

REVIEW ARTICLE

Open Access



# Blessings in disguise: a review of phytochemical composition and antimicrobial activity of plants belonging to the genus *Eryngium*

Sinem Aslan Erdem<sup>1</sup>, Seyed Fazel Nabavi<sup>2</sup>, Ilkay Erdogan Orhan<sup>3</sup>, Maria Daglia<sup>4</sup>, Morteza Izadi<sup>5</sup> and Seyed Mohammad Nabavi<sup>2\*</sup>

## Abstract

Medicinal and edible plants play a crucial role in the prevention and/or mitigation of different human diseases from ancient times to today. In folk medicine, there are different plants used for infectious disease treatment. During the past two decades, much attention has been paid to plants as novel alternative therapeutic agents for the treatment of infectious diseases due to their bioactive natural compounds such as phenol, flavonoids, tannins, etc. The genus *Eryngium* (Apiaceae) contains more than 250 flowering plant species, which are commonly used as edible and medicinal plants in different countries. In fact, some genus *Eryngium* species are used as spices and are cultivated throughout the world and others species are used for the treatment of hypertension, gastrointestinal problems, asthma, burns, fevers, diarrhea, malaria, etc. Phytochemical analysis has shown that genus *Eryngium* species are a rich source of flavonoids, tannins, saponins, and triterpenoids. Moreover, eryngial, one the most important and major compounds of genus *Eryngium* plant essential oil, possesses a significant antibacterial effect. Thus, the objective of this review is to critically review the scientific literature on the phytochemical composition and antibacterial effects of the genus *Eryngium* plants. In addition, we provide some information about traditional uses, cultivation, as well as phytochemistry.

**Keywords:** Antibacterial, *Eryngium*, Flavonoids, Saponins, Infection

## Background

Infectious diseases are known as one of the most important leading causes of long and short-term morbidity and mortality worldwide [1, 2]. According to the World Health Organization, in 2011, infectious diseases were responsible for approximately 18 million deaths worldwide. In addition to the high prevalence of infectious diseases, there are some microorganisms resistant to antibiotic therapy, which lead to the increase of death rate due their ability to acquire and transmit drug resistance [2]. Nowadays, antibiotic resistance is known as one the most important and challenging health problems in the global health programs. Therefore, during the past two decades, much attention has been paid to

the discovery and development of natural multi-target antimicrobial agents with high efficacy and low adverse effects [3]. Natural products are known as one of the most important and effective drugs for human disease treatment [4–6]. In addition to their efficacy, natural products are mostly non-toxic and therefore, they can be used as safe therapeutic strategies [7–9]. A plethora of scientific evidence reported that edible and medicinal plants have significant potential to synthesize antimicrobial agents as their defense mechanisms against biotic stresses such as microorganisms [10]. It has been reported that plant-derived antimicrobial compounds can be categorized into the different groups such as phenols, flavonoids, terpenoids, lectins, polypeptides, polyacetylenes as well as alkaloids [11]. In addition, in traditional medicine, many edible and medicinal plants have been widely used for the treatment of different infectious diseases [11, 12].

\* Correspondence: Nabavi208@gmail.com

<sup>2</sup>Applied Biotechnology Research Center, Baqiyatallah University of Medical Sciences, P.O. Box 19395-5487, Tehran, Iran

Full list of author information is available at the end of the article



The genus *Eryngium* contains more than 250 flowering species worldwide [13]. Genus *Eryngium* is the largest and most complex genus in Apiaceae family [13, 14]. Some species in the genus *Eryngium* are endangered such as *E. alpinum* L., *E. aristulatum* Jeps., *E. constancei* M.Y. Sheikh, *E. cuneifolium* Small, and *E. viviparum* J. Gay [13, 14]. According to the morphological studies, the genus *Eryngium* has been classified into five subgenera, including *Eryngium* subgenus *Eryngium*, *E.* subgenus *Monocotyloidea*, *E.* subgenus *Fruticosa*, *E.* subgenus *Semiaquatica*, and *E.* subgenus *Foetida* [15, 16]. *E.* subgenus *Eryngium* is the most common one throughout Europe, Africa and Asia, while the other subgenera are widely distributed in Australia [15, 16]. However, infrageneric analysis through sequence data of chloroplast DNA trnQ-trnK 5'-exon and nuclear ribosomal DNA ITS regions showed that there are two different subgenera including *Eryngium* and *Monocotyloidea* [17–19].

Like the other members of Apiaceae family, the genus *Eryngium* plants have various culinary and/or medicinal uses (Fig. 1) [20–23]. Several species have been widely used in traditional medicine such as *E. foetidum* L., *E. caucasicum* Trautv. (syn. *Eryngium caeruleum* M. Bieb.), *E. maritimum* L., *E. planum* L., *E. dichotomum* Desf., *E. campestre* L. and *E. creticum* Lam. [24–27], whereas *E. foetidum* and *E. caucasicum* have been widely cultivated in some Asian countries such as Iran, Turkey, etc. [27, 28].

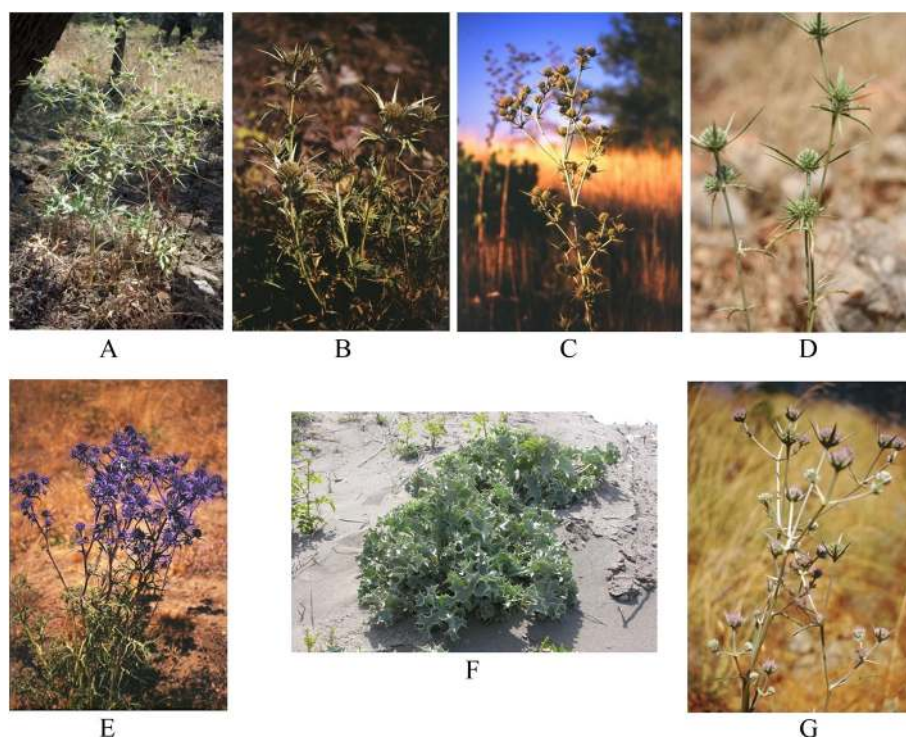
*E. caucasicum* is known as one the most common edible leafy vegetables in northern part of Iran and widely used in different foodstuff, pickles, etc. [28, 29]. Besides, the fruits of *E. foetidum* are known as common edible food components in Nigeria [30]. Actually, some *Eryngium* species are also used as ornamental plants [31]. A mountain of scientific evidence has shown that different species of the genus *Eryngium* possess antimicrobial effects under *in vitro* and *in vivo* conditions [32–36].

Therefore, the present paper aims to review the scientific literature on the phytochemical composition and antimicrobial activities of essential oils and extracts obtained from genus *Eryngium* species. In addition, we discuss about traditional uses, cultivation and phytochemistry of *Eryngium* species to provide a complete picture of this genus.

## Materials and methods

### Data sources and search strategy

Data were collected from Medline, Pubmed, Scopus, Web of Science (ISI Web of Knowledge), Science Direct, Embase, and BIOSIS Previews (from 1950 to July 20, 2015), via searching of these keywords: “*Eryngium* and phytochemistry or chemical compounds”, “*Eryngium* and antibacterial”, “*Eryngium* and antimicrobial”, and “*Eryngium* and biological effect”. We also scanned the reference list of each paper and searched Cochrane review library.



**Fig. 1** Some of species from *Eryngium* genus, *Eryngium campestre* L. (a), *Eryngium davisii* Kit Tan & Yildiz (b), *Eryngium isauricum* Contandr. & Quezel (c), *Eryngium falcatum* Delar. (d), *Eryngium kotschyi* Boiss. (e), *Eryngium maritimum* L. (f), *Eryngium trisetum* Wörz & H. Duman. (g)

Thereafter, the bibliographies of collected data were screened for further publications. Finally, collected data were analyzed and judged by second and third authors according to the scientific standard of conduct. However, some of the references may be published after the initial search date July 2015.

#### Traditional uses

In traditional medicine, some of *Eryngium* species have been used for treatment of several human diseases [24–27]. It has been reported that *E. campestre* L. is widely used as antitussive, stimulant, aphrodisiac, and diuretic agent in Turkish traditional medicine [37, 38]. *E. caucasicum* is one of the most important edible plants in the northern part of Iran due to its multiple beneficial effects on human health [29, 31, 39, 40]. Moreover, *E. creticum* has been used as hypoglycemic plant in the Jordanian traditional medicine [41], while *E. elegans* Cham. & Schltdl. has been reported to be utilized as diuretic agent in the Argentinian traditional medicine [42]. Most of *Eryngium* species are also known as medicinal plants worldwide for the treatment of several human diseases such as diarrhea, gastrointestinal problems, bladder and kidney dysfunctions, and venereal diseases [24–27, 43–45]. In Chinese traditional medicine, *E. foetidum* is widely used for treatment of inflammation [24] and *E. yuccifolium* Michx. roots have been traditionally used to treat snakebites, toothache [27, 46, 47], digestive problems, diarrhea, headache, etc. [24–27, 43–45]. A large scale of evidence has pointed out to multiple pharmacological effects of the genus *Eryngium* species including antioxidant, anti-inflammatory, antihemolytic, antinociceptive effects, and protective agent against neurodegenerative diseases [25, 28, 48–50]. For instance, *Eryngium planum*, which is a rare medicinal plant, was studied to determine the effect of subchronic administration of a 70 % ethanol root extract (200 mg/kg, p.o.) on behavioral and cognitive responses in experimental animals (Wistar rats) linked with the expression levels of mRNA coding for enzymes such as acetylcholinesterase (AChE), butyrylcholinesterase (BuChE), and beta-secretase (BACE-1). At the end of the experiment, after the last dose of the *Eryngium* extract, scopolamine (SC) was administered intraperitoneally to a group of animals (treated). In the animals treated with the *Eryngium* extract, an improvement in long-term memory produced by the EP extract in both scopolamine treated and control group was registered with decreased mRNA AChE, BuChE, and BACE-1 levels, especially in the frontal cortex, suggesting the potential efficacy of this extract in this kind of pathologies [25, 28, 48–50].

This is only an example of the fact in the last decade some investigations have been carried out to demonstrate

the potential pharmacological activity of *Eryngium* species extracts [51, 52].

#### Cultivation

Several genus *Eryngium* species have been widely used as edible plants in many countries and, consequently, mainly cultivated as an economic crop in tropical areas of the world [24, 28, 29]. In fact, numerous reports refer to the ideal and effective conditions for cultivating, harvesting as well as post-harvesting conditions of *Eryngium* species [24, 31, 53]. In the northern parts of Iran, *E. caucasicum* is one of the most important garden vegetables, which is mostly used in preparation of foodstuff, pickles, etc. [28, 29]. It has been reported that some *Eryngium* species are easily cultivated in dry, sandy, well-drained soils, and full sun [24, 31, 53]. Root cuttings are a common protocol for propagation of *Eryngium* species [24, 31, 53–55], which can also be propagated using other plant cuttings [24, 31, 53–55]. In addition, there is a close correlation between *Eryngium* species growth and fertilizer levels in the soil [24, 31, 53–55]. However, *Eryngium* species are significantly endangered by plant diseases as well as insect attacks [24, 31, 53–55].

#### Phytochemistry

Based on the review of the literature up to now, the aerial parts of *Eryngium* species have been reported to contain mainly saponins, flavonoids, and essential oil, while the underground parts contain triterpene saponins, monoterpene glycosides, phenolic compounds such as flavonoids and phenolic acids, coumarin derivatives, terpene aldehyde esters, acetylenes, essential oil, and oligosaccharides [56–60].

#### Saponins

The *Eryngium* species are the rich sources of triterpene saponins (Tables 1 and 2). Most of the saponins isolated from *Eryngium* species possess mainly hydroxylated oleanane-type aglycons such as A1-barrigenol (1), R1-barrigenol (2), or barringtogenol C (3) (Fig. 2). In addition to these core structures, cameliagenin A (4), erynginol A (5) and B, betulinic acid, oleanolic acid, and steganogenin (6) having glucose, glucuronic acid, rhamnose, xylose, galactose, and arabinose moieties have been also found in various *Eryngium* species (Fig. 2). The general saponin structures possess generally acetic, angelic, dimethylacrylic, and tiglic acid substituents, located predominantly at C21, C22 or C28 positions. On the other hand, isovaleric, *n*-butyric, and methyl butyric acids occur relatively rare substituents. Saponin glycosides found in *Eryngium* species are usually monodesmosidic saponins, where the bidesmosidic ones contain sugar groups at C3 and C28 positions [59, 61–65].

**Table 1** Triterpene saponins from *Eryngium* species isolated between 1970–1978

Source	Sapogenol	Type of sapogenol	Plant part	Ref.
<i>Eryngium planum</i> L.	Eryngiumgenin A	A1-barrigenol	Roots	[69]
	Eryngiumgenin B	A1-barrigenol		
	Eryngiumgenin C	R1- barrigenol		
	Eryngiumgenin D	R1- barrigenol		
<i>Eryngium planum</i> L.	Erynginol A	Barringtogenol C	Aerial	[70]
<i>Eryngium bromeliifolium</i> Delar.	Oleanic acid type of sapogenols	Oleanic acid	Leaves	[66]
<i>Eryngium planum</i> L.	Eryngiumgenin F	Barringtogenol C	Roots	[61]
	Eryngiumgenin G	n/a		
	Eryngiumgenin H	n/a		
	Eryngiumgenin J	n/a		
	Eryngiumgenin K	R1- barrigenol		
	Eryngiumgenin L	n/a		
<i>Eryngium bromeliifolium</i> Delar.	Betulinic acid		Leaves	[71]
<i>Eryngium giganteum</i> L.	Giganteumgenin A	n/a	Leaves	[67]
	Giganteumgenin B	n/a		
	Giganteumgenin C	Oleanic acid		
	Giganteumgenin D	n/a		
	Giganteumgenin E	n/a		
	Giganteumgenin G	n/a		
	Giganteumgenin H	n/a		
	Giganteumgenin K	n/a		
	Giganteumgenin M	Barringtogenol C		
	Giganteumgenin N	R1- barrigenol		
<i>Eryngium planum</i> L.	Eryngiumgenin E		Roots	[72]
<i>Eryngium bromeliifolium</i> Delar.	Betulinic acid-3-O- $\beta$ -glycoside		Leaves	[73]
<i>Eryngium maritimum</i> L.	Eryngiumgenin C and sapogenols with A1-barrigenol, R1-barrigenol and barringtogenol C structures		Aerial parts	[74]
<i>Eryngium amethystinum</i> L.	Main structure: Barringtogenol C			[68]
	R1-barrigenol			
	Erynginol A			
	A1-barrigenol			
<i>Eryngium bromeliifolium</i> Delar.	3-O-D-Glucopyranosyloleanolic acid-28-O-D-xylopyranoside (Saponin F)		Leaves	[62]
<i>Eryngium planum</i> L.	R1-barrigenol + an acid substituent and 2 glycopyranosyl moieties		Roots	[75] <sup>a</sup>

<sup>a</sup>This study was published in 1985 and it is the only study published between 1978-2002

The first phytochemical studies performed on the genus *Eryngium* starting from early 1970s were focused on their saponin content. According to the survey of the literature data published between 1970–1978 and in 1985, the identification of the isolated compounds was limited to the absolute definition of the aglycons with possible positions of sugars and acyl substituents because of inadequate chemical facilities in structure elucidation techniques [61, 66–68]. In this period, *E. planum*, *E. amethystinum* L., *E. giganteum* M. Bieb.,

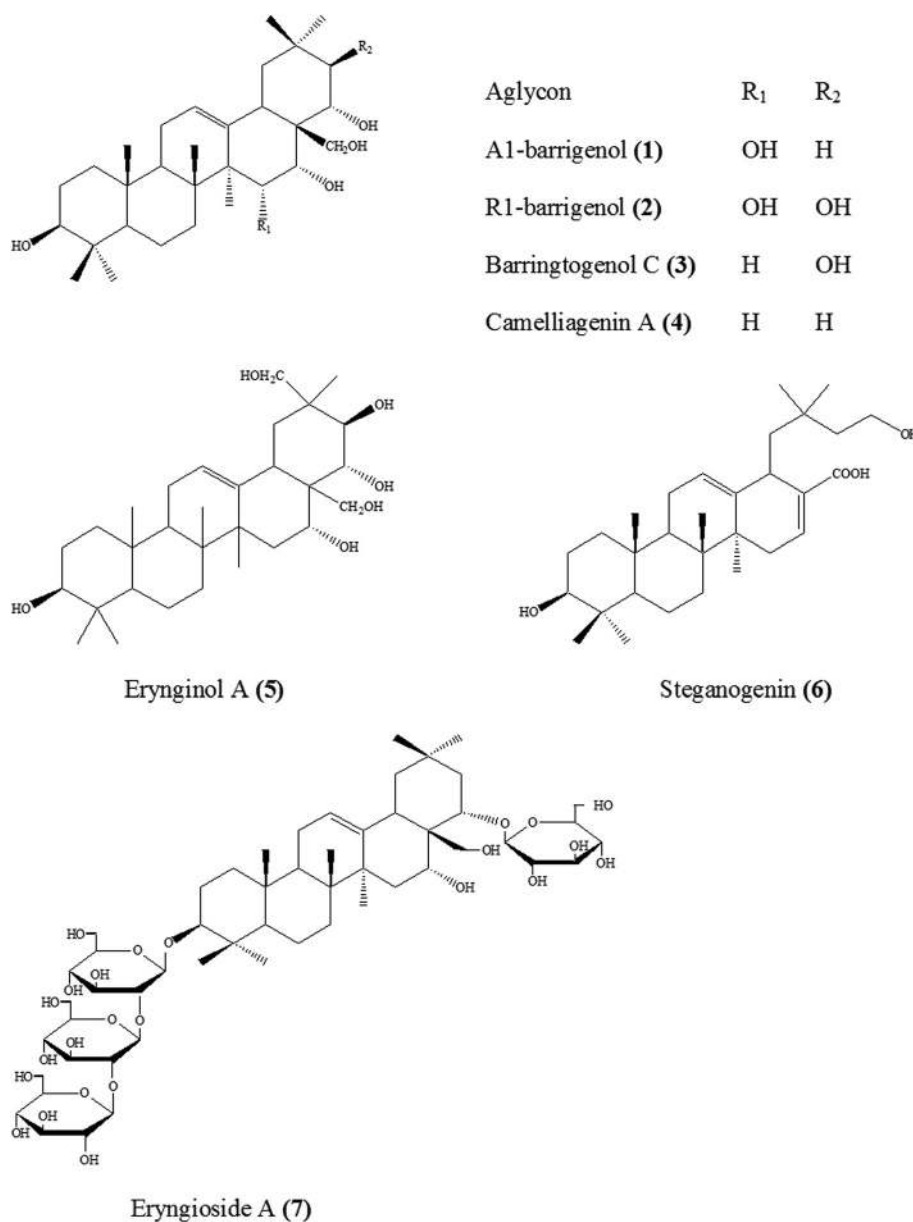
and *E. bromeliifolium* F. Delaroché were studied in more detail. As summarized in Table 1, A1-barrigenol and R1-barrigenol-type of aglycons containing dimethylacrylic, angelic, and/or tyglic acids as the acid moieties were isolated from the roots of the *E. planum*, named as eryngiumgenine A-D [69] of which only aglycon types were identified and classified according to the  $R_f$  values. Later, compound (5) was isolated from the aerial parts of this species [70]. Further phytochemical studies on the same plant were continued on the leaves and

**Table 2** Triterpene saponins from *Eryngium* species isolated after 2002

Source	Saponins	Plant part	Ref.
<i>Eryngium foetidum</i> (Linn)	O-(3)-[β-D-Glucopyranosyl-(1 → 2 rham)-β-D-fucopyranosyl-(1 → 3 rham)-α-L-rhamnopyranosyl-(1 → 4 glu)-β-D-glucopyranosyl]-olean-12-en-23,28-diol	Aerial parts	[30]
<i>Eryngium campestre</i> L.	3-O-β-D-Glucopyranosyl-(1 → 2)-[α-L-rhamnopyranosyl-(1 → 4)]-β-D-glucuronopyranosyl-22-O-Angeloyl-R1-barrigenol 3-O-β-D-Glucopyranosyl -(1 → 2)-[α-L- rhamnopyranosyl -(1 → 4)]-β-D- glucuronopyranosyl-22-O-β,β-dimethylacryloyl-A1-barrigenol	Roots	[59]
<i>Eryngium campestre</i> L.	3-O-α-L- Rhamnopyranosyl -(1 → 2)-β-D- glucuronopyranosyl -22-O-β,β- dimethylacryloyl -A1-barrigenol 3-O-α-L- rhamnopyranosyl -(1 → 2)-β-D- glucuronopyranosyl -22-O- angeloyl -R1-barrigenol 3-O-α-L- Rhamnopyranosyl -(1 → 2)-β-D- glucuronopyranosyl -21-O-acetyl-22-O- angeloyl -R1-barrigenol 3-O-α-L- Rhamnopyranosyl -(1 → 2)-β-D- glucuronopyranosyl -21-O- acetyl -22-O-β,β- dimethylacryloyl -R1-barrigenol 3-O-α-L- Rhamnopyranosyl -(1 → 2)-β-D- glucuronopyranosyl -22-O- angeloyl -28-O- acetyl -R1-barrigenol	Roots	[63]
<i>Eryngium yuccifolium</i> Michx.	3β-[β-D-Glucopyranosyl-(1 → 2)-β-D-glucopyranosyl-(1 → 2)]-β-D-glucopyranosyloxy-22α-β-D-glucopyranosyloxyolean-12-ene-16a, 28-diol (Eryngioside A) 3β-[β-D-Galactopyranosyl-(1 → 2)-β-D-glucopyranosyl-(1 → 2)]-β-D-glucopyranosyloxy-22α-β-D-glucopyranosyloxyolean-12-ene-16a, 28-diol (Eryngioside B) 3β-[β-D-Glucopyranosyl-(1 → 2)-β-D-glucopyranosyl-(1 → 2)]-β-D-glucopyranosyloxy-22α-β-D-glucopyranosyloxyolean-12-ene-16-oxo-28-ol (Eryngioside C) 3β-[β-D-Glucopyranosyl-(1 → 2)-β-D-glucopyranosyl-(1 → 2)]-β-D-glucopyranosyloxy-28-β-D-glucopyranosyloxyolean-12-ene-16a,22a-diol (Eryngioside D) 22α-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene-15a, 16a, 21β,28-tetrol (Eryngioside E) 22α-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene- 16a, 21β,28-triol (Eryngioside F) 21β-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[α-L-arabinopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene-15a, 16a, 22a,28-tetrol (Eryngioside G) 22α-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene- 15a, 16a,28-triol (Eryngioside H) 22α-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[α-L-arabinopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene- 15a, 16a,28-triol (Eryngioside I) 21β-Angeloyloxy-22α-acetyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D-glucuronopyranosyloxyolean-12-ene-15a, 16a,28-triol (Eryngioside J) 21β-Angeloyloxy-22α-acetyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene-16a,28-diol (Eryngioside K) 21β-Angeloyloxy-22α-acetyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[α-L-arabinopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene-16a,28-diol (Eryngioside L)	Whole plant	[64]
<i>Eryngium yuccifolium</i> Michx.	Saniculasaponin III Eryngiosides A-L 21 β-Acetyloxy-22 α -angeloyloxy-3 β-[β-D-glucopyranosyl-(1 → 2)]-[β-D-xylopyranosyl-(1 → 3)]-β-D-glucuronopyranosyloxyolean-12-ene-15a,16a,28-triol (Eryngioside M) 22α-Angeloyloxy-3β-[β-D-glucopyranosyl-(1 → 2)]-[α-L-arabinopyranosyl-(1 → 3)]-β-D- glucuronopyranosyloxyolean-12-ene-15a, 16a, 21β,28-tetrol (Eryngioside N)	Roots	[47]

**Table 2** Triterpene saponins from *Eryngium* species isolated after 2002 (Continued)

	Saniculasaponin II and III		
<i>Eryngium planum</i> L.	3-O-β-D-Glucopyranosyl-(1 → 2)-β-D-glucuronopyranosyl-21-O-acetyl-22-O-angeloyl-R1-barrigenol	Roots	[76]
	3-O-β-D-Glucopyranosyl-(1 → 2)-β-D-glucuronopyranosyl-22-O-angeloyl-A1-barrigenol		
	3-O-β-D-glucopyranosyl-(1 → 2)-β-D-glucuronopyranosyl-22-O-angeloyl-R1-barrigenol		
<i>Eryngium kotschy</i> Boiss.	3-O-α-L-Rhamnopyranosyl-(1 → 4)-β-D-glucuronopyranosyl-22-O-β,β-dimethylacryloylA1-barrigenol	Roots	[65]
	3-O-α-L-Rhamnopyranosyl-(1 → 4)-β-D-glucuronopyranosyl-22-O-angeloylA1-barrigenol		
	3-O-β-D-glucopyranosyl-(1 → 2)-[β-D-glucopyranosyl-(1 → 6)]-β-D-Glucopyranosyl-21,22,28-O-triacetyl-(3β,21β,22α)-olean-12-en-16-one		
	3-O-β-D-Glucopyranosyl-(1 → 2)- glucopyranosyl-22-O-β-D- glucopyranosylsteganogenin		
	3-O-β-D-Galactopyranosyl-(1 → 2)-[α-L-arabinopyranosyl-(1 → 3)]-β-D-glucuronopyranosyl-22-O-angeloyl-A1-barrigenol		
	3-O-α-L-Rhamnopyranosyl-(1 → 4)-β-D-glucuronopyranosyloleanolic acid		

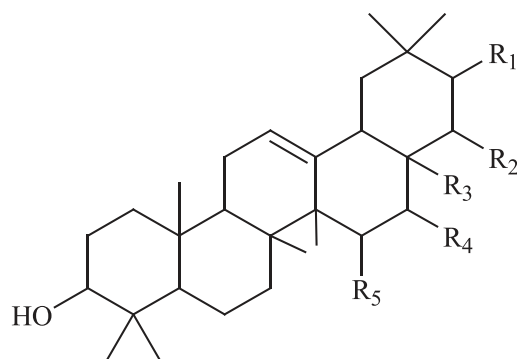


**Fig. 2** Saponin derivatives frequently found in *Eryngium* species

roots. These studies led to the isolation of a number of aglycons with (4), (3), (2) types possessing acetic, tyglic, butyric, and isovaleric acids located at C16, C21, C22 or C28 positions [71, 72]. Isolation of saponin aglycones such as (2) and (3), and saponins bearing (2) and (3) skeletons, named as giganteumgenin A (7), B (8), C (9), D (10), E (11), G (12), H (13), K (14), M (15), and N (16) (Fig. 3), was achieved from the methanol extract of the leaves of *E. giganteum* [67]. Another phytochemical investigation on *E. amethystinum* led to isolation of the saponins with main structures in (1), (2), (3), and (5) [68]. Other sapogenols isolated from various *Eryngium* species

until 1978 are listed in Table 1 [58, 62, 72–74]. Many years later, another R1-barringtogenol derivative with an acid moiety and two glycopyranosyl moieties was reported from *E. planum* roots by Voigt et al. in 1985 [75].

Most of the scientific articles concerning saponins of the genus *Eryngium* remained limited to the identification of the sapogenol type and determination of the acid or sugar substituents. After the late 70's, publications concerning the saponins from the genus *Eryngium* have become much more detailed as giving the whole structure elucidations as a result of the developments of the techniques used for structure elucidation. For



Sapogenol	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>5</sub>
<b>Giganteumgenin (7)</b>	A* -O-Angeloyl -O-Tigloyl -O-Dimethylacryloyl	-OCOCH <sub>3</sub>	-CH <sub>2</sub> OCOCH <sub>3</sub>	-OH	-H
<b>Giganteumgenin (8)</b>	B* -O-Angeloyl -O-Tigloyl -O-Dimethylacryloyl	-OCOCH <sub>3</sub>	-CH <sub>2</sub> OH	-OH	-H
<b>Giganteumgenin C (9)</b>	-H	-H	-COOH	-H	-H
<b>Giganteumgenin (10)</b>	D -OCOC <sub>4</sub> H <sub>7</sub>	-OCOCH <sub>3</sub>	-CH <sub>2</sub> OH	-OH	-OCOCH <sub>3</sub>
<b>Giganteumgenin (11)</b>	E* -O-Angeloyl -O-Tigloyl	-OH	-CH <sub>2</sub> OH	-OH	-H
<b>Giganteumgenin (12)</b>	G* -O-Angeloyl -O-Tigloyl	-OH	-CH <sub>2</sub> OH	-OH	-OH
<b>Giganteumgenin (13)</b>	H -OH	-OCOC <sub>4</sub> H <sub>7</sub>	-CH <sub>2</sub> OH	-OH	-OH
<b>Giganteumgenin (14)</b>	K -OH	-OCOC <sub>4</sub> H <sub>7</sub>	-CH <sub>2</sub> OH	-OH	-OH
<b>Giganteumgenin (15)</b>	M -OH	-OH	-CH <sub>2</sub> OH	-OH	-H
<b>Giganteumgenin (16)</b>	N -OH	-OH	-CH <sub>2</sub> OH	-OH	-OH

\*Mixture compound

**Fig. 3** Structures of giganteumgenins A-N

instance, Anam [30] reported the full configuration of a new oleanane-type triterpene saponin structure (17) from the aerial parts of *E. foetidum* (Fig. 4). Kartal et al. [59] characterized two new triterpene saponins (18, 19) from the roots of *E. campestre* bearing A(1) and (2) types, and isolated five new triterpene saponins (20–24), one of which was (1) and the others with (2) main skeleton (Fig. 5) [63]. Another phytochemical study performed on the whole parts of *E. yuccifolium* was reported by Zhang et al. [64], who described the isolation and identification of 12 new polyhydroxylated triterpenoid saponins named as eryngiosides A-L (28–39) and two known triterpenoid saponins {21 $\beta$ -angeloyloxy-3 $\beta$ -[ $\beta$ -D-glucopyranosyl-(1  $\rightarrow$  2)]-[ $\beta$ -D-xylopyranosyl-(1  $\rightarrow$  3)]- $\beta$ -D-glucuronopyranosyloxyolean-12-ene-15 $\alpha$ , 16 $\alpha$ , 22 $\alpha$ , 28-tetrol (44) and saniculasaponin III (43)} from the same species (Fig. 6). Furthermore, the root of *E. yuccifolium*

afforded two new polyhydroxyoleanene saponins [eryngioside M (40) and N (41)], together with 15 known triterpenoid saponins (28–39; 42–44) elucidated [47].

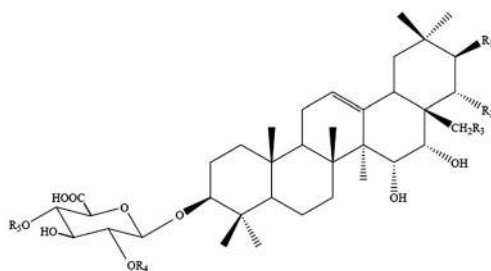
Further studies on the roots of *E. planum* led to the isolation of two R1- and one A1-barrigenol type of triterpene saponins [76], where 3-O- $\beta$ -D-glucopyranosyl-(1  $\rightarrow$  2)- $\beta$ -D-glucuronopyranosyl-21-O-acetyl-22-O-angeloyl-R1-barrigenol (25), 3-O- $\beta$ -D-glucopyranosyl-(1  $\rightarrow$  2)- $\beta$ -D-glucuronopyranosyl-22-O-angeloyl-A1-barrigenol (26) and 3-O- $\beta$ -D-glucopyranosyl-(1  $\rightarrow$  2)- $\beta$ -D-glucuronopyranosyl-22-O-angeloyl-R1-barrigenol (27) (Fig. 5) were also found to be present in the roots of *E. planum* [76]. Detailed phytochemical investigation on the roots of *E. kotschyi* Boiss., which is an endemic plant to Turkey, led to isolation of two known and four new triterpene saponins (45–48) (Fig. 7) [77].



### Flavonoids

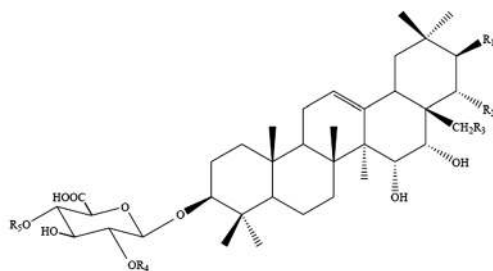
In an earlier study [78], isolation from *E. planum* of a new flavonol glycoside (identified as kaempferol-3-O-(6-O-β-D-glucopyranosyl)-β-D-galactopyranoside) was reported. A phytochemical study on the aerial parts of *E. campestre* led to the characterization of a new acylated flavonol named as kaempferol 3-O-β-D-(2'-Z-p-coumaroylglucoside) (**49**) along with 10 known compounds including tiliroside (**50**), kaempferol 3-O-β-D-glucosyl-7-O-α-L-rhamnoside (**51**), rutin (**52**), kaempferol (**53**), quercetin (**54**), isorhamnetin (**55**), caffeic acid, chlorogenic acid, and mannitol [58] as well as luteolin 7-glucoside [79] of which some selected structures are given in Fig. 8. Using UHPLC-ESI-Q-TOF-MS technique, quantification of a number of flavonols (quercetin, kaempferol, isorhamnetin, and their derivatives) and naringenin rhamnoglucoside (a flavanone derivative) was performed in *E. bourgatii* Gouan

by Cádiz-Gurrea et al. [48]. Hawas et al. [80] isolated 11 flavonoid glycosides (including isorhamnetin 3-O-α-rhamnoside, isorhamnetin 3-O-β-galactoside, isorhamnetin 3-O-β-glucoside, isorhamnetin 3-O-β-rutinoside, myricetin 3-O-β-galactoside 4'-methylether, myricetin 3-O-β-glucoside 3'-methylether, myricetin 3-O-β-glucoside 4'-methylether, quercetin 3-O-β-glucoside, quercetin 3-O-β-glucuronide 4'-methylether, and rutoside) from the aerial parts of *E. campestre*. Then, most recently, Khalfallah et al. [36] characterized five flavonoid derivatives from the aerial parts of *E. triquetrum* Vahl. described as kaempferol 3-O-β-D-glucoside, kaempferol 3-O-[6''-O-E-p-coumaroyl]-β-D-glucopyranoside, kaempferol 3-O-[2'',6''-di-O-E-p-coumaroyl]-β-D-glucoside, kaempferol 3-O-[α-L-rhamnosyl-(6 → 1)-O-β-D-glucoside], and quercetin 3-O-[α-L-rhamnosyl-(6 → 1)-O-β-D-glucoside].



Plant Name	Compound	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>5</sub>	Ref.
<i>E. campestre</i>	18	OH	Angeloyl	OH	Glycose	Rhamnose	56
<i>E. campestre</i>	19	H	Dimethylacryloyl	OH	Glycose	Rhamnose	56
<i>E. campestre</i>	20	H	Dimethylacryloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	21	OH	Angeloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	22	Acetyl	Angeloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	23	Acetyl	Dimethylacryloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	24	OH	Angeloyl	Acetyl	Rhamnose	H	60
<i>E. planum</i>	25	Acetyl	Angeloyl	OH	Glycose	H	73
<i>E. planum</i>	26	H	Angeloyl	OH	Glycose	H	73
<i>E. planum</i>	27	OH	Angeloyl	OH	Glycose	H	73

**Fig. 4** Structure of the (17) isolated from *E. foetidum*



Plant Name	Compound	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>5</sub>	Ref.
<i>E. campestre</i>	18	OH	Angeloyl	OH	Glucose	Rhamnose	56
<i>E. campestre</i>	19	H	Dimethylacryloyl	OH	Glucose	Rhamnose	56
<i>E. campestre</i>	20	H	Dimethylacryloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	21	OH	Angeloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	22	Acetyl	Angeloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	23	Acetyl	Dimethylacryloyl	OH	Rhamnose	H	60
<i>E. campestre</i>	24	OH	Angeloyl	Acetyl	Rhamnose	H	60
<i>E. planum</i>	25	Acetyl	Angeloyl	OH	Glucose	H	73
<i>E. planum</i>	26	H	Angeloyl	OH	Glucose	H	73
<i>E. planum</i>	27	OH	Angeloyl	OH	Glucose	H	73

**Fig. 5** Saponins isolated from *E. campestre* and *E. planum*

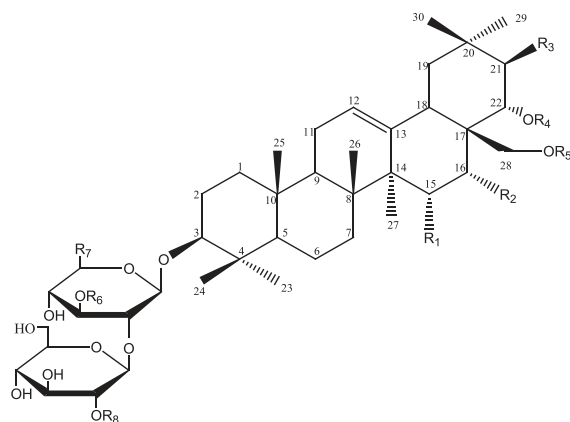
### Coumarin derivatives

The first coumarin derivatives isolated from *E. campestre* by Sticher & Erdelmeier [56] were agasyllin (**56**), grandivittin (**57**), aegelinol benzoate (**58**), and aegelinol (**59**) which structures are given in Fig. 9 [56]. The isolation of marmesin tiglate [also known as nodakenetin (**60**), Fig. 10] together with metetoin, a nitrogenous compound, was achieved from *E. ilicifolium* Lam. [81].

### Phenolic acid derivatives

Many *Eryngium* species have been reported to contain phenolic substances. Le Claire et al. [82] characterized chlorogenic (**63**), *R*-(+)-rosmarinic (**61**), and *R*-(+)-3'-*O*- $\beta$ -D-glucopyranosyl rosmarinic acids (**62**) in the roots of *E. alpinum* through medium pressure liquid chromatography

(MPLC) and preparative high pressure liquid chromatography (HPLC) (Fig. 11). Besides, the presence of *R*-(+)-rosmarinic acid and *R*-(+)-3'-*O*- $\beta$ -D-glucopyranosyl rosmarinic acid was also shown in several *Eryngium* species which could be used as chemotaxonomic markers specific to this genus. Two new caffeic acid derivatives, i.e. 3,4-dihydroxyphenyl caffeate and (4- $\beta$ -D-glucopyranosyloxy)-3-hydroxyphenyl caffeate, along with a new flavonoid (kaempferol-3-*O*-(2-*O*-*trans-p*-methoxycoumaroyl-6-*O*-*trans-p*-coumaroyl)- $\beta$ -D-glucopyranoside) were isolated from the whole parts of *E. yuccifolium* in addition to following known compounds, i.e. caffeic acid and kaempferol-3-*O*-(2,6-di-*O*-*trans-p*-coumaroyl)- $\beta$ -D-glucopyranoside [64]. Cádiz-Gurrea et al. [48] also revealed presence of cinnamic acid derivatives



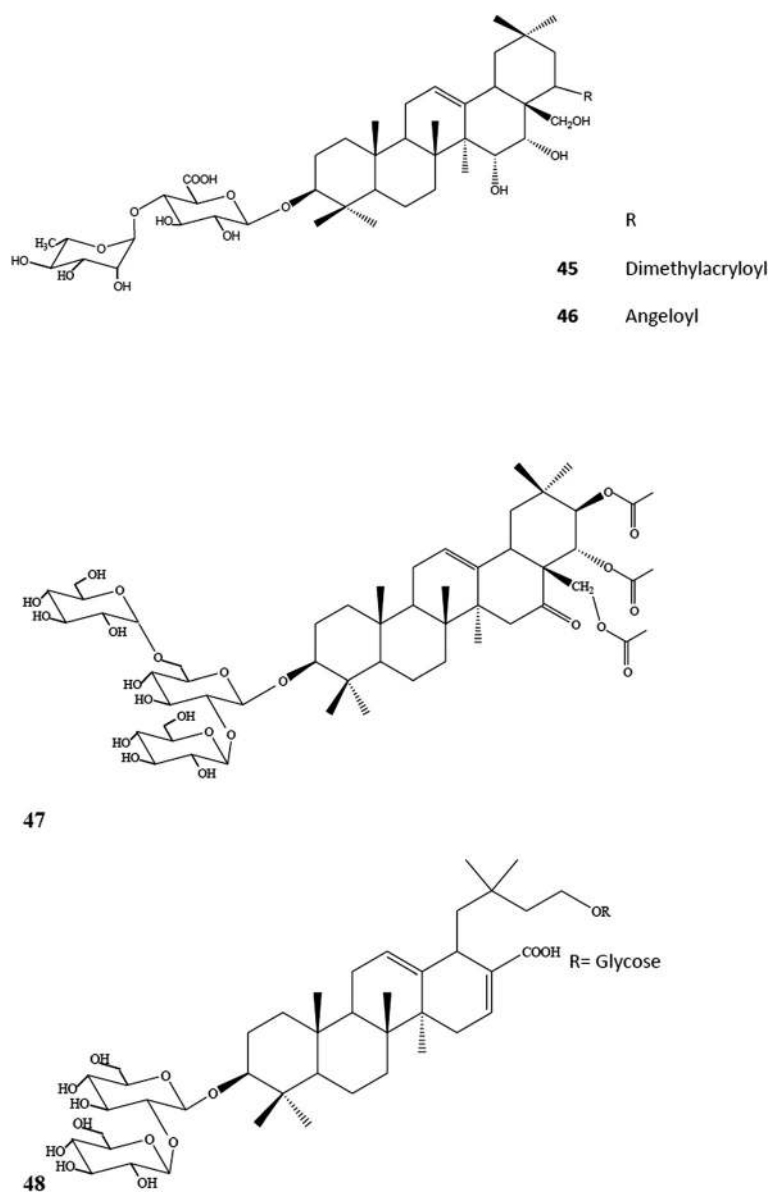
	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>5</sub>	R <sub>6</sub>	R <sub>7</sub>	R <sub>8</sub>
Eryngioside A (28)	H	OH	H	Glycose	H	H	CH <sub>2</sub> OH	Glycose
Eryngioside B (29)	H	OH	H	Glycose	H	H	CH <sub>2</sub> OH	Galactose
Eryngioside C (30)	H	=O	H	Glycose	H	H	CH <sub>2</sub> OH	Glycose
Eryngioside D (31)	H	OH	H	H	Glycose	H	CH <sub>2</sub> OH	Glycose
Eryngioside E (32)	OH	OH	OH	Angeloyl	H	Xylose	COOH	H
Eryngioside F (33)	H	OH	OH	Angeloyl	H	Xylose	COOH	H
Eryngioside G (34)	OH	OH	O- Angeloyl	H	H	Arabinose	COOH	H
Eryngioside H (35)	OH	OH	H	Angeloyl	H	Xylose	COOH	H
Eryngioside I (36)	OH	OH	H	Angeloyl	H	Arabinose	COOH	H
Eryngioside J (37)	OH	OH	O- Angeloyl	Acetyl	H	Xylose	COOH	H
Eryngioside K (38)	H	OH	O- Angeloyl	Acetyl	H	Xylose	COOH	H
Eryngioside L (39)	H	OH	O- Angeloyl	Acetyl	H	Arabinose	COOH	H
Eryngioside M (40)	OH	OH	O-Acetyl	Angeloyl	H	Xylose	COOH	H
Eryngioside N (41)	OH	OH	OH	Angeloyl	H	Arabinose	COOH	H
Saniculasaponin II (42)	OH	OH	O-Acetyl	Angeloyl	H	Arabinose	COOH	H
Saniculasaponin III (43)	OH	OH	O- Angeloyl	Acetyl	H	Arabinose	COOH	H
Compound 44	OH	OH	O- Angeloyl	H	H	Xylose	COOH	H

**Fig. 6** Saponins isolated from *E. yuccifolium*

(chlorogenic, rosmarinic, ferulic, caffeic acids, and their derivatives), benzoic acid derivatives (*p*-hydroxybenzoic acid glucoside, arbutin, syringic acid, glucogallin, gentisic acid, and their derivatives) and various organic acids (gluconic, citric, quinic acids, and their derivatives) in *E. bourgatii* using hyphenated advance liquid chromatographic separation techniques. On the other hand, catechin, epicatechin, chlorogenic, gallic, and rosmarinic acids were determined quantitatively in the roots of *E. palmatum* Pančić & Vis. [83]. In a similar study [60], chlorogenic, hydroxybenzoic, and caftaric acids were detected in *E. bornmuelleri* Nábělek along with trace amounts of caffeic, ferulic, and rosmarinic acids.

#### Other types of compounds

Drake and Lam [84] reported the isolation of falcarinone, a widespread acetylenic compound occurring in Apiaceae. 6-Pentyl-2-[2-oxo-butin(3)-yliden]-tetrahydropyranone from the aerial parts and roots of *E. bourgatii* and the acetylenic compounds identified as *Z* and *E* isomers of the same compound were also obtained from this species in addition to falcarinone, falcarinolone, falcarinol, and scopoletin [85]. Further phytochemical studies ensued in the characterization of two new monoterpene glycosides of the cyclohexenone type, elucidated as 3-(β-D-glucopyranosyloxymethyl)-2,4,4-trimethyl-2,5-cyclohexadien-1-one and 3-(β-D-glucopyranosyloxymethyl)-2,4,4-trimethyl-2-

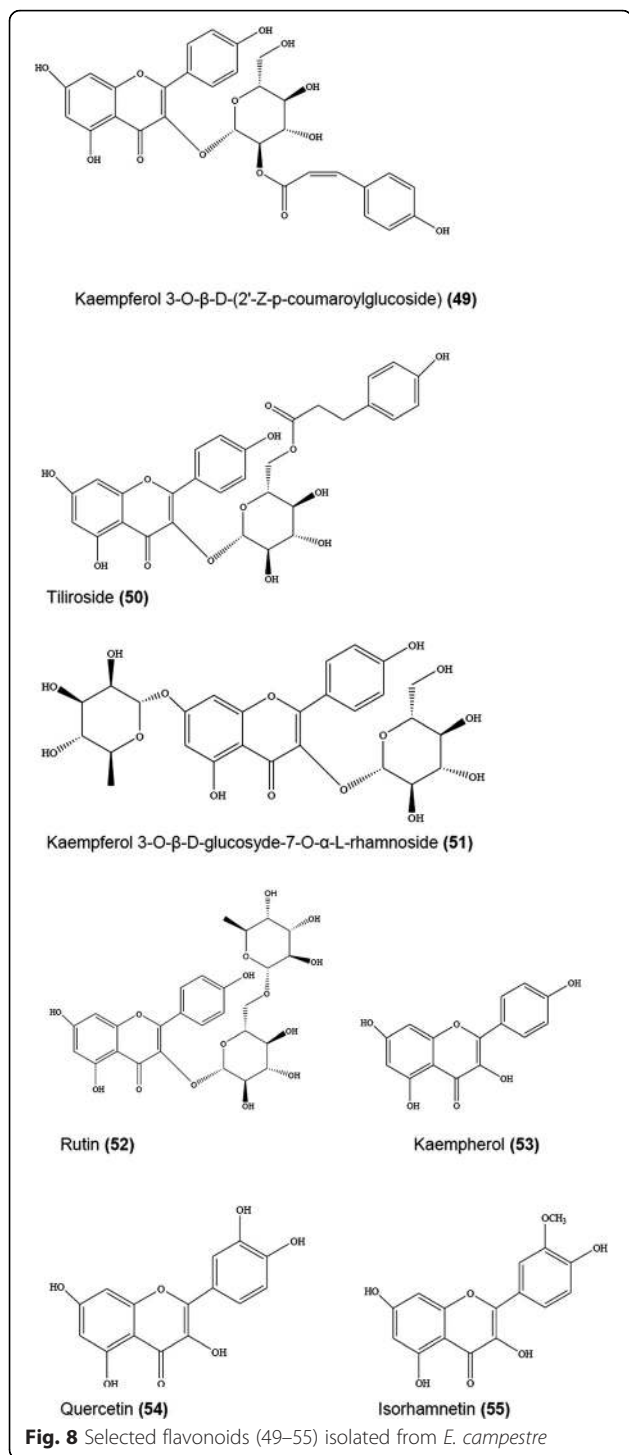


**Fig. 7** Chemical structure of triterpene saponins

cyclohexen-1-one [57]. An unusual sesquiterpene whose structure was established as 1-*n*-propyl-perhydronaphthalene 1,2,4a,5,6,7,8,8a-octahydro-4-methyl-1-propyl-naphthalene-7-carbaldehyde was reported from the aerial parts of *E. creticum* [86], while new ester derivatives, characterized as *cis*-chrysanthenyl hexanoate and *cis*-chrysanthenyl octanoate, were isolated from *E. planum* [87].

In order to find out the compounds possibly responsible for the anti-inflammatory activity of *E. foetidum*, composition of the hexane extract from the leaves of this species was subjected to GC and GC-MS analyses [88]. Hereby,  $\alpha$ -cholesterol, brassicasterol, campesterol, stigmasterol (as the main component, 95 %), clerosterol,  $\beta$ -sitosterol,  $\Delta_5$ -avenasterol,  $\Delta_5$ 24-stigmastadienol, and  $\Delta_7$ -avenasterol

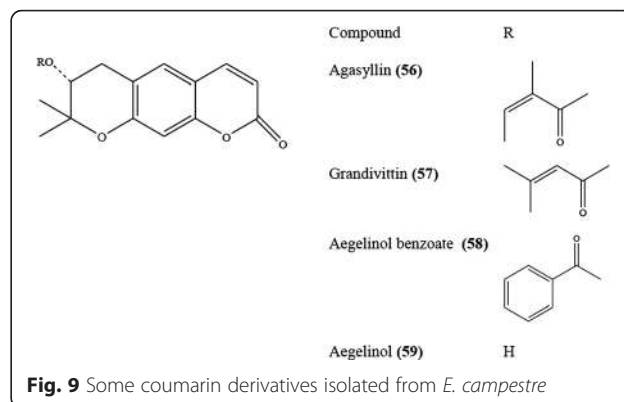
were detected in the extract. Muckensturm et al. [89] reported a phytochemical study performed on the diethyl ether extracts from *E. giganteum*, *E. variifolium* Coss., *E. planum*, and *E. maritimum*. Chromatographic separation techniques applied to the seed extract of *E. giganteum* led to the elucidation of a new *nor*-sesquiterpene hydrocarbon, i.e. 15-*nor*- $\alpha$ -muurolene (gigantene), and germacrene-D, *trans*- $\beta$ -farnesene, 15-oxy- $\alpha$ -muurolene, 15-hydroxy- $\alpha$ -muurolene, ledol, and spatulenol. Similar studies on the seeds of the *E. planum* gave way to isolation of *cis*-chrysanthenyl acetate, while isoferulyl senecioate and 2,3,4-trimethylbenzaldehyde were obtained from the leaves of *E. variifolium*. Nevertheless, it should be noted that the latter compound was considered as artifact by these authors. In



another study [90], *E. foetidum* was subjected to isolation procedures which finally afforded *trans*-2-dodecanal (eryngial) in pure form.

#### Essential oil

Essential oil compositions of numerous *Eryngium* species have been investigated by many researchers. As illustrated

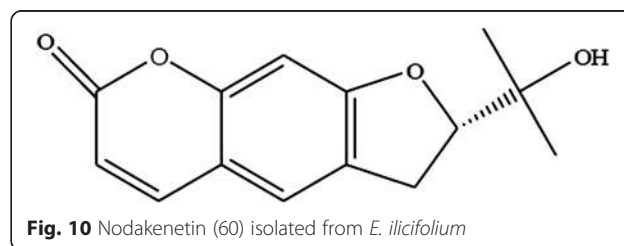


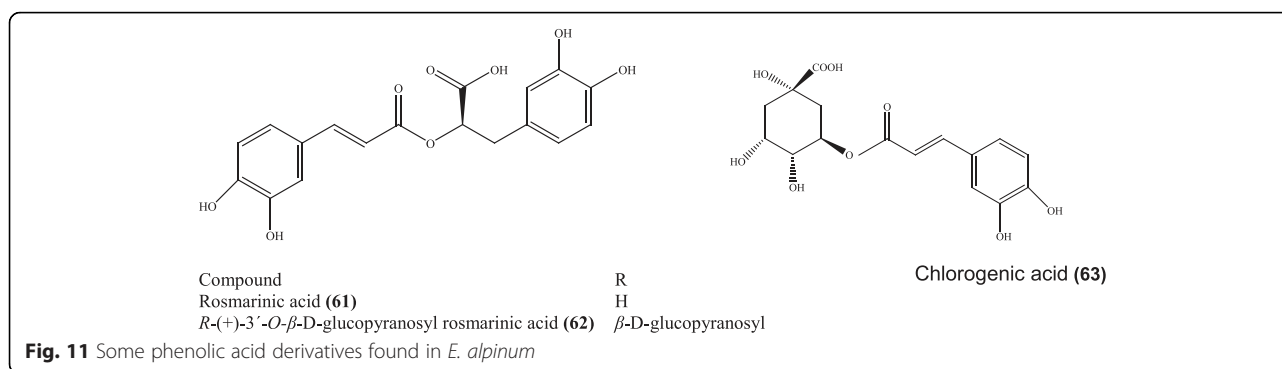
with their corresponding references in Table 3, a great interspecies variation could be easily observed. However, the most common monoterpenes analyzed in different plant parts of *Eryngium* species have been as follows; germacrene D,  $\alpha$ -pinene, caryophyllene, muurolene,  $\alpha$ - and  $\beta$ -selinene, limonene,  $\alpha$ - and  $\beta$ -bisabolol, etc., whereas many hydrocarbons and some aromatics such as trimethylbenzaldehyde and dodecenal have been detected.

#### Antimicrobial effects of the genus *Eryngium* plants

Plants are known to produce antimicrobial substances [10], which act as plant defense mechanisms and protect them against abiotic and biotic stresses. These antimicrobial agents, which are often characterized by low adverse effects and wide spectrum activities, belong to many chemical classes such as phenolics and polyphenolics, terpenoids, alkaloids, lectins, polypeptides, and polyacetylenes [11].

Among the plants belonging to the genus *Eryngium*, some species exhibit considerable antimicrobial activity against gram-positive and gram-negative bacteria, some species of fungi and yeasts and viruses. Within this genus, the most studied species has been *E. foetidum*, which is cultivated across South Asia and Europe, Tropical Africa, and Pacific islands. As regards the antibacterial activity of *E. foetidum* extracts, the literature data are conflicting. In fact, in 2003, Alzoreky and Nakahara reported that the acetone and buffered methanol extracts obtained from *E. foetidum* leaves did not show any antibacterial activity against *Escherichia coli*, *Salmonella*





*infantis*, *Listeria monocytogenes* Tottori, *Staphylococcus aureus* and *Bacillus cereus* [91].

More recently, Ndip et al. showed that the methanolic extract from *E. foetidum* leaves showed moderate antibacterial activity against 6 clinical strains of *Helicobacter pylori* out of 15 tested strains, using the disk diffusion technique as antibacterial susceptibility test [92]. Besides antibacterial activity, *E. foetidum* was tested for its antiplasmodial activity, using chloroquine as positive control to evaluate the sensitivity of susceptible *Plasmodium falciparum* strains. The leaf extracts were prepared using hexane, dichloromethane, and methanol to obtain three extracts. The dried extracts were then dissolved in DMSO to give a stock solution at 10 mg/mL, used for the biological tests. The results indicated that *E. foetidum* showed low in vitro antiplasmodial activity against *P. falciparum*, with an IC<sub>50</sub> value of 25 μg/mL [93].

Another species belonging to genus *Eryngium*, is *E. maritimum*, which is a wild perennial species growing on sand beaches in West Europe, the Mediterranean basin, and the Black Sea and has been used for its diuretic, stimulant, cystotonic, stone inhibitor, aphrodisiac, expectorant, and anthelmintic properties (<http://www.botanicals.com>, <http://www.crescentbloom.com>). The essential oil, obtained from hydrodistillation of the aerial parts, was found to contain a known sesquiterpene (muurol-9-en-15-al) and three new oxygenated sesquiterpenes with a muurolane or cadinane skeleton (4βH-cadin-9-en-15-al, 4βHmuurol-9-en-15-ol, and 4βH-cadin-9-en-15-ol). The sesquiterpenoid-rich fraction was tested in vitro using the agar diffusion method and the minimum inhibitory concentration (MIC) in the liquid phase against *L. monocytogenes* and *E. coli*. The finding revealed that the antibacterial activity of the new oxygenated sesquiterpenes against the tested bacteria, with an inhibition diameter higher than 15 mm and a MIC value lower than 90 μg/mL [94].

Another investigation on *E. maritimum* showed that the leaf hydromethanolic extract fractionated into a polar (aqueous) and apolar (chloroformic) fraction and tested using the microdilution method against food-

borne pathogens and clinical isolates, exhibited antimicrobial activity. The tested Gram-positive bacteria were *S. aureus* subsp. *aureus*, *Micrococcus luteus*, *L. monocytogenes* and *B. cereus*. The Gram-negative bacteria were two strains of *Salmonella* (*S. enterica* subsp. *arizonae* and *S. enterica* subsp. *montevideo*), three strains of *Pseudomonas* (*P. aeruginosa*, *P. fluorescens*, and *P. marginalis*), *E. coli*, and *Erwinia carotovora* subsp. *carotovora*, and a yeast (*Candida albicans*). According to the data obtained, the fractions resulted to be active against all bacteria with the exception of *L. monocytogenes*, while the most sensitive bacteria were *P. aeruginosa* and *P. fluorescens*, with MIC values of 1 and 2 μg/mL for the polar and apolar fractions, respectively [95].

The essential-oil composition and antimicrobial activity of three other species belonging to genus *Eryngium* (*E. creticum*, *E. campestre*, and *E. thorifolium*), whose infusions obtained from the aerial and root parts are commonly used in Turkish folk medicine as antitussive, diuretic, stimulant, and aphrodisiac, were studied [96]. The composition of *E. thorifolium* was found to be rich in α-pinene, a known antibacterial terpenic compound, which was present in fewer amounts in the other two species. Differently, *E. creticum* was found to be rich in hexanal, which was present in less amount in *E. thorifolium* and was not detected in *E. campestre*. Antibacterial activity of the essential oils was tested with the disc diffusion method against nine clinical strains of methicillin-resistant *S. aureus* (MRSA). The essential oil obtained from *E. thorifolium*, which caused an inhibition zone ranging from 13 to 19 mm (similar to that exhibited by vancomycin and oregano essential oil tested at 10 μL/disc and 5 μL/disc, respectively), was demonstrated to be the most active species [37]. As aforementioned, many *Eryngium* species, e.g. *E. maritimum* exerted antifungal activity against *C. albicans* and other strains. Especially, the essential oil obtained by water distillation of the aerial parts of *E. duriaei* Gay ex Boiss subsp. *juresianum* (M.Lainz) M. Lainz was tested for its antifungal activity against 13 fungi, among which there were seven dermatophyte species (*Microsporum canis* FF1,

**Table 3** The major components in the essential oils of various *Eryngium* species

Plant Name	Plant part	Major components	Ref.
<i>Eryngium alpinum</i> L.	Aerial parts	Caryophyllene oxide (21.6 %) Bicyclgermacrene (11.8 %) Germacrene D (10.3 %)	[98]
<i>Eryngium amethystinum</i> L.	Aerial parts	$\beta$ -Caryophyllene (19.7 %) $\alpha$ -Bisabolol (7.9 %) 2,3,6-Trimethylbenzaldehyde (7.9 %)	[98]
	Leafy parts of the shoots	$\alpha$ -Pinene (11.8 %) 2,3,6-Trimethylbenzaldehyde (24.7 %) Germacrene D (31.3 %)	[99]
	Inflorescence	$\alpha$ -Pinene (25.6 %) 2,3,6- Trimethylbenzaldehyde (22.0 %) Germacrene D (14.5 %)	
	Fruit	$\alpha$ -Pinene (17.0 %) 2,3,6-Trimethylbenzaldehyde (16.9 %) Germacrene D (7.6 %)	
<i>Eryngium billardieri</i> F. Delaroche	Aerial parts	$\alpha$ -Muuroleone (42.0 %) $\beta$ -Gurjunene (17.0 %) $\delta$ -Cadinene (6.2 %) Valencene (5.7 %)	[39]
<i>Eryngium bourgatii</i> Gouan	Inflorescence	Phyllocladene (37.6 %) Bicyclgermacrene (15.1 %)	[13]
	Stems & leaves	Phyllocladene (20.4 %) $\gamma$ -Muuroleone (11.8 %) (E)-Caryophyllene (10.1 %)	
	Roots	$\gamma$ -Muuroleone (15.4 %) Phyllocladene (15.0 %)	
<i>Eryngium bungei</i> Boiss.	Aerial parts	Cumin alcohol (55.3 %) Terpinolene (14.6 %) Carvacrol (8.9 %) Limonene (7.5 %)	[100]
	Aerial parts	Borneol (44.4 %) Isobornyl formate (14.7 %) Isoborneol (9.2 %) 1,8-Cineol (9.1 %) Camphor (7.9 %)	[101]
<i>Eryngium caeruleum</i> M.B.	Aerial parts	Limonene (60.5 %) $\delta$ -3-Carene (13.0 %)	[102]
	Aerial parts	Cyclobuta[1-4]dicycloocten Hexadecahydro (47.03 %) <i>n</i> -Hexadecanoic acid (11.16 %) Limonene (4.23 %) <i>Cis</i> - $\alpha$ -bisabolene (2.14 %)	[35]

**Table 3** The major components in the essential oils of various *Eryngium* species (Continued)

<i>Eryngium campestre</i> L.	Inflorescence	Germacrene D (30.3–40.3 %) β-Curcumene (0.7–22.2 %) Myrcene (3.0–21.7 %) (E)-β-Farnesene (0.1–19.0 %)	[103]
	Stems & leaves	Germacrene D (31.1–42.4 %) Myrcene (0.5–23.15 %)	
<i>Eryngium caucasicum</i> Trautv.	Leaves (coastal samples)	4(5)-Acetyl-1H-imidazole (63.6 %) Thymol (13.9 %) β-Sesquiphellandrene (10.0 %)	[104]
	Leaves (hill slope samples)	β-Sesquiphellandrene (44.3 %) Limonene (20.1 %) Trans-β-Farnesene (14.1 %)	
<i>Eryngium corniculatum</i> Lam.	Inflorescence	2,4,6-Trimethylbenzaldehyde (50.8 %) α-Pinene (4.0 %) Crystanethylacetate (4.0 %) 2,4,5-Trimethylbenzaldehyde (3.3 %)	[105]
	Stems & leaves	2,4,6-Trimethylbenzaldehyde (50.0 %) 2,4,5-Trimethylbenzaldehyde (3.8 %)	
	Roots	2,4,6-Trimethylbenzaldehyde (29.8 %) Phyllocladene isomer (13.0 %) (E)-Nerolidol (9.4 %)	
<i>Eryngium creticum</i> Lam.	Flowering aerial parts	Hexanal (52.9 %) Heptanal (13.9 %) Octane (8.95 %)	[37]
<i>Eryngium duriaei</i> subsp. <i>juresianum</i> (M. Lainz) M. Lainz	Aerial parts	α-Neocallitropsene (26.0 %) Isocaryophyllen-14-al (16.2 %) 14-Hidroxy-β-caryophyllene (13.4 %) Caryophyllene oxide (7.6 %) E-β-Caryophyllene (6.3 %)	[106]
<i>Eryngium expansum</i> F. Muell.	Aerial parts	7-Epi-Selinene (38.3 %) Cis-β-Guaiene (10.8 %) 2,3,6-Trimethylbenzaldehyde (8.0 %)	[107]
<i>Eryngium foetidum</i> L.	Aerial parts	2,3,6-Trimethylbenzaldehyde (5.5–23.7 %) (E)-2-Dodecenal (15.9–37.5 %) (E)-2-Tetradecenal (18.7–25.3 %)	[108]
	Aerial parts	2,4,5-Trimethylbenzaldehyde (27.7 %) (E)-2-Dodecenal (27.5 %) Carotol (8.8 %) 3-Dodecenal (5.2 %)	[109]
	Aerial parts	(E)-2-Dodecenal (57.79–67.08 %) Lauraldehyde (7.04–11.53 %) 13-Tetradecenal (8.99–9.03 %)	[110]
	Leaves	2,4,5-Trimethylbenzaldehyde (20.53 %) Hexadecanoic acid (12.05 %) Carotol (9.94 %)	[111]



**Table 3** The major components in the essential oils of various *Eryngium* species (Continued)

	Roots	Duraldehyde (37.60–53.14 %) 13-Tetradecenal (7.22–13.16 %) (E)-2-Dodecenal (7.14–11.62 %) Falcarinol (3.44–8.06 %)	[110]
<i>Eryngium glaciale</i> Boiss.	Inflorescence	Phyllocladene isomer (43.5 %) (E)-Caryophyllene (15.2 %) Valencene (11.5 %)	[112]
	Stems & leaves	Phyllocladene isomer (41.3 %)	
	Roots	Phyllocladene isomer (49.4 %) Linalool (19.1 %)	
<i>Eryngium maritimum</i> L.	Aerial parts	Spathulenol (18.99 %) Caryophyllene oxide (8.18 %)	[77]
	Aerial parts	Germacrene D (10.4 %) 2,4,5-Trimethylbenzaldehyde (8.3 %)	[113]
	Roots	Germacrene D (15.9 %) 2,4,5-Trimethylbenzaldehyde (6.7 %)	
	Aerial parts	Germacrene D (13.7–45.9 %) 4 $\beta$ H-Cadin-9-en-15-al (18.4–27.6 %) 4 $\beta$ H-Cadin-9-en-15-ol (2.2–14.3 %) 4 $\beta$ H-Muurool-9-en-15-al (4.3–9.3 %)	[114]
<i>Eryngium pandanifolium</i> Cham. et Schlecht	Leaves	Bornyl acetate (20.8 %) $\beta$ -Selinene (13.8 %) $\alpha$ -Selinene (11.3 %)	[107]
	Fruit	Octanal (11.5 %) $\beta$ -Selinene (9.2 %)	
<i>Eryngium palmatum</i>	Roots	Octanal (31.7 %) Curcumene (5.9 %) 2,3,6-Trimethylbenzaldehyde (5.4 %)	[115]
<i>Eryngium paniculatum</i> Cav.	Inflorescence	(E)-Anethole (52.6 %) $\alpha$ -Pinene (19.1 %)	[116]
<i>Eryngium planum</i> L.	Inflorescence	Cis-Chrysanthenyl acetate (43.2 %)	[117]
	Stalk leaves	Limonene (14.7 %) $\beta$ -Pinene (9.8 %)	
	Rosette leaves	Bornyl acetate (18.1 %) Limonene (11.3 %) Terpinen-4-ol (10.9 %)	
	Roots	Falcarinol (64.4 %)	
<i>Eryngium rostratum</i> Cav.	Stem	Spathulenol (20.0 %) $\beta$ -Bisabolol (8.6 %) Caryophyllene oxide (8.0 %)	[107]
	Fruit	$\gamma$ -Terpinene (4.5 %) $\alpha$ -Muurolene (3.9 %)	
<i>Eryngium rosulatum</i> P. W. Michael ined.	Aerial parts	$\beta$ -Elemene (16.0 %) Bicyclogermacrene (12.5 %) $\delta$ -Elemene (7.0 %)	[118]

**Table 3** The major components in the essential oils of various *Eryngium* species (Continued)

<i>Eryngium thoriifolium</i> Boiss.	Flowering aerial parts	(1R)- $\alpha$ -Pinene (58.6 %) Limonene (3.14 %)	[37]	
<i>Eryngium tricuspdatum</i> L.	Aerial parts	$\alpha$ -Bisabolol (32.6 %) $\alpha$ -Curcumene (6.5 %)	[34]	
<i>Eryngium vesiculaosum</i> Labill.	Winter leaves	$\beta$ -Caryophyllene (20.3 %) Germacrene D (19.2 %) $\alpha$ -Humulene (8.8 %)	[119]	
	Summer leaves	Bicyclgermacrene (22.2 %) $\beta$ -Caryophyllene (15.6 %) Germacrene D (15.8 %) $\alpha$ -Humulene (8.1 %)		
<i>Eryngium yuccifolium</i> Michaux.	Leaves	Germacrene D (18.3 %) Terpinolene (17.8 %) Bicyclgermacrene (8.8 %) $\alpha$ -Pinene (7.6 %) $\beta$ -Caryophyllene (6.2 %) Falcarinol (9.6 %)	[120]	
		Stalks		Germacrene D (38.4 %) $\gamma$ -Amorphene (12.2 %) Bicyclgermacrene (10.1 %) Bicyclosquiphellandrene (3.4 %) Falcarinol (3.2 %)
				Roots

*Trichophyton mentagrophytes* FF7, *Epidermophyton floccosum* FF9, *M. gypseum* CECT 2905, *T. rubrum* CECT 2794, *T. mentagrophytes* var *interdigitale* CECT 2958 and *T. verrucosum* CECT 2992), five *Candida* species (two clinical isolates from recurrent cases of vulvovaginal or oral candidosis, *C. krusei* (H9) and *C. guilliermondii* MAT23, along with three reference species of *C. albicans* ATCC 10231, *C. tropicalis* ATCC 13803, and *C. parapsilosis* ATCC 90018) and a strain of *Cryptococcus neoformans* CECT 1078. Using the macrodilution broth method the MIC and Minimal Lethal Concentrations (MLC) were determined. The results disclosed that the essential oil did not possess antifungal activity against *Candida* strains, with the exception of *C. guilliermondii*, which resulted to be sensitive to the antifungal activity of the oil with a MIC and MLC of 2.5  $\mu$ L/mL. On the contrary, the essential oil had MIC values of 0.16–0.32  $\mu$ L/mL against all the tested dermatophyte species. The essential oil was further studied to determine its chemical composition by GC-MS and the authors suggested that caryophyllene derived compounds [isocaryophyllen-14-

al (16.2 %), 14-hidroxy- $\beta$ -caryophyllene (13.4 %), caryophyllene oxide (7.6 %) and *E*- $\beta$ -caryophyllene (6.3 %)] are probably the responsible for the antifungal activity [97].

Finally, in 2013, the antiphytoviral activity of the essential oils obtained by water distillation of the aerial parts of *E. alpinum* and *E. amethystinum* cultivated in Croatia was described. The antiviral activity was shown in *Chenopodium quinoa* treated with the essential oils (250 ppm) prior to the inoculation of cucumber mosaic virus associated with a satellite RNA. The number of leaf local lesions, registered in the presence of the essential oils, was strongly reduced from an average value of  $14.9 \pm 0.8$  to  $3.3 \pm 0.2$  and  $2.9 \pm 0.2$ , for *E. alpinum* and *E. amethystinum* essential oils, respectively. The authors ascribed the antiviral activity to the occurrence of caryophyllene oxide and  $\beta$ -caryophyllene, which were identified as the major components of *E. alpinum* and *E. amethystinum*, respectively. Moreover, other components such as germacrene D,  $\alpha$ -bisabolol, and  $\gamma$ -eudesmol, which were detected as minor oil

**Table 4** Antimicrobial activity of *Eryngium* species extracts

<i>Eryngium</i> plant	Type of extract	Used method	Microbes	Positive control	Ref.
<i>E. foetidum</i>	Methanolic extract of leaves	disk diffusion technique	6 clinical strains of <i>Helicobacter pylori</i>	ns <sup>a</sup>	[92]
<i>E. foetidum</i>	hexane, dichloromethane, and methanol extracts	disk diffusion technique	<i>Plasmodium falciparum</i>	chloroquine	[93]
<i>E. maritimum</i>	hydrodistillation of the aerial parts	agar diffusion method and minimum inhibitory concentration (MIC)	<i>L. monocytogenes</i> <i>E. coli</i> .	ns <sup>a</sup>	[94]
<i>E. maritimum</i>	hydromethanolic extract of leaves	microdilution method	<i>S. aureus</i> subsp. <i>aureus</i> , <i>Micrococcus luteus</i> , <i>B. cereus</i> . <i>S. enterica</i> subsp. <i>arizonae</i> <i>S. enterica</i> subsp. <i>Montevideo</i> <i>P. aeruginosa</i> , <i>P. fluorescens</i> , <i>P. marginalis</i> <i>E. coli</i> <i>Erwinia carotovora</i> subsp. <i>carotovora</i> , <i>Candida albicans</i>	ns <sup>a</sup>	[95]
<i>E. creticum</i> , <i>E. campestre</i> , <i>E. thoriifolium</i>	essential oils from aerial and root parts	disk diffusion method	9 clinical strains of methicillin-resistant <i>S. aureus</i> (MRSA)	ns <sup>a</sup>	[37]
<i>E. duriaei</i>	essential oil obtained by water distillation of the aerial parts	macrodilution broth method	<i>Microsporium canis</i> FF1, <i>Trichophyton mentagrophytes</i> FF7, <i>Epidermophyton floccosum</i> FF9, <i>M. gypseum</i> CECT 2905, <i>T. rubrum</i> CECT 2794, <i>T. mentagrophytes</i> var <i>interdigitale</i> CECT 2958 <i>T. verrucosum</i> CECT 2992 <i>Candida guilliermondii</i> MAT23, <i>Cryptococcus neoformans</i> CECT 1078.	ns <sup>a</sup>	[97]
<i>E. alpinum</i> , <i>E. amethystinum</i>	essential oils obtained by water distillation of the aerial parts	count of leaf local lesions in <i>Chenopodium quinoa</i> treated with the essential oils prior to the inoculation of virus	cucumber mosaic virus associated with a satellite RNA	ns <sup>a</sup>	[98]

<sup>a</sup>not specified

constituents, might be responsible for the inhibition of viral infection [98].

The summary of the literature data was reported in Table 4.

## Conclusion

The present paper shows that essential oils and extracts obtained from various *Eryngium* species have broad range antimicrobial activity against several strains of gram-positive and gram-negative bacteria, some species of fungi and yeasts, and viruses. The findings point out to the fact that these activities can be ascribed to the presence of different phytochemicals, especially apolar compounds. However, our search at <https://clinicaltrials.gov/> with keyword "*Eryngium*" accessed on February 9, 2015 showed no clinical trial regarding the beneficial effects of the genus *Eryngium* plants against different types of infection available up to date. In addition, there are only a few papers on the toxicity of the active constituents belonging to the genus *Eryngium* plants, which resulted to be cytotoxic especially at high doses. It can be suggested that more toxicity studies should be carried out prior to the clinical trials.

According to this study, we conclude that the essential oils and extracts of those *Eryngium* species that have been submitted to in vitro investigation (Table 4) should be proceeded to toxicological studies and *in vivo*

experiments as multi-target antimicrobial agents for the treatment of human infectious diseases, especially antibiotic-resistant bacterial infections. Thus, it is not quite possible to make a clear statement or comment about their clinical uses. Hence, we recommend that future studies should be performed on:

- toxicity of the *Eryngium* plant extracts and essential oil resulted to be active in in vitro experiments.
- clinical studies of the safe extracts of *Eryngium* species with in vitro activity,
- finding the exact mechanism underlying the antibacterial effects of the essential oils and extracts of members of the genus *Eryngium* and their antibacterial constituents,
- separation, isolation, and structure identification of the most antibacterial constituents of the essential oils and extracts of different members of the genus *Eryngium* and their interactions with foods as well as common synthetic antibacterial compounds,
- ascertaining the most effective and safe doses for clinical studies regarding the antibacterial effects of the essential oils and extracts of different genus *Eryngium* species against different infectious diseases.

## Competing interests

The authors declare that they have no competing interests.

**Authors' contributions**

SMN and IEO designed the paper, SAE, MI and MD collected and selected and analyzed the literature data, SAE, SFN, SMN, IEO and MD wrote the paper. All authors participated in the analysis and interpretation of literature data, corrected the paper and approved the final manuscript.

**Acknowledgement**

Declared none.

**Author details**

<sup>1</sup>Department of Pharmacognosy, Faculty of Pharmacy, Ankara University, 06100 Ankara, Turkey. <sup>2</sup>Applied Biotechnology Research Center, Baqiyatallah University of Medical Sciences, P.O. Box 19395-5487, Tehran, Iran. <sup>3</sup>Department of Pharmacognosy, Faculty of Pharmacy, Gazi University, 06330 Ankara, Turkey. <sup>4</sup>Department of Drug Sciences, Medicinal Chemistry and Pharmaceutical Technology Section, University of Pavia, Pavia, Italy. <sup>5</sup>Health Research Center, Baqiyatallah University of Medical Sciences, Tehran, Iran.

Received: 23 October 2015 Accepted: 3 December 2015

Published online: 14 December 2015

**References**

- World Health Organization. World health statistics 2010. WHO Press. Geneva, Switzerland. 2010.
- Nabavi SM, Marchese A, Izadi M, Curti V, Daglia M, Nabavi SF. Plants belonging to the genus *Thymus* as antibacterial agents: From farm to pharmacy. *Food Chem.* 2015;173:339–47.
- Högberg LD, Heddi A, Cars O. The global need for effective antibiotics: challenges and recent advances. *Trends Pharmacol Sci.* 2010;31(11):509–15.
- Alinezhad H, Azimi R, Zare M, Ebrahimzadeh MA, Esлами S, Nabavi SF, et al. Antioxidant and antihemolytic activities of ethanolic extract of flowers, leaves, and stems of *Hyssopus officinalis* L. Var. *angustifolius*. *Int J Food Prop.* 2013;16(5):1169–78.
- Nabavi SF, Nabavi SM, Habtemariam S, Moghaddam AH, Suređa A, Jafari M, et al. Hepatoprotective effect of gallic acid isolated from *Peltiphyllum peltatum* against sodium fluoride-induced oxidative stress. *Ind Crops Prod.* 2013;44:50–5.
- Curti V, Capelli E, Boschi F, Nabavi SF, Bongiorno AI, Habtemariam S, et al. Modulation of human miR-17–3p expression by methyl 3-O-methyl gallate as explanation of its in vivo protective activities. *Mol Nutr Food Res.* 2014;58(9):1776–84.
- Nabavi SF, Daglia M, Moghaddam AH, Habtemariam S, Nabavi SM. Curcumin and liver disease: from chemistry to medicine. *Compr Rev Food Sci Food Saf.* 2014;13(1):62–77.
- Nabavi SF, Russo GL, Daglia M, Nabavi SM. Role of quercetin as an alternative for obesity treatment: you are what you eat! *Food Chem.* 2015;179:305–10.
- Nabavi SF, Nabavi SM, Setzer NW, Nabavi SA, Nabavi SA, Ebrahimzadeh MA. Antioxidant and antihemolytic activity of lipid-soluble bioactive substances in avocado fruits. *Fruits.* 2013;68(03):185–93.
- Daglia M. Polyphenols as antimicrobial agents. *Curr Opin Biotechnol.* 2012;23(2):174–81.
- Simoes M, Bennett RN, Rosa EA. Understanding antimicrobial activities of phytochemicals against multidrug resistant bacteria and biofilms. *Nat Prod Rep.* 2009;26(6):746–57.
- Cowan MM. Plant products as antimicrobial agents. *Clin Microbiol Rev.* 1999;12(4):564–82.
- Palá-Paúl J, Perez-Alonso MJ, Velasco-Negueruela A, Vadaré J, Villa AM, Sanz J, et al. Essential oil composition of the different parts of *Eryngium bourgatii* Gouan from Spain. *J Chromatogr A.* 2005;1074(1):235–9.
- Capetanos C, Saroglu V, Marin PD, Simić A, Skaltsa HD. Essential oil analysis of two endemic *Eryngium* species from Serbia. *J Serb Chem Soc.* 2007;72(10):961–5.
- Wörz A, Diekmann H. Classification and evolution of the genus *Eryngium* L. (Apiaceae-Saniculoideae): results of fruit anatomical and petal morphological studies. *Plant Divers Evol.* 2010;128(3–4):387–408.
- Wörz A. A new subgeneric classification of the genus *Eryngium* L. (Apiaceae, Saniculoideae). *Bot Jahrbücher.* 2005;126(2):253–9.
- Calvino CI, Martínez SG, Downie SR. The evolutionary history of *Eryngium* (Apiaceae, Saniculoideae): Rapid radiations, long distance dispersals, and hybridizations. *Mol Phylogenet Evol.* 2008;46(3):1129–50.
- Calvino CI, Downie SR. Circumscription and phylogeny of Apiaceae subfamily Saniculoideae based on chloroplast DNA sequences. *Mol Phylogenet Evol.* 2007;44(1):175–91.
- Magee AR, van Wyk B-E, Tilney PM, van der Bank M. A Taxonomic Revision Of the South African Endemic Genus *Arctopus* (Apiaceae, Saniculoideae) 1. *Ann Missouri Bot Garden.* 2008;95(3):471–86.
- Singh S, Singh D, Banu S, Salim K. Determination of bioactives and antioxidant activity in *Eryngium foetidum* L.: a traditional culinary and medicinal herb. *Proc Natl Acad Sci, India Section B: Biological Sciences.* 2013;83(3):453–60.
- Ignacimuthu S, Arockiasamy S, Antonysamy M, Ravichandran P. Plant regeneration through somatic embryogenesis from mature leaf explants of *Eryngium foetidum*, a condiment. *Plant Cell Tissue Organ Cult.* 1999;56(2):131–7.
- Shavandi MA, Haddadian Z, Ismail MHS. *Eryngium foetidum* L. *Coriandrum sativum* and *Persicaria odorata* L.: A review. *J Asian Sci Res.* 2012;2(8):410–26.
- Singh B, Ramakrishna Y, Ngachan S. Spiny coriander (*Eryngium foetidum* L.): a commonly used, neglected spicing-culinary herb of Mizoram, India. *Genet Resour Crop Evol.* 2014;61(6):1085–90.
- Paul J, Seaforth C, Tikasingh T. *Eryngium foetidum* L.: a review. *Fitoterapia.* 2011;82(3):302–8.
- Kupeli E, Kartal M, Aslan S, Yesilada E. Comparative evaluation of the anti-inflammatory and antinociceptive activity of Turkish *Eryngium* species. *J Ethnopharmacol.* 2006;107(1):32–7.
- De Natale A, Pollio A. Plants species in the folk medicine of Montecorvino Rovella (inland Campania, Italy). *J Ethnopharmacol.* 2007;109(2):295–303.
- Wang P, Su Z, Yuan W, Deng G, Li S. Phytochemical constituents and pharmacological activities of *Eryngium* L. (Apiaceae). *Pharm Crops.* 2012;3:99–120.
- Nabavi S, Nabavi S, Alinezhad H, Zare M, Azimi R. Biological activities of flavonoid-rich fraction of *Eryngium caucasicum* Trautv. *Eur Rev Med Pharmacol Sci.* 2012;16:81–7.
- Esلامي S, Ebrahimzadeh M, Moghaddam HA, Nabavi S, Jafari N, Nabavi S. Renoprotective effect of *Eryngium caucasicum* in gentamicin-induced nephrotoxic mice. *Arch Biol Sci.* 2011;63(1):157–60.
- Anam EM. A novel triterpenoid saponin from *Eryngium foetidum*. *Indian J Chem Section B.* 2002;41(7):1500–3.
- Khoshbakhht K, Hammer K, Pistrick K. *Eryngium caucasicum* Trautv. cultivated as a vegetable in the Elburz Mountains (Northern Iran). *Genet Resour Crop Evol.* 2007;54(2):445–8.
- Homer S, Baccus-Taylor GS, Akingbala JA, Hutchinson SD, editors. Antibacterial efficacy of *Eryngium foetidum* (culantro) against select food-borne pathogens: Proceedings of the West Indies Agricultural Economics Conference. 2009.
- Türker H, Yildirim AB, Karakaş FP, Köylüođlu H. Antibacterial activities of extracts from some Turkish endemic plants on common fish pathogens. *Turk J Biol.* 2009;33(1):73–8.
- Merghache D, Boucherit-Otmani Z, Merghache S, Chikhi I, Selles C, Boucherit K. Chemical composition, antibacterial, antifungal and antioxidant activities of Algerian *Eryngium tricuspdatum* L. essential oil. *Nat Prod Res.* 2014;28(11):795–807.
- Dehghanzadeh N, Ketabchi S, Alizadeh A. Essential oil composition and antibacterial activity of *Eryngium caeruleum* grown wild in Iran. *J Essential Oil Bearing Plants.* 2014;17(3):486–92.
- Khalfallah A, Berrehal D, Kabouche A, Karioti A, Bilia A-R, Kabouche Z. Flavonoids, antioxidant and antibacterial activities of *Eryngium triquetrum*. *Chem Nat Comp.* 2014;50(1):130–2.
- Çelik A, Aydınlik N, Arslan I. Phytochemical constituents and inhibitory activity towards methicillin-resistant *Staphylococcus aureus* strains of *Eryngium* species (Apiaceae). *Chem Biodivers.* 2011;8(3):454–9.
- Ozcelik B, Kusmenoglu S, Turkoz S, Abbasoglu U. Antimicrobial activities of plants from the Apicaceae. *Pharm Biology.* 2004;42(7):526–8.
- Sefidkon F, Dabiri M, Alamshahi A. Chemical composition of the essential oil of *Eryngium billardieri* F. Delaroché from Iran. *J Essential Oil Res.* 2004;16(1):42–3.
- Ebrahimzadeh M, Nabavi S, Nabavi S. Antioxidant activity of leaves and inflorescence of *Eryngium caucasicum* Trautv at flowering stage. *Pharmacogn Res.* 2009;1(6):435.
- Aburjai T, Hudaid M, Tayyem R, Yousef M, Qishawi M. Ethnopharmacological survey of medicinal herbs in Jordan, the Ajloun Heights region. *J Ethnopharmacol.* 2007;110(2):294–304.

42. Goleniowski ME, Bongiovanni G, Palacio L, Nuñez C, Cantero J. Medicinal plants from the "Sierra de Comechingones", Argentina. *J Ethnopharmacol*. 2006;107(3):324–41.
43. Redzic S. Wild medicinal plants and their usage in traditional human therapy (Southern Bosnia and Herzegovina, W. Balkan). *J Med Plants Res*. 2010;4(11):1003–27.
44. Morton JF. Some folk-medicine plants of Central American markets. *Pharm Biol*. 1977;15(4):165–92.
45. Morton JF. Caribbean and Latin American folk medicine and its influence in the United States. *Pharm Biol*. 1980;18(2):57–75.
46. Mathias ME. Magic, myth and medicine. *Econ Bot*. 1994;48(1):3–7.
47. Wang P, Yuan W, Deng G, Su Z, Li S. Triterpenoid saponins from *Eryngium yuccifolium* 'Kershaw Blue'. *Phytochem Lett*. 2013;6(2):306–9.
48. de la Luz C-GM, Fernández-Arroyo S, Joven J, Segura-Carretero A. Comprehensive characterization by UHPLC-ESI-Q-TOF-MS from an *Eryngium bourgatii* extract and their antioxidant and anti-inflammatory activities. *Food Res Int*. 2013;50(1):197–204.
49. Erdem SA, Anhan O, Offer AM, Iskit A, Miyamoto T, Kartal M, et al. Antinociceptive activity of *Eryngium kotschy* Boiss. root extracts. *Planta Med*. 2011;77(12):F66.
50. Ozarowski M, Thiem B, Mikolajczak PL, Piasecka A, Kachlicki P, Szulc M, et al. Improvement in Long-Term Memory following Chronic Administration of *Eryngium planum* Root Extract in Scopalamine Model: Behavioral and Molecular Study. *Evid Based Complement Alternat Med*. 2015;2015:145140.
51. Khalili M, Dehdar T, Hamedif F, Ebrahimpzadeh M, Karami M. Antihypoxic activities of *Eryngium caucasicum*. *Eur Rev Med Pharmacol Sci*. 2015;19(17):3282–5.
52. Dawilai S, Muangnoi C, Praengamthanachoti P, Tuntipopipat S. Anti-inflammatory activity of bioaccessible fraction from *Eryngium foetidum* leaves. *BioMed Res Int*. 2013;2013:958567.
53. Mozumder S, Hossain M. Effect of seed treatment and soaking duration on germination of *Eryngium foetidum* L. seeds. *Int J Hort*. 2013;3:1046–51.
54. Njenga J. Production of *Eryngium*. *NC Flower Growers' Bulletin*. 1995;40:9–11.
55. Martin K. In vitro propagation of the herbal spice *Eryngium foetidum* L. on sucrose-added and sucrose-free medium without growth regulators and CO<sub>2</sub> enrichment. *Sci Hort*. 2004;102(2):277–82.
56. Erdelmeier C, Sticher O. Coumarin derivatives from *Eryngium campestre*. *Planta Med*. 1985;51(5):407–9.
57. Erdelmeier CA, Sticher O. A cyclohexenone and a cyclohexadienone glycoside from *Eryngium campestre*. *Phytochemistry*. 1986;25(3):741–3.
58. Hohmann J, Pall Z, Günther G, Mathe I. Flavonolacyl glycosides of the aerial parts of *Eryngium campestre*. *Planta Med*. 1997;63(1):96.
59. Kartal M, Mitaine-Offer A-C, Abu-Asaker M, Miyamoto T, Calis I, Wagner H, et al. Two new triterpene saponins from *Eryngium campestre*. *Chem Pharm Bull*. 2005;53(10):1318–20.
60. Dalar A, Türker M, Zabarar D, Konczak I. Phenolic composition, antioxidant and enzyme inhibitory activities of *Eryngium bommuelleri* leaf. *Plant Foods Hum Nutr*. 2014;69(1):30–6.
61. Hiller K, Keipert M, Pfeifer S, Kraft R. The leaf saponin spectrum in *Eryngium planum* L. 20. Contribution to the content of several Saniculoideae. *Pharmazie*. 1974;29(1):54.
62. Hiller K, Nguyen K, Franke P. Isolation of 3-OD-glucopyranosyl oleanolic acid 28-OD-xylo-pyranoside from *Eryngium bromeliifolium* Delar. 29. Constituents of some Saniculoideae. *Pharmazie*. 1978;33(1):78–80.
63. Kartal M, Mitaine-Offer A-C, Paululat T, Abu-Asaker M, Wagner H, Mirjolet J-F, et al. Triterpene saponins from *Eryngium campestre*. *J Nat Prod*. 2006;69(7):1105–8.
64. Zhang Z, Li S, Ownby S, Wang P, Yuan W, Zhang W, et al. Phenolic compounds and rare polyhydroxylated triterpenoid saponins from *Eryngium yuccifolium*. *Phytochemistry*. 2008;69(10):2070–80.
65. Erdem SA, Mitaine-Offer AC, Miyamoto T, Kartal M, Lacaille-Dubois MA. Triterpene saponins from *Eryngium kotschy*. *Phytochemistry*. 2015;110:160–5.
66. Hiller K, Thi N, Franke P. On saponin of *Eryngium bromeliifolium* Delar. 19. Information on the components of various Saniculoideae. *Pharmazie*. 1973;28(8):546.
67. Hiller K, Thi N, Döhnert H, Franke P. Isolation of new ester saponins from *Eryngium giganteum* MB 22. Knowledge of various Saniculoideae components. *Pharmazie*. 1975;30(2):105.
68. Hiller K, Nguyen K, Döhnert H, Franke P. The saponine-saponinogen spectrum in *Eryngium amethystinum* L. 27. Contribution to chemicals contained in various Saniculoideae. *Pharmazie*. 1977;32(3):184.
69. Hiller K, Keipert M, Pfeifer S, Tökes L, Maddox M. Structure of *Eryngium saponin*s. 14. Information on components of some Saniculoideae. *Pharmazie*. 1970;25(12):769.
70. Hiller K, Keipert M, Pfeifer S, Tökes L, Nelson J. Erynginol A- A new triterpenesapogenin. 18. Knowledge of component substances of some Saniculoideae. *Pharmazie*. 1973;28(6):409–10.
71. Hiller K, Von Thi N, Lehmann G, Gründemann E. Betulinic acid—a saponin in *Eryngium bromeliifolium* Delar. 21. The contents of a Saniculoideae. *Pharmazie*. 1974;29(2):148.
72. Hiller K, Keipert M, Missbach U, Lehmann G. Eryngiumgenin E-a new ester saponin. 23. The contents of some Saniculoideae. *Pharmazie*. 1975;30(5):336.
73. Hiller K, Nguyen K, Franke P, Hintsche R. Isolation of betulinic acid 3-O-beta-D-glucoside, a saponin of *Eryngium bromeliifolium* Delar. 26. The contents of Saniculoideae. *Pharmazie*. 1976;31(12):891.
74. Hiller K, Von Mach B, Franke P. Saponins of *Eryngium maritimum* L. 25. Contents of various Saniculoideae. *Pharmazie*. 1976;31(1):53.
75. Voigt G, Thiel P, Hiller K, Franke P, Habisch D. Zur struktur des hauptsaponins der Wurzeln von *Eryngium planum* L. XL: Zur Kenntnis der inhaltsstoffe einiger Saniculoideae. *Pharmazie*. 1985;40(9):656–59.
76. Kowalczyk M, Masullo M, Thiem B, Piacente S, Stochmal A, Oleszek W. Three new triterpene saponins from roots of *Eryngium planum*. *Nat Prod Res*. 2014;28(9):653–60.
77. Aslan S, Kartal M. GC-MS Analysis of *Eryngium maritimum* L. volatile oil. *Planta Med*. 2006;72(11):P\_340.
78. Hiller K, Otto A, Grundemann E. Isolation of kaempferol-3-o-(6-O-beta-D-glucopyranosyl)-beta-D-galactopyranoside, a new flavonol glycoside from *Eryngium planum* L. 34. on the knowledge of the constituents of some Saniculoideae. *Pharmazie*. 1980;35(2):113–4.
79. Kartnig T, Wolf J. Flavonoids from the aboveground parts of *Eryngium campestre*. *Planta Med*. 1993;59(3):285.
80. Hawas UW, El-Kassem T, Lamia A, Awad M, Hanem AA, Taie H. Anti-Alzheimer, antioxidant activities and flavonol glycosides of *Eryngium campestre* L. *Curr Chem Biol*. 2013;7(2):188–95.
81. Pinar M, Galan MP. Coumarins from *Eryngium ilicifolium*. *J Nat Prod*. 1985;48(5):853–4.
82. Le Claire E, Schwaiger S, Banaigs B, Stuppner H, Gafner F. Distribution of a new rosmarinic acid derivative in *Eryngium alpinum* L. and other Apiaceae. *J Agric Food Chem*. 2005;53(11):4367–72.
83. Marčetić MD, Petrović SD, Milenković MT, Niketić MS. Composition, antimicrobial and antioxidant activity of the extracts of *Eryngium palmatum* Pančić and Vis. (Apiaceae). *Cent Eur J Biol*. 2014;9(2):149–55.
84. Drake D, Lam J. Seseli acetylene from *Eryngium bourgatii*. *Phytochemistry*. 1972;11(8):2651–2.
85. Lam J, Christensen LP, Thomassen T. Acetylenes from roots of *Eryngium bourgatii*. *Phytochemistry*. 1992;31(8):2881–2.
86. Ayoub N, Kubeczka K-H, Nawwar M. An unique n-propyl sesquiterpene from *Eryngium creticum* L. (Apiaceae). *Pharmazie*. 2003;58(9):674–6.
87. Korbel E, Bighelli A, Kurowska A, Kalembe D, Casanova J. New cis-chrysanthenyl esters from *Eryngium planum* L. *Nat Prod Commun*. 2008;3(2):113–6.
88. Garcia M, Saenz M, Gomez M, Fernandez M. Topical anti-inflammatory activity of phytosterols isolated from *Eryngium foetidum* on chronic and acute inflammation models. *Phytother Res*. 1999;13(1):78–80.
89. Muckensturm B, Boulanger A, Farahi M, Reduron J. Secondary metabolites from *Eryngium species*. *Nat Prod Res*. 2010;24(5):391–7.
90. Forbes W, Gallimore W, Mansingh A, Reese P, Robinson R. Eryngial (*trans*-2-dodecenal), a bioactive compound from *Eryngium foetidum*: its identification, chemical isolation, characterization and comparison with ivermectin in vitro. *Parasitology*. 2014;141(02):269–78.
91. Alzoreky N, Nakahara K. Antibacterial activity of extracts from some edible plants commonly consumed in Asia. *Int J Food Microbiol*. 2003;80(3):223–30.
92. Ndip RN, Tarkang AEM, Mbulah SM, Luma HN, Malongue A, Ndip LM, et al. In vitro anti-*Helicobacter pylori* activity of extracts of selected medicinal plants from North West Cameroon. *J Ethnopharmacol*. 2007;114(3):452–7.
93. Roumy V, Garcia-Pizango G, Gutierrez-Choquevilca A-L, Ruiz L, Jullian V, Winterton P, et al. Amazonian plants from Peru used by Quechua and Mestizo to treat malaria with evaluation of their activity. *J Ethnopharmacol*. 2007;112(3):482–9.
94. Darriet F, Bendahou M, Desjoberg J-M, Costa J, Muselli A. Bicyclo [4.4.0] decane oxygenated sesquiterpenes from *Eryngium maritimum* essential oil. *Planta Med*. 2012;78(4):386.
95. Meot-Duros L, Le Floch G, Magné C. Radical scavenging, antioxidant and antimicrobial activities of halophytic species. *J Ethnopharmacol*. 2008;116(2):258–62.
96. Baytop T. Therapy with Medicinal Plants in Turkey (Past and Present). 1999;2:169.

97. Abou-Jawdah Y, Sobh H, Salameh A. Antimycotic activities of selected plant flora, growing wild in Lebanon, against phytopathogenic fungi. *J Agric Food Chem*. 2002;50(11):3208–13.
98. Dunkić V, Vuko E, Bezić N, Kremer D, Ruščić M. Composition and antiviral activity of the essential oils of *Eryngium alpinum* and *E. amethystinum*. *Chem Biodivers*. 2013;10(10):1894–902.
99. Flamini G, Tebano M, Cioni PL. Composition of the essential oils from leafy parts of the shoots, flowers and fruits of *Eryngium amethystinum* from Amiata Mount (Tuscany, Italy). *Food Chem*. 2008;107(2):671–4.
100. Morteza-Semnani K. Essential oil composition of *Eryngium bungei* Boiss. *J Essential Oil Res*. 2005;17(5):485–6.
101. Mohammadhosseini M, Mahdavi B, Akhlaghi H. Characterization and chemical composition of the volatile oils from aerial parts of *Eryngium bungei* Boiss. (Apiaceae) by using traditional hydrodistillation, microwave assisted hydrodistillation and head space solid phase microextraction methods prior to GC and GC/MS analyses: A comparative approach. *J Essential Oil Bearing Plants*. 2013;16(5):613–23.
102. Assadian F, Masoudi S, Nematollahi F, Rustaiyan A, Larjani K, Mazloomifar H. Volatile constituents of *Xanthogalum purpurascens* Ave-Lall., *Eryngium caeruleum* MB and *Pimpinella aurea* DC. Three Umbelliferae herbs growing in Iran. *J Essential Oil Res*. 2005;17(3):243–5.
103. Pala-Paul J, Usano-Aleman J, Soria AC, Perez-Alonso MJ, Brophy JJ. Essential oil composition of *Eryngium campestre* L. growing in different soil types. A preliminary study. *Nat Prod Commun*. 2008;3(7):1121–6.
104. Hashemabadi D, Kaviani B. Chemical constituents of essential oils extracted from the leaves and stems of *Eryngium caucasicum* Trautv. from Iran. *J Essential Oil Bearing Plants*. 2011;14(6):693–8.
105. Palá-Paúl J, Brophy JJ, Pérez-Alonso MJ, Usano J, Soria SC. Essential oil composition of the different parts of *Eryngium corniculatum* Lam. (Apiaceae) from Spain. *J Chromatogr A*. 2007;1175(2):289–93.
106. Cavaleiro C, Gonçalves MJ, Serra D, Santoro G, Tomi F, Bighelli A, et al. Composition of a volatile extract of *Eryngium duriae* subsp. juresianum (M. Lánz) M. Lánz, signalled by the antifungal activity. *J Pharm Biomed Anal*. 2011;54(3):619–22.
107. Brophy JJ, Goldsack RJ, Copeland LM, Palá-Paúl J. Essential oil of *Eryngium* L. species from New South Wales (Australia). *J Essential Oil Res*. 2003;15(6):392–7.
108. Martins AP, Salgueiro LR, da Cunha AP, Vila R, Cañigueral S, Tomi F, et al. Essential oil composition of *Eryngium foetidum* from S. Tome e Principe. *J Essential Oil Res*. 2003;15(2):93–5.
109. Cardozo E, Rubio M, Rojas L, Usubillaga A. Composition of the essential oil from the leaves of *Eryngium foetidum* L. from the Venezuelan Andes. *J Essential Oil Res*. 2004;16(1):33–4.
110. Thi NDT, Anh TH, Thach LN. The essential oil composition of *Eryngium foetidum* L. in South Vietnam extracted by hydrodistillation under conventional heating and microwave irradiation. *J Essential Oil Bearing Plants*. 2008;11(2):154–61.
111. Pino JA, Rosado A, Fuentes V. Composition of the leaf oil of *Eryngium foetidum* L. from Cuba. *J Essential Oil Res*. 1997;9(4):467–8.
112. Palá-Paúl J, Pérez-Alonso MJ, Velasco-Negueruela A, Varadé J, Villa AM, Sanz J, et al. Analysis of the essential oil composition from the different parts of *Eryngium glaciale* Boiss. from Spain. *J Chromatogr A*. 2005;1094(1):179–82.
113. Maggio A, Bruno M, Formisano C, Rigano D, Senatore F. Chemical composition of the essential oils of three species of Apiaceae growing wild in Sicily: *Bonannia graeca*, *Eryngium maritimum* and *Opopanax chironium*. *Nat Prod Commun*. 2013;8(6):841–4.
114. Darriet F, Andreani S, De Cian MC, Costa J, Muselli A. Chemical variability and antioxidant activity of *Eryngium maritimum* L. essential oils from Corsica and Sardinia. *Flav Fragr J*. 2014;29(1):3–13.
115. Marcetic M, Petrovic S, Milenkovic M, Vujisic L, Tesevic V, Niketic M. Composition and antimicrobial activity of root essential oil of Balkan endemic species *Eryngium palmatum*. *Chem Nat Comp*. 2014;49(6):1140–2.
116. Cobos MI, Rodriguez JL, De Petre A, Spahn E, Casermeiro J, Lopez AG, et al. Composition of the essential oil of *Eryngium paniculatum* Cav. *J Essential Oil Res*. 2002;14(2):82–3.
117. Thiem B, Kikowska M, Kurowska A, Kalemba D. Essential oil composition of the different parts and in vitro shoot culture of *Eryngium planum* L. *Molecules*. 2011;16(8):7115–24.
118. Palá-Paúl J, Copeland LM, Brophy JJ, Goldsack RJ. Essential oil composition of *Eryngium rosulatum* PW Michael ined.: A new undescribed species from eastern Australia. *Biochem System Ecol*. 2006;34(11):796–801.
119. Palá-Paúl J, Brophy JJ, Goldsack RJ, Copeland LM, Pérez-Alonso MJ, Velasco-Negueruela A. Essential oil composition of the seasonal heterophyllous leaves of *Eryngium vesiculosum* from Australia. *Austr J Bot*. 2003;51(5):497–501.
120. Ayoub N, Al-Azizi M, König W, Kubeczka KH. Essential oils and a novel polyacetylene from *Eryngium yuccifolium* Michaux. (Apiaceae). *Flav Fragr J*. 2006;21(6):864–8.

Submit your next manuscript to BioMed Central and we will help you at every step:

- We accept pre-submission inquiries
- Our selector tool helps you to find the most relevant journal
- We provide round the clock customer support
- Convenient online submission
- Thorough peer review
- Inclusion in PubMed and all major indexing services
- Maximum visibility for your research

Submit your manuscript at  
[www.biomedcentral.com/submit](http://www.biomedcentral.com/submit)

