioxidant activity and phenolic content of some medicinal plants traditionally used in Northern Iraq, Phytopharmacology 2 (2012) 224–233.
[213] W.H. Organization, Medicinal Plants in Mongolia, 2013.

[214] A. Nelly, D.-D. Annick, D. Frederic, Plants used as remedies antirheumatic and antineuralgic in the traditional medicine of Lebanon, J. Ethnopharmacol. 120 (2008) 315–334.
[216] M.Z. Uddin, M.A. Hassan, M. Rahman, K. Arefin, Ethno-medico-botanical study in lawachara national park, Bangladesh, Bangladesh J. Bot. 41 (2012) 97–104.
[217] M.A.S.A. Khan, F. Sultana, M.H. Rahman, B. Roy, S.I. Anik, Status and ethno-medicinal usage of invasive plants in traditional health care practices: a case study from northeastern Bangladesh, J. For. Res. 22 (2011) 649–658.
[218] K. Ganesan, B. Xu, Ethnobotanical studies on folkloric medicinal plants in nainamalai, namakkal district, Tamil nadu, India, Trends in Phytochemical Research 1 (2017) 153–168.
[219] M.J. Rodrigues, A. Matkowski, S. Ślusarczyk, C. Magne, T. Poleze, C. Pereira, L. Custodio, Sea knotgrass (Polygonum maritimum L.) as a potential source of innovative industrial products for skincare applications, Ind. Crop. Prod. 128 (2019) 391–398.
[220] T. Sultana, M. Ahmed, N. Akhtar, M.K. Okla, A. Al-Hashimi, W.H. Al-Qahtani, H. Abdelgawad, Polarity directed appraisal of pharmacological potential and HPLC-DAD based phytochemical profiling of Polygonum glabrum Willd, Molecules 27 (2022) 474.
[221] Y.F.G. da Costa, E.J. Llorent-Martínez, L.S. Fernandes, P.H.S. de Freitas, E. Scio, O.V. de Sousa, P.C. Castilho, M.S. Alves, Phenolics profiling by HPLC-DAD-ESI/MSn of the scientific unknown polygonum hydropiperoides michx. And its antioxidant and anti-methicillin-resistant Staphylococcus aureus activities, Plants 12 (2023) 1606.
[222] S.W. Qader, M.A. Abdulla, L.S. Chua, H.M. Sirat, S. Hamdan, Pharmacological mechanisms underlying gastroprotective activities of the fractions obtained from Polygonum minus in Sprague Dawley rats, Int. J. Mol. Sci. 13 (2012) 1481–1496.
[223] L. Custódio, S. Slusarczyk, A. Matkowski, V. Castañeda-Loaiza, E. Fernandes, C. Pereira, M.J. Rodrigues, A first approach for the micropropagation of the medicinal halophyte Polygonum maritimum L. and phenolic profile of acclimatized plants, Front. Plant Sci. 13 (2022) 960306.
[224] M. Saleem, M.F. Mushtaq, M.F. Akhtar, A. Saleem, S. Zahid, A. Sharif, B. Akhtar, E. Dar, M. Ullah, M. Badshah, Validation of hepatoprotective use of polygonum perfoliatum extract against paracetamol induced toxicity in Wistar rats, Acta Poloniae Pharmaceutica-Drug Research 76 (2019) 283–289.
[225] D. Han, J. Zhao, J. Xu, H. Peng, X. Chen, S. Li, Quality evaluation of Polygonum multiflorum in China based on HPLC analysis of hydrophilic bioactive compounds and chemometrics, J. Pharmaceut. Biomed. Anal. 72 (2013) 223–230.
[226] S. Liao, L. Zhang, F. Sun, Z. Wang, X. He, A. Wang, Y. Li, Y. Huang, Y. Lan, B. Zhang, Identification and characterisation of phenolics in Polygonum capitatum by ultrahigh-performance liquid chromatography with photodiode array detection and tandem mass spectrometry, Phytochem. Anal. 24 (2013) 556–568.
[227] S. Yang, W. Tian, Z. Pan, T. Lin, G. Wang, Q. Zhou, Y. Xue, H. Chen, Polyphenols from Polygonum cuspidatum reactivate latent HIV, Chem. Nat. Compd. 56 (2020) 318–322.
[228] Y.-X. Yang, M.-M. An, Y.-S. Jin, H.-S. Chen, Chemical constituents from the rhizome of Polygonum paleaceum and their antifungal activity, J. Asian Nat. Prod. Res. 19 (2017) 47–52.
[229] M. Cao, J. Wu, L. Wu, Z. Gu, C. Xie, L. Wu, J. Hu, G. Xu, Separation of three flavonoid glycosides from Polygonum multiflorum Thunb. leaves using HSCCC and their antioxidant activities, Eur. Food Res. Technol. (2022) 1–11.
[230] S. Das, S. Ganapaty, Phytochemical evaluation of roots of Polygonum viscosum Buch-ham, Indian J. Pharmaceut. Sci. 77 (2015) 352.
[231] M.Z. Abdullah, J. Mohd Ali, M. Abolmaesoomi, P.S. Abdul-Rahman, O.H. Hashim, Anti-proliferative, in vitro antioxidant, and cellular antioxidant activities of the leaf extracts from Polygonum minus Huds: effects of solvent polarity, Int. J. Food Prop. 20 (2017) 846–862.
[232] Y. Zhao, M.X. Chen, K.T. Kongstad, A.K. Jäger, D. Staerk, Potential of Polygonum cuspidatum root as an antidiabetic food: dual high-resolution α-glucosidase and PTP1B inhibition profiling combined with HPLC-HRMS and NMR for identification of antidiabetic constituents, J. Agric. Food Chem. 65 (2017) 4421–4427.
[233] J. Jiang, Volatile composition of the laksa plant (Polygonum hydropiper L.), a potential source of green note aroma compounds, Flavour Fragrance J. 20 (2005) 455–459.
[234] H. Ullah, C.D. Wilfred, M.S. Shaharun, Comparative assessment of various extraction approaches for the isolation of essential oil from polygonum minus using ionic liquids, J. King Saud Univ. Sci. 31 (2019) 230–239.
[235] F. Chen, J. Jia, Q. Zhang, L. Yang, H. Gu, Isolation of essential oil from the leaves of Polygonum viscosum Buch-ham. using microwave-assisted enzyme pretreatment followed by microwave hydrodistillation concatenated with liquid–liquid extraction, Ind. Crop. Prod. 112 (2018) 327–341.
[236] B.L. Narayanan, K. Kannappan, T. Subburaju, C. Sajeeth, GC-MS analysis and HPTLC fingerprinting profile of hydroalcoholic extract of Polygonum barbatum Linn. leaves, Indian J. Pharmaceut. Sci. 79 (2017) 477–482.
[237] A.F. Murray, H. Satooka, K. Shimizu, W. Chavasiri, I. Kubo, Polygonum odoratum essential oil inhibits the activity of mushroom derived tyrosinase, Heliyon 5 (2019) 12345.
[238] S. Saeidnia, P. Sarkhail, F. Moradi-Afrapoli, A. Gohari, M. Nikan, N. Mokhber-Dezfuli, G. Amin, A. Hajiakhondi, GC/Mass analysis of the volatile compounds of P. hyrcanicum diethyl ether extract and GC profiling of some Iranian Polygonum species, Research Journal of Pharmacognosy 1 (2014) 3–7.
[239] M. Ayaz, M. Junaid, F. Ullah, A. Sadiq, M. Ovais, W. Ahmad, S. Ahmad, A. Zeb, Chemical profiling, antimicrobial and insecticidal evaluations of Polygonum hydropiper L, BMC Compl. Alternative Med. 16 (2016) 1–14.
[240] R. Kawaree, W. Phutdhawong, P. Picha, J. Ngamkham, S. Chowwanapoonpohn, Chemical compounds, anticancer and antioxidant activities of volatile oil from piper sarmentosum roxb., Polyscias fruticose harms. And polygonum odoratum Lour, CURRENT APPLIED SCIENCE AND TECHNOLOGY 6 (2006) 499–504.
[241] I. Ismail, M.-C. Gor, Z.-A. Mohamed-Hussein, Z. Zainal, N.M. Noor, Alteration of abiotic stress responsive genes in Polygonum minus roots by jasmonic acid elicitation, Plants and Environment 3 (2011) 49–88.
[242] M. Derita, S. Zacchino, Chemotaxonomic importance of sesquiterpenes and flavonoids in five Argentinian species of Polygonum genus, J. Essent. Oil Res. 23 (2011) 11–14.
[243] Y.-S. Kim, C.-S. Hwang, D.-H. Shin, Volatile constituents from the leaves of Polygonum cuspidatum S. et Z. and their anti-bacterial activities, Food Microbiol. 22 (2005) 139–144.
[244] C.T.T. Quynh, STUDY ON THE AROMA MODEL OF Vietnamese CORIANDER LEAVES (Polygonum odoratum), Vietnam Journal of Science and Technology 54 (2016), 73–73.
[245] M.J. Rodrigues, L. Custódio, A. Lopes, M. Oliveira, N.R. Neng, J.M. Nogueira, A. Martins, A.P. Rauter, J. Varela, L. Barreira, Unlocking the in vitro anti-inflammatory and antidiabetic potential of Polygonum maritimum, Pharmaceut. Biol. 55 (2017) 1348–1357.
[246] W. Fan, J. Wu, M. Gao, X. Zhang, W. Zhu, Preparation of solid dispersion of polygonum cuspidatum extract by hot melt extrusion to enhance oral bioavailability of resveratrol, Molecules 28 (2023) 737.