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A critical review on *Pulicaria* species occurring in Qatar: traditional uses, phytochemistry and biological activities

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Abstract In Qatar, three main species of *Pulicaria* (from Asteraceae) such as *Pulicaria undulata* (L.) C.A.Mey, *Pulicaria gnaphalodes* (Vent.) Boiss. and *Pulicaria sicula* (L.) Moris are reported. Traditionally, these species have almost the same ethnomedical uses, including their use as herbal tea. This could be because of morphological similarities among some of these species, which also results in taxonomic ambiguity. Altogether, this indicates that these species need to be reviewed comparatively, to understand the phytochemical uniqueness and therapeutic significance of each species individually, including species differentiation at the subspecies level. Hence, this review aims to comparatively review the available literature about traditional uses, phytochemistry, and bio-activities of these species. Being aromatic plants, the chemical composition of essential oils of these species has been extensively studied and reported over 300 volatile organic compounds. Among these, oxygenated monoterpenes and sesquiterpenes are dominant. The diverse and distinguishable composition of essential oils can differentiate *P. undulata* and *Pulicaria crispa* (Forssk.) Oliv. (Synonyme: *Pulicaria undulata* subsp. *undulata*). Likewise, flavonoids and sesquiterpenes are the most reported classes of compounds in non-essential oil fractions. Various biological and pharmacological activities are reported to the essential oils, crude extracts, and their fractions, or isolated compounds of these species. Among these, antimicrobial, anticancer, and anti-oxidant activities were mostly investigated, mainly under in vitro conditions. Several distinguishable compounds are listed for each species that can potentially be used as chemical markers while characterizing these species. Most of the traditional claims of these species are validated in recent scientific studies. However, further detailed in vivo clinical interventions are needed for their potential use as therapeutic agents.

Keywords *Pulicaria* · Asteraceae · Essential oil · Traditional uses · Phytochemistry · Ethnopharmacology

Abbreviations

ABTS	2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)
ACAEs	Acarbose equivalents
AFP	Alpha fetoprotein
ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
BHT	Butylated hydroxyl toluene
CH_2Cl_2	Dichloromethane
CPZ	Chlorpromazine
CUPRAC	CUPric reducing antioxidant capacity

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DPPH	2,2-Diphenyl-1-picrylhydrazyl
EAC	Ehrlich's ascites carcinoma
EAF	Ethyl acetate fraction
FIC	Ferrous Iron Chelating
FRAP	Ferric reducing ability of plasma
GAE	Gallic acid equivalent
GALAEs	Galanthamine equivalents
GC-MS	Gas chromatography-mass spectrometry
GGT	Gamma-glutamyl transferase
GSH	Glutathione
HBV	Hepatitis B virus
HD	Hydro-distillation
HF	Hexane fraction
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-level glycoprotein cholesterol
LPS	Lipopolysaccharide
MBC	Minimum bactericidal concentration
MDA	Malondialdehyde
MIC	Minimum inhibitory concentration
MICBs	Minimal inhibitory concentrations of biofilm
MRSA	Methicillin-resistant *Staphylococcus aureus*
MTT	3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
NO	Nitric oxide
SOD	Superoxide dismutase
SPME	Solid phase micro-extraction
TBHP	Tert-butyl hydroperoxide
TC	Total cholesterol
TG	Triglyceride
TNF-α	Tumour necrosis factor-α
TP	Total lipids
VEGF	Vascular endothelial growth factor
VOCs	Volatile organic compounds
8-OHdG	8-Hydroxydeoxyguanosine

Introduction

The genus *Pulicaria* Gaertn. (family: Asteraceae) belongs to the tribe Inuleae, which comprises 82 accepted species of shrubs, shrublets, and herbs (Coutinho and Dinis 2009; POWO 2024). These *Pulicaria* species are native to Africa, temperate Eurasia to the Indian Subcontinent (Salleh et al. 2021; POWO 2024). Traditionally, *Pulicaria* species have a long history of use as a tonic, herbal tea, galactagogues, anti-epileptics, carminative, and insect repellent (Mirghani et al. 2020; Zekry et al. 2021). Recent pharmacological investigations on *Pulicaria* species showed various medicinal properties, such as antimicrobial, anticancer, antioxidant, anti-inflammatory, and antipyretic (Maggio et al. 2015). Among these, anticancer activity is commonly reported in most *Pulicaria* species (Alamdary and Baharfar 2023). These *Pulicaria* species are essential oil-bearing plants. The phytochemicals reported in these *Pulicaria* species include polyphenols, terpenes, diterpenes, sesquiterpenes, triterpenes, caryophyllenes, and steroids (Alamdary and Baharfar 2023). However, flavonoids and sesquiterpenoids are the major class of phytochemicals within the genus *Pulicaria* (Liu et al. 2010).

Basically, *Pulicaria* is a taxonomically problematic genus (Coutinho and Dinis 2009). Taxonomic ambiguities have also been reported in the *Pulicaria* species occurring in Qatar, primarily because of their morphological resemblance. In Qatar, *Pulicaria* species such as *Pulicaria crispa* (Forssk.) Oliv. (Synonym: *Pulicaria undulata* subsp. *undulata*), *Pulicaria undulata* (L.) C.A.Mey., *Pulicaria sicula* (L.) Moris, and *Pulicaria gnaphalodes* (Vent.) were reported earlier (Abdel-Bari 2012). However, *P. crispa* has merged into *P. undulata* and is considered a single species (Hind and Boulos 2002). The local taxonomists believe that there are two distinct species or perhaps subspecies of *P. undulata* in Qatar, but this has not yet been proven scientifically (Abdel-Bari 2012). Here, it is noteworthy that *P. undulata* subsp. *undulata* is an accepted subspecies (POWO 2024). *P. undulata* is widely spread across Qatar and is locally called Jithjath/Yethyas (Abdel-Bari 2012). *P. gnaphalodes*, locally known as Nufaij, is more commonly found in northeast and central Qatar. However, *P. sicula* (local name: Shay Al Jabal) is a rarely occurring species in Qatar (Abdel-Bari 2012; Norton et al. 2009). Figure 1 shows the images of the three main species of *Pulicaria* that occur in Qatar.

Besides medicinal uses, these *Pulicaria* species have considerable significance in the local food chain of Qatar, including Arabian/Persian region countries. Hence, to understand the phytochemical uniqueness and therapeutic significance of each of these species, including species differentiation at the subspecies level, a comparative review of literature about these

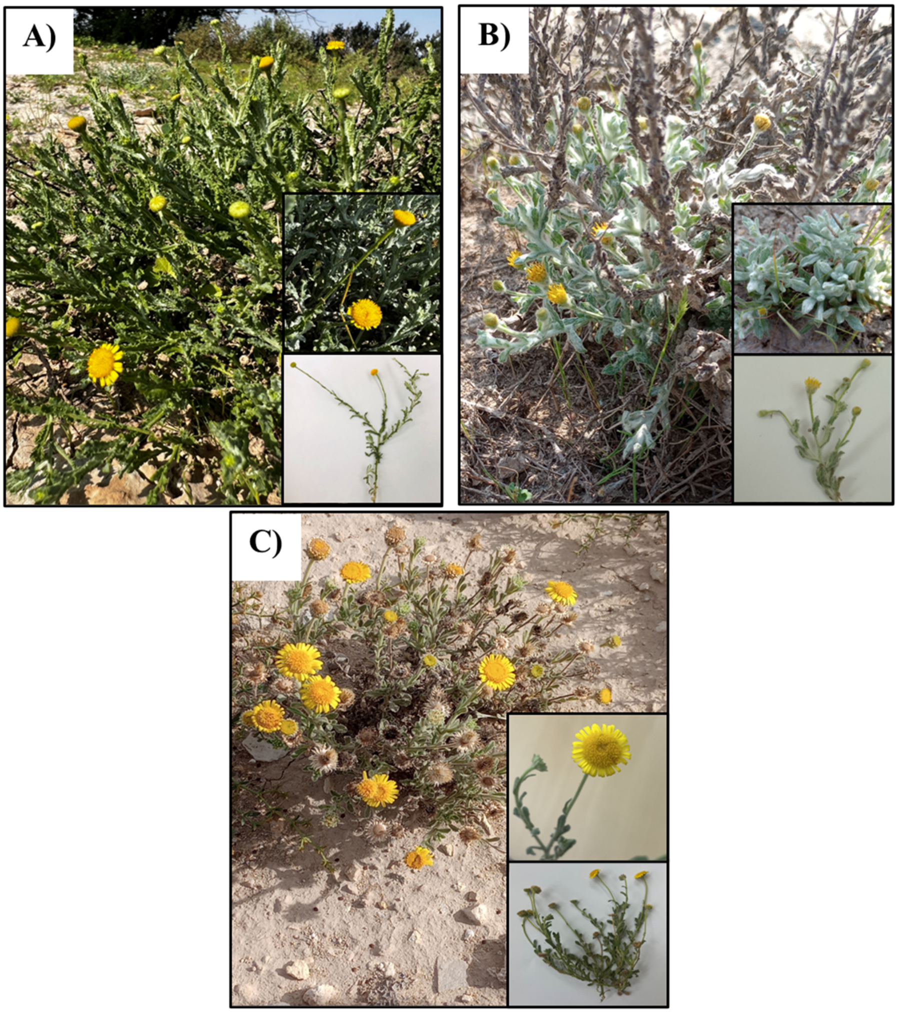


Fig. 1 **A** *Pulicaria undulata* C.A.Mey **B** *Pulicaria gnaphalodes* (Vent.) Boiss. and C) *Pulicaria sicula* (L.) Moris [Photos: M. Alsafran, D. Kasote]

species based on their traditional knowledge, phytochemistry, and health benefits is critical. Thus, this article aims to comparatively review the available literature about botany, traditional uses, phytochemistry, and biological and pharmacological activities of these species, and provide insight into their phytochemical uniqueness and future potential utilization. We believe that this review will help to understand the phytochemical diversity among these species, including the therapeutic or nutraceutical value of each of these species.

Research methodology

The available information on the three species and one subspecies of *Pulicaria* was retrieved using electronic databases such as Scopus, and PubMed. Books and monographs published in English were used to collect information. The search was conducted from publications from all years until Dec. 2023 by the combination of the search terms and Boolean operators; ‘*Pulicaria*’ OR ‘traditional uses’ OR ‘ethnopharmacology’ AND ‘essential oil’ OR ‘flavonoids’ OR ‘biological and pharmacological activity’. The Plant List and Royal Botanical Garden, Kew databases were used to authenticate the botanical names of plants (POWO 2024). The information about the occurrence and distribution of species in Qatar was obtained from the Digital Flora of Qatar (https://www.floraofqatar.com/).

Botanical description

P. undulata is a perennial aromatic low compact suffrutescent herb with numerous basal branches that form a circular compact growth. Flowers in small yellow capitula on long peduncles (Abdel-Bari 2012). *P. sicula* is a yellow flowered woolly aromatic herb with numerous upright branches ending in sweet-scented capitula much larger than in other *Pulicaria* species (Abdel-Bari 2012). *P. gnaphalodes* is an aromatic perennial plant producing a cluster of strongly branched stems from a thick rootstock. Flowers yellow, small, in capitula carried on slender peduncles (Abdel-Bari 2012).

Traditional uses in Qatar and the arabian/persian region

In Qatar, all these *Pulicaria* species are traditionally used as herbal tea (Abdel-Bari 2012). However, several other medicinal properties have been reported for these species in the Arabian/Persian region countries (Table 1). The significance of each of these species in traditional uses appears to be linked with their widespread distribution in the region. *P. undulata* is a widespread species in Saudi Arabia, Egypt, Sudan, Qatar, and Yemen. It is locally known as "Gethgath" in Saudi Arabia and Egypt, and in Yemen, its local name is "Koaa, ensif. Mashmoom" (Al-Haj et al. 2019; Abd-ELGawad et al. 2021; Foudah et al. 2015). Due to the inconsistent use of names, the reported traditional uses of *P. crispa* and *P. undulata* are almost identical (Foudah et al. 2015; Abd-ELGawad et al. 2021). There is little known information about the traditional use of *P. sicula* due to its limited and rare occurrence in the region. In the Persian region, *P. gnaphalodes* widely distributed species and is reported as a medicinal plant, locally known as "Kakkosh-Biabani" (Hassanabadi et al. 2023).

Phytochemistry

Volatile organic compounds (VOCs)

Being aromatic plants, the chemical composition of essential oils of these species has been extensively studied. In general, aerial parts of these species were mostly used for the extraction of essential oils. However, in some studies, essential oils were also extracted from Flowers and leaves (Al-Qudah et al.

Table 1 Traditional uses of *Pulicaria* species

Species	Country	Part used	Traditional uses	References
P. crispa	Saudi Arabia, Egypt, Sudan, Qatar	Whole plant, leaves	anti-inflammatory agent, anti-colic, antitussive, anticold, insect-repellent in livestock shelters, anticonvulsant, anti-influenza, treat heart and gastrointestinal disorders, including as an herbal tea and tonic	Mirghani et al. (2020), Foudah et al. (2015), Abdel-Bari (2012), Al-Haj et al. (2019)
P. undulata	Saudi Arabia, Egypt, Sudan, Yemen, Qatar	Whole plant	Treat diabetes, abscesses, cardiac and skin diseases, epilepsy, influenza, common cold, gastrointestinal disorders, inflammatory diseases, including anti-alopecia, anti-spasmoic, diuretics, including as an herbal tea, and insect repellent in livestock shelters	Abd-ELGawad et al. (2021), Mohammed et al. (2021), Mohamed et al. (2020), Alasbahi and Groot (2022), Abdel-Bari (2012), Norton et al. (2009)
P. sicula	Qatar		Herbal tea	Abdel-Bari (2012)
P. gnaphalodes	Iran, Qatar	Whole plant	As an herbal tea, flavoring, anti-microbial and anti-inflammatory agents	Kazemi et al. (2022), Abdel-Bari (2012)

2022; Abd-ELGawad et al. 2021; Maggio et al. 2015). Hydro-distillation (HD) is the preferred method for the extraction of essential oils from these species. Along with this, solid phase micro-extraction (SPME) is also used to extract the essential oils from the Flowers and leaves (Al-Qudah et al. 2022). Extraction methods were found to have a considerable impact on the composition and amounts of volatile organic compounds (VOCs) extracted in essential oils (Al-Qudah et al. 2022). In almost all reported studies, gas chromatography-mass spectrometry (GC–MS) is used for qualitative and quantitative estimation of VOCs in essential oils of these species.

P. crispa is a synonym of *P. undulata* subsp. *undulata*. However, almost all information about this subspecies is found in the literature with the older name '*P. crispa*', though this is not currently an 'accepted' name. Herein, we have reviewed literature about *P. crispa* and *P. undulata* to differentiate them at the subspecies level based on reported phytochemistry and bioactivities. VOCs of essential oils mainly include compounds from two groups: terpene hydrocarbans and oxygenated compounds (Tongnuanchan and Benjakul, 2014). So far, over 300 VOCs have been reported in the essential oils of these *Pulicaria* species (Table 2). Approximately 147, 176, 64, and 54 VOCs have been reported in *P. crispa, P. undulata, P. sicula,* and *P. gnaphalodes*, respectively. Of these, nearly 83, 110, 37, and 22 VOCs were exclusively reported in the essential oils of *P. crispa, P. undulata, P. sicula,* and *P. gnaphalodes*, respectively. On the contrary, around 64 VOCs are reported in two or more species (Table 2). Oxygenated monoterpenes and sesqueiterpenes are the dominant VOCs in the essential oils of these species, followed by sesquiterpene and monoterpene hydrocarbans, respectively (Table 2).

Essential oils from aerial parts, Flowers, and leaves of *P. crispa* have been extracted and chemically characterized using GC–MS. Hydro-distillation of *P. crispa* aerial parts, Flowers, and leaves yielded yellow-colored oils (Al-Qudah et al. 2022; Mohamed et al. 2020). Available literature suggested that essential oils extracted from different parts of *P. crispa* are dominated by oxygenated hydrocarbans (sesquiterpenes and monoterpenes). *P. crispa* can be distinguished from other *Pulicaria* species based on the presence of sesquiterpenes of the xanthane nucleus, which is not common in the genus (Liu et al. 2010). The main reported constituents in the essential oil from aerial parts of *P. crispa* were 1,4-ditert butylbenzene (22.81%), caryophyllene (13.19%), carvone (11.80%), and neryl(s)-2-methylbutanoate (10.33%) (Mohamed et al. 2020). Chrysanthenone, *p*-cymene-8-ol, 7-*epi*-α-eudesmol, and 2,6-dimethyl phenol were the major VOCs in the essential oils of *P. crispa* leaves and Flowers (Al-Qudah et al. 2022). The essential oil extracted from aerial parts of the Saudi *P. crispa* was rich in β-caryophyllene oxide (33.97%) and modephene (23.34%) (AlMotwaa and Al-Otaibi 2022). However, it has been found that essential oils obtained from the different parts of *P. crispa* showed considerable quantitative and qualitative differences (Al-Qudah et al. 2022). Similar variations in the composition of essential oils of *P. crispa* have been seen in plants collected from different locations (Yusufoglu et al. 2021). Moreover, the essential oil extracted from *P. crispa* leaves and Flowers using an HD method had a higher amount of phenolic compounds than SPME, this highlights the impact of the extraction procedure as well (Al-Qudah et al. 2022). Similarly, the essential oil obtained from aerial parts of Iranian *P. crispa* was characteristically rich in τ-cadinol (53.5%) and β-caryophyllene (10.8%) (Yusufoglu et al. 2021). Taken together, eleven VOCs (1,4-ditert butylbenzene, β-caryophyllene, carvone, neryl(s)-2-methylbutanoate, Chrysanthenone, *p*-cymene-8-ol, 7-*epi*-α-eudesmol, 2,6-dimethyl phenol, β-caryophyllene oxide, modephene, τ -cadinol) have been reported to be present in the high amount in the different essential oils of *P. crispa* (Fig. 2). Of this, carvone, eryl(s)-2-methylbutanoate, *p*-cymene-8-ol,7-*epi*-α-eudesmol, 2,6-dimethyl phenol, and modephene are solely reported in essential oils of *P. crispa* so far that can be marker compounds for characterization *P. crispa* essential oils.

The yellow-colored essential oil was obtained from aerial parts and leaves of *P. undulata*, with a yield of 0.5–2.1% (Ali et al. 2012; Issa et al. 2020a, b). Carvotanacetone (< 90%) was the major VOC in the essential oils of Egyptian and Yemeni P. *undulata* leaves and aerial parts followed by 2,5-dimethoxy-*p*-cymene (Ali et al. 2012; Issa et al. 2020a, b).

However, the essential oil of Algerian *P. undulata* also had carvotanacetone (14.8%) as a main compound, followed by δ-cadinene (8.2%), α-cadinol (4.7%), epi-α-cadinol (3.4%), and thujanol (4.6%). The observed low level of carvotanacetone compared

Table 2 Distribution of the volatile compounds in the Qatari *Pulicaria* species

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Bornylene	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
8,9-Dehydrothymol	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
8,9-Dehydrothymol isobutyrate	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
D-Limonene	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
β-Ocimene	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
β-Phellandrene	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Terpinolene	Monoterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
α-Carene	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Carvone	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
cis-Carveol	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
cis-Carvyl acetate	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Citronellal	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
p-Cymene-8-ol	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Dihydrocarveol	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Dihydrocarvyl acetate	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Eucalyptol	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Lavandulyl acetate	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Levomenthol	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Limonen-6-ol	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
trans-*p*-Menth-2-one	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Methyl-γ-ionone	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Neryl (S)-2-methylbutanoate	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Neryl propionate	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Perillaldehyde	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
cis-Pulegol	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
L-α-Terpineol	Oxygenated monoterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
trans-Thujone	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Thymoquinone	Oxygenated monoterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
(-)-Aristolene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Aromadendrene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
4-Cadinadiene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
E-Caryophyllene	Sesquiterpene hydrocarbans	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Drima-7,9(11)-diene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Eremophilene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
α-Farnesene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Ginsinsene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
α-Isocomene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Modephene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Patchoulane	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Silphinene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Valencene	Sesquiterpene hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
β-Costol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
γ-Costol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
1,10-*di*-*epi*-Cubenol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
1-*epi*-Cubenol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
7-*epi*-α-Eudesmol	Oxygenated sesquiterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
8*S*,13-Cedranediol	Oxygenated sesquiterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Caryophyllenol I	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Caryophyllenol II	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Farnesylacetone	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Helenin	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Khusinol	Oxygenated sesquiterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Linolenic acid methyl ester	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
trans-Longipinocarveol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
6-Methyl-5(3-methylphenyl)-2-heptanone	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Muurola-410(14)-dien-1-ol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
trans-Muurolol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
(*E*)-Nerolidol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
cis-Thujopsenic acid	Oxygenated sesquiterpenes	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
β-Santalol	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Ylangenal	Oxygenated sesquiterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Cembrene	Diterpene hydrocarbans	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Sclarene	Diterpene hydrocarbans	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Isophytol	Oxygenated diterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
trans-Geranylgeraniol	Oxygenated diterpenes	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
4-Hexadecen-6-yne, (Z)-	Aliphatic hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Heneicosane	Aliphatic hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Melonal	Aliphatic hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
(*E*)-2-Octene	Aliphatic hydrocarbans	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Tetradecane	Aliphatic hydrocarbans	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Benzenepropanoic acid, 3,7-dimethylocta-2,6-dienyl ester	Aromatic hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
1,4-Bis-(1,1-dimethylethyl)-benzene	Aromatic hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
2,6-Dimethyl phenol	Aromatic hydrocarbans	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
2(1H)-Naphthalenone, 4a,5,8,8a-tetrahydro-1,1,4a-trimethyl	Aromatic hydrocarbans	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
2-Acetyl-Resorcinol	Carbonyl compounds	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
(*E,Z*)-2,4-Decadienal	Carbonyl compounds	*P. crispa*	Aerial parts	Saudi Arabia	AlMotwaa and Al-Otaibi (2022)
Hexyl tiglate	Carbonyl compounds	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
E-Jasmone	Carbonyl compounds	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Methyl hexadecanoate	Carbonyl compounds	*P. crispa*	Aerial parts	Saudi Arabia	Yusufoglu et al. (2021)
Pivalate	Carbonyl compounds	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
trans-Chrysnthenyl acetate	Other compounds	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
10,12-Pentacosadiynoic acid	Other compounds	*P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020)
Vanillin	Other compounds	*P. crispa*	Flowers, leaves	Jordan	Al-Qudah et al. (2022)
Dill ether	Monoterpene hydrocarbans	*P. undulata*	leaves	Yemen	Ali et al. (2012)
α-Fenchene	Monoterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
1,3,8-*p*-Menthatriene	Monoterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
endo-Borneol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Carvenone	Oxygenated monoterpenes	*P. undulata*	Leaves	Yemen	Ali et al. (2012)
cis-Carvotanacetol	Oxygenated monoterpenes	*P. undulata*	leaves	Yemen	Ali et al. (2012)
E-Citral	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Z-Citral	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Citronellyl acetate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Citronellyl iso-valerate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Citronellyl valerate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Ho-trienol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Isobornyl formate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Isolimonenol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
6-Isopropenyl-4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-naphthalen-2-ol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Linalool oxide	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
trans-*p*-Mentha-2,8-dienol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
p-2-Menthen-1-ol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Myrtenal	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Myrtenyl acetate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021, Ravandeh et al. (2011)
Neryl isovalerate	Oxygenated monoterpenes	*P. undulata*	Leaves	Yemen	Ali et al. (2012)
β-Nopinone	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Pinocarveol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Pinocarvone	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
trans-Piperitol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Thujanol	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Thymohydroquinone	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Thymol acetate	Oxygenated monoterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Amorpha-4,7(11)-diene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Berkheyaradulen	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
trans-γ-Bisabolene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
1*S*-*cis*-Calamenene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Copaene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
α-Curcumene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Germacrene-D	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
α-Guaiene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
α-Gurjunene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
γ-Gurjunene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Egypt, Saudi Arabia	Abd-ELGawad et al. (2021)
δ-Gurjunene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Junipene	Sesquiterpene hydrocarbans	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Azulenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
α-Bisabolol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Cadina-4,1(10)-diene-7-β-ol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
epi-α-Cadinol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Calarene epoxide	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
8-Cedren-13-ol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Cubenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
epi-Cubebol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
4,4-Dimethyl-tetracyclo [6.3.2.0(2,5).0(1,8)] tridecan-9-ol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
β-Eudesmol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Fenenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
epi-Globulol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Hexahydrofarnesyl acetone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Humuladienone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Humuleneepoxide II	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
7-Hydroxyfarnesen	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
14-Hydroxy-α-muurolene	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Isocalamendiol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Isoshyobunone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Isospathulenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Juniper camphor	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Ledene oxide-(I)	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Longifolenaldehyde	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
epi-α-Muurolol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
trans-Nerolidol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Oplopenone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Palustrol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Salvial-4(14)-en-1-one	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
6-*epi*-Shyobunol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
6-*epi*-Shyobunone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Shyobunone	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Spathulenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Valerenol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Iran	Ravandeh et al. (2011)
Veridiflorol	Oxygenated sesquiterpenes	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
α-Citronellol	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Docosane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Dotriacontane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Ethanone	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Heptan-2-ol	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Hexacosane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Hexatriacontane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
1-Hexene	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
9-Hexyl-heptadecane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Nonadecane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Pentacosane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2,6,10,15-Tetramethyl-heptadecane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Triacontane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
n-Tricosane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2,6,10-Trimethyl-tetradecane	Aliphatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2,5-Dimethoxy-*p*-cymene	Aromatic hydrocarbans	*P. undulata*	Aerial, leaves	Algeria, Yemen	Ali et al. (2012), Boumaraf et al. (2016)
Dihydroedulan II	Aromatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
Fonenol	Aromatic hydrocarbans	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Phenol, 3-methyl-5-(1-methylethyl)	Aromatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
1-Penylpentane	Aromatic hydrocarbans	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Citronellyl propionate	Carbonyl compounds	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2-Cyclohexen-1-one	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Cyclohexanemethanol	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Cyclohexanone	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Cyclohexanone, 2-(1-methyl-2-oxopropyl)-	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
cis-9-Hexadecenoic acid	Carbonyl compounds	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2-Hexenal	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
cis-Jasmone	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
cis-*p*-Menthan-2-one	Carbonyl compounds	*P. undulata*	Aerial parts, leaves	Algeria and Yemen	Ali et al. (2012), Boumaraf et al. (2016)
trans- *p*-Menthan-2-one	Carbonyl compounds	*P. undulata*	Aerial parts	Algeria	Boumaraf et al. (2016)
Oleic acid	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Propanoic acid	Carbonyl compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
9,12-Octadecadienoic acid	Other compounds	*P. undulata*	Aerial parts	Egypt, Saudi Arabia, Sudan	Abd-ELGawad et al. (2021), Mohammed et al. (2020)
Oxirane	Other compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Vitispirane	Other compounds	*P. undulata*	Aerial parts	Saudi Arabia and Egypt	Abd-ELGawad et al. (2021)
2-Cyclohexen-1-ol	Other compounds	*P. undulata*	Aerial parts	Sudan	Mohammed et al. (2020)
Bornyl acetate	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Bornyl formate	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
β-Cyclocitral	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Geranyl butyrate	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Isothymol isobutyrate	oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
trans-*p*-Menth-2-en-1-ol	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Neryl acetone	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Thymohydroquinone dimethyl ether	Oxygenated monoterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Calarene	Sesquiterpene hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Longipinene	Sesquiterpene hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
β-Maaliene	Sesquiterpene hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
β-Selinene	Sesquiterpene hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
α-Betulenol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
β-Betulenol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Caryophylla-3,8(13)-dien-5b-ol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Caryophylladienol I	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Caryophylladienol II	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
α-Caryophyllene alcohol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Caryophyllenone	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
cis-α-Copaen-8-ol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Eudesm-7(11)-en-4-ol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Humulene oxide II	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
(*Z*)-Nerolidyl isobutyrate	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Selin-11-en-4a-ol	Oxygenated sesquiterpenes	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Decanal	Aliphatic hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Heptacosane	Aliphatic hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Pentacosane	Aliphatic hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Benzyl isobutyrate	Aromatic hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Phenylacetaldehyde	Aromatic hydrocarbans	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Benzaldehyde	Carbonyl compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
(*E*)-Hex-2-enal	Carbonyl compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Oct-1-en-3-ol	Carbonyl compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Octan-3-ol	Carbonyl compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Pentadecanal	Carbonyl compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Camphene hydrate	Other compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
1-naphthalenol	Other compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
2-Pentylfuran	Other compounds	*P. sicula*	Aerial parts	Italy	Maggio et al. (2015)
Filifolene	Monoterpene hydrocarbans	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
δ-Terpinene	Monoterpene hydrocarbans	*P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
α-terpinene	Monoterpene hydrocarbans	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
trans-Carveol	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014)
cis-Chrysanthenol	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
α-Citral	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Filifolone	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014)
β-Ionone	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Neral	Oxygenated monoterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Alloaromadendrene	Sesquiterpene hydrocarbans	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
cis-Calamenene	Sesquiterpene hydrocarbans	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Amorpha-4,9-dien-2-ol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
trans-Calamenen-10-ol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
Calamenene-10-one	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
Caryophyllene epoxide	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Cedr-8(15)-en-9-α-ol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
ar-Curcumen-15-al	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
Curcumenol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
Ledol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Longifolol	Oxygenated sesquiterpenes	*P. gnaphalodes*	Aerial parts	Iran	Hassanabadi et al. (2022), Batoli et al. (2017)
β-Citronellol	Other compounds	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Eugenol methyl ether	Other compounds	*P. gnaphalodes*	Aerial parts	Iran	Gandomi et al. (2015)
Camphene	Monoterpene hydrocarbans	*P. undulata, P. sicula*	Aerial parts	Egypt, Italy, Saudi Arabia	Abd-ELGawad et al. (2021), Maggio et al. (2015)
p-Cymene	Monoterpene hydrocarbans	*P. crispa, P. sicula, P. gnaphalodes*	Aerial parts, flowers, leaves	Italy, Iran, Jordan	Al-Qudah et al. (2022), Gandomi et al. (2015), Maggio et al. (2015)
β-Myrcene	Monoterpene hydrocarbans	*P. undulata, P. crispa*	Aerial parts	Iran, Saudi Arabia, Sudan	AlMotwaa and Al-Otaibi (2022), Mohamed et al. (2020), Ravandeh et al. (2011)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Sabinene	Monoterpene hydrocarbans	*P. crispa, P. undulata*	Aerial parts	Iran, Egypt, Saudi Arabia	Abd-ELGawad et al. (2021), AlMotwaa and Al-Otaibi (2022), Ravandeh et al. (2011)
α-Phellandrene	Monoterpene hydrocarbans	*P. undulata, P. crispa, P. gnaphalodes,*	Aerial parts	Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), Gandomi et al. (2015), Ravandeh et al. (2011)
α-Pinene	Monoterpene hydrocarbans	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts, flowers, leaves	Jordan, Italy, Iran, Egypt, Saudi Arabia, Yemen	Abd-ELGawad et al. (2021), Al-Qudah et al. (2022), Ali et al. (2012), Asghari et al. (2014), Maggio et al. (2015)
β-Pinene	Monoterpene hydrocarbans	*P. undulata, P. sicula, P. crispa, P. gnaphalodes*	Aerial parts	Egypt, Iran, Italy, Saudi Arabia	Abd-ELGawad et al. (2021), AlMotwaa and Al-Otaibi (2022), Asghari et al. (2014), Maggio et al. (2015)
γ-Terpinene	Monoterpene hydrocarbans	*P. undulata, P. gnaphalodes*	Aerial parts	Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), Gandomi et al. (2015), Ravandeh et al. (2011)
α-Terpinolene	Monoterpene hydrocarbans	*P. undulata, P. gnaphalodes*	Aerial parts	Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), Gandomi et al. (2015), Ravandeh et al. (2011)
α-Thujene	Monoterpene hydrocarbans	*P. undulata, P. gnaphalodes*	Aerial parts	Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), Gandomi et al. (2015), Ravandeh et al. (2011)
Borneol	Oxygenated monoterpenes	*P. undulata, P. sicula*	Aerial parts, leaves	Algeria, Italy, Yemen	Ali et al. (2012), Boumaraf et al. (2016), Maggio et al. (2015)
Camphor	Oxygenated monoterpenes	*P. undulata,P. crispa, P. sicula, P. gnaphalodes*	Aerial parts, flowers, leaves	Algeria, Egypt, Iran, Italy, Jordan Saudi Arabia, Sudan, Yemen	Abd-ELGawad et al. (2021), Al-Qudah et al. (2022), Ali et al. (2012), Boumaraf et al. (2016), Gandomi et al. (2015), Maggio et al. (2015), Mohamed et al. (2020)
Carvacrol	Oxygenated monoterpenes	*P. crispa, P. undulata*	Aerial parts, flowers, leaves	Algeria, Jordan, Yemen	Al-Qudah et al. (2022), Ali et al. (2012), Boumaraf et al. (2016)
Carvotanacetone	Oxygenated monoterpenes	*P. crispa, P. undulata*	Aerial parts, flowers, leaves	Algeria, Egypt, Jordan, Saudi Arabia, Yemen	Abd-ELGawad et al. (2021), Al-Qudah et al. (2022), Ali et al. (2012), Boumaraf et al. (2016)
Chrysanthenone	Oxygenated monoterpenes	*P. crispa, P. gnaphalodes*	Aerial parts, flowers, leaves	Jordan, Iran	Al-Qudah et al. (2022), Asghari et al. (2014)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
1,8-Cineole	Oxygenated monoterpenes	*P. undulata, P. crispa, P. gnaphalodes*	Arial parts, flowers, leaves	Yemen, Jordan, Iran	Al-Qudah et al. (2022), Ali et al. (2012), Asghari et al. (2014), Ravandeh et al. (2011)
p-Cymen-8-ol	Oxygenated monoterpenes	*P. sicula, P. crispa*	Aerial parts, flowers, leaves	Italy, Jordan	Al-Qudah et al. (2022), Maggio et al. (2015)
1,8-Dehydrocineole	Oxygenated monoterpenes	*P. undulata, P. sicula, P. crispa*	Aerial parts, flowers, leaves	Egypt, Jordan, Saudi Arabia	Abd-ELGawad et al. (2021), Al-Qudah et al. (2022), Maggio et al. (2015)
Geraniol	Oxygenated monoterpenes	*P. undulata, P. crispa, P. sicula, P. gnaphalodes*	Aerial parts	Saudi Arabia, Italy, Iran	AlMotwaa and Al-Otaibi (2022), Asghari et al. (2014), Maggio et al. (2015), Yusufoglu et al. (2021)
Geranyl acetate	Oxygenated monoterpenes	*P. undulata, P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014), Ravandeh et al. (2011)
(*E*)-Geranyl acetone	Oxygenated monoterpenes	*P. undulata, P. crispa*	Aerial parts, leaves	Italy, Saudi Arabia, Yemen	Ali et al. (2012), Maggio et al. (2015), Yusufoglu et al. (2021)
Geranyl isovalerate	Oxygenated monoterpenes	*P. crispa, P. sicula*	Aerial parts	Italy, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Maggio et al. (2015)
Geranyl propionate	Oxygenated monoterpenes	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts	Iran, Saudi Arabia, Sudan	AlMotwaa and Al-Otaibi (2022), Asghari et al. (2014), Mohamed et al. (2020)
Isopulegol acetate	Oxygenated monoterpenes	*P. undulata, P. crispa*	Aerial parts	Egypt, Sudan, Saudi Arabia	Abd-ELGawad et al. (2021), Mohamed et al. (2020)
Limonene	Oxygenated monoterpenes	*P. undulata, P. crispa, P. sicula*	Aerial parts	Algeria, Egypt, Italy, Saudi Arabia	Abd-ELGawad et al. (2021), Boumaraf et al. (2016), Maggio et al. (2015)
Linalool	Oxygenated monoterpenes	*P. undulata, P. crispa, P. sicula, P. gnaphalodes*	Aerial parts, leaves	Iran, Italy, Saudi Arabia, Sudan, Yemen	Gandomi et al. (2015), Maggio et al. (2015), Mohamed et al. (2020), Mohammed et al. (2020), Ravandeh et al. (2011), Yusufoglu et al. (2021)
Myrtenol	Oxygenated monoterpenes	*P. undulata, P. gnaphalodes*	Aerial parts	Iran	Ravandeh et al. (2011)
Nerol oxide	Oxygenated monoterpenes	*P. sicula, P. gnaphalodes*	Aerial parts	Iran, Italy	Gandomi et al. (2015), Maggio et al. (2015)
Neryl acetate	Oxygenated monoterpenes	*P. gnaphalodes, P. undulata*	Aerial parts	Iran	Asghari et al. (2014)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
Neryl isobutanoate	Oxygenated monoterpenes	*P. crispa, P. undulata*	Flowers, leaves	Jordan, Yemen	Al-Qudah et al. (2022), Ali et al. (2012)
cis-Sabinene hydrate	Oxygenated monoterpenes	*P. undulata, P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014), Ravandeh et al. (2011)
1-Terpineol	Oxygenated monoterpenes	*P. gnaphalodes, P. crispa*	Aerial parts, flowers, leaves	Iran, Jordan	Al-Qudah et al. (2022), Gandomi et al. (2015)
4-Terpineol	Oxygenated monoterpenes	*P. gnaphalodes, P. undulata*	Aerial parts	Iran	Gandomi et al. (2015)
Terpinen-4-ol	Oxygenated monoterpenes	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts	Algeria, Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), AlMotwaa and Al-Otaibi (2022), Asghari et al. (2014), Boumaraf et al. (2016)
Thujol	Oxygenated monoterpenes	*P. crispa, P. undulata*	Aerial parts	Algeria, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Boumaraf et al. (2016)
Thymol	Oxygenated monoterpenes	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts, flowers, leaves	Iran, Jordan, Yemen	Ali et al. (2012), Asghari et al. (2014), Mohamed et al. (2020)
trans-Linalool oxide	Oxygenated monoterpenes	*P. undulata, P. crispa*	Aerial parts, flowers, leaves	Jordan, Sudan	Al-Qudah et al. (2022), Mohamed et al. (2020)
trans-*p*-Menthan-2-one	Oxygenated monoterpenes	*P. undulata, P. crispa*	Flowers, leaves	Yemen, Jordan	Al-Qudah et al. (2022), Ali et al. (2012)
trans-Sabinene hydrate	Oxygenated monoterpenes	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts, flowers, leaves	Iran, Jordan	Al-Qudah et al. (2022), Gandomi et al. (2015), Ravandeh et al. (2011)
α-Terpineol	Oxygenated monoterpenes	*P. undulata, P. sicula, P. crispa, P. gnaphalodes*	Aerial parts, flowers, leaves	Jordan, Italy Iran	Al-Qudah et al. (2022), Asghari et al. (2014), Maggio et al. (2015)
cis-Verbenol	Oxygenated monoterpenes	*P. undulata, P. crispa*	Aerial parts, flowers, leaves	Egypt, Jordan, Saudi Arabia	Al-Qudah et al. (2022)
α-Amorphene	Sesquiterpene hydrocarbans	*P. undulata, P. gnaphalodes*	Aerial parts	Iran	Asghari et al. (2014, Ravandeh et al. (2011)
Cadalene	Sesquiterpene hydrocarbans	*P. gnaphalodes, P. undulata*	Aerial parts	Iran	Gandomi et al. (2015), Ravandeh et al. (2011)
α-Cadinene	Sesquiterpene hydrocarbans	*P. undulata, P. crispa, P. gnaphalodes*	Aerial parts	Algeria, Iran, Saudi Arabia	Asghari et al. (2014), Boumaraf et al. (2016), Yusufoglu et al. (2021)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
δ-Cadinene	Sesquiterpene hydrocarbans	*P. undulata, P. crispa, P. sicula, P. gnaphalodes*	Aerial parts	Algeria, Iran, Egypt, Saudi Arabia, Sudan	Abd-ELGawad et al. (2021), Asghari et al. (2014), Boumaraf et al. (2016), Gandomi et al. (2015), Maggio et al. (2015), Mohamed et al. (2020), Ravandeh et al. (2011)
γ-Cadinene	Sesquiterpene hydrocarbans	*P. undulata, P. sicula, P. crispa, P. gnaphalodes*	Aerial parts	Algeria, Iran, Italy, Saudi Arabia	Boumaraf et al. (2016), Maggio et al. (2015), Ravandeh et al. (2011), Yusufoglu et al. (2021)
trans-Calamenene	Sesquiterpene hydrocarbans	*P. crispa, P. undulata*	Aerial parts	Iran, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Ravandeh et al. (2011)
Humulene	Sesquiterpene hydrocarbans	*P. crispa, P. undulata*	Aerial parts	Sudan, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Mohamed et al. (2020)
α-Humulene	Sesquiterpene hydrocarbans	*P. undulata, P. sicula, P. crispa*	Aerial parts	Egypt, Italy, Saudi Arabia	Abd-ELGawad et al. (2021), AlMotwaa and Al-Otaibi (2022), Yusufoglu et al. (2021)
α-Murolene	Sesquiterpene hydrocarbans	*P. undulata, P. gnaphalodes, P. crispa*	Aerial parts	Algeria, Egypt, Iran, Saudi Arabia	Abd-ELGawad et al. (2021), Boumaraf et al. (2016), Gandomi et al. (2015), Ravandeh et al. (2011), Yusufoglu et al. (2021)
γ-Muurolene	Sesquiterpene hydrocarbans	*P. undulata, P. crispa*	Aerial parts	Algeria, Sudan	Boumaraf et al. (2016), Mohamed et al. (2020)
α-Cadinol	Oxygenated sesquiterpenes	*P. undulata, P. sicula, P. crispa, P. gnaphalodes*	Aerial parts	Algeria, Egypt, Italy, Saudi Arabia, Sudan	Abd-ELGawad et al. (2021), Boumaraf et al. (2016), Maggio et al. (2015), Mohamed et al. (2020), Mohammed et al. (2020)
δ-Cadinol	Oxygenated sesquiterpenes	*P. crispa, P. sicula*	Aerial parts	Italy, Saudi Arabia	Maggio et al. (2015), Yusufoglu et al. (2021)
τ-Cadinol	Oxygenated sesquiterpenes	*P. undulata, P. sicula, P. crispa*	Aerial parts, leaves	Egypt, Italy, Sudan, Saudi Arabia, Yemen	Ali et al. (2012), Mohamed et al. (2020), Yusufoglu et al. (2021)
α-Calacorene	Oxygenated sesquiterpenes	*P. undulata, P. sicula, P. crispa*	Aerial parts	Algeria, Italy, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Boumaraf et al. (2016), Maggio et al. (2015)

Table 2 continued

Compounds	Class	*Pulicaria* spp.	Plant part used	Country	References
β-Caryophyllene	Oxygenated sesquiterpenes	*P. crispa, P. sicula, P. undulata*	Aerial parts	Algeria, Italy, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Boumaraf et al. (2016), Maggio et al. (2015), Yusufoglu et al. (2021)
Caryophyllene oxide	Oxygenated sesquiterpenes	*P. undulata, P. crispa, P. sicula,*	Aerial parts, flowers, leaves	Algeria, Egypt, Iran, Italy, Jordan, Saudi Arabia, Sudan, Yemen	Abd-ELGawad et al. (2021), Al-Qudah et al. (2022), Ali et al. (2012), Boumaraf et al. (2016), Maggio et al. (2015), Mohamed et al. (2020), Ravandeh et al. (2011), Yusufoglu et al. (2021)
(*E*)-Phytol	Oxygenated diterpenes	*P. sicula, P. crispa*	Aerial parts	Italy, Saudi Arabia	Maggio et al. (2015), Yusufoglu et al. (2021)
Hexadecanoic acid	Aliphatic hydrocarbans	*P. undulata, P. crispa*	Aerial parts	Sudan, Saudi Arabia	Mohamed et al. (2020), Yusufoglu et al. (2021)
n-Nonacosane	Aliphatic hydrocarbans	*P. undulata,P. sicula*	Aerial parts	Egypt, Italy, Saudi Arabia	Abd-ELGawad et al. (2021), Maggio et al. (2015)
Nonanal	Aliphatic hydrocarbans	*P. undulata, P. sicula*	Aerial parts	Sudan, Italy	Maggio et al. (2015), Mohamed et al. (2020)
Butanoic acid	Carbonyl compounds	*P. undulata, P. crispa*	Aerial parts	Sudan	Mohamed et al. (2020), Mohammed et al. (2020)
(*E*)-β-Damascenone	Carbonyl compounds	*P. crispa, P. sicula*	Aerial parts	Italy, Saudi Arabia	Maggio et al. (2015), Yusufoglu et al. (2021)
(E,E)-2,4-Decadienal	Carbonyl compounds	*P. crispa, P. sicula*	Aerial parts	Italy, Saudi Arabia	AlMotwaa and Al-Otaibi (2022), Maggio et al. (2015)
Methyl eugenol	Phenylpropanoids	*P. undulata, P. gnaphalodes*	Aerial parts, leaves	Iran, Yemen	Ali et al. (2012), Asghari et al. (2014)

to the literature was attributed to the different climates, seasons, geographic locations, and harvesting periods of the plants (Boumaraf et al. 2016). However, carvotanacetone was not reported as the main compound in the essential oil obtained from aerial parts of Iranian *P. undulata*. The main components identified in this oil were 4-terpineole (20.12%), 1S-*cis*-calamenene (13.37%), junipene (8.66%), α-terpinene (4.02%), cis-sabinene hydrate (8.29%), γ-terpinene (7.00%), and linalool (5.60%) (Ravandeh et al. 2011).

Similarly, essential oils of Saudi and Egyptian ecospecies of *P. undulata* had major VOCs: pinene, isoshyobunone, 6-epi-shyobunol, α-pinene, α-terpinolene, pathulenol, hexahydrofarnesyl acetone, α-bisabolol, and τ -cadinol. Substantial variations (both quantity and quality) have been seen in essential oils obtained from these species, which was attributed to the difference in the environmental and climatic conditions (Abd-ELGawad et al. 2021). Among these, some of these VOCs (2,5-dimethoxy-*p*-cymene, *epi*-α-cadinol, thujanol, 1S-*cis*-calamenene, junipene, isoshyobunone, 6-epi-shyobunol, spathulenol, hexahydrofarnesyl acetone, α-bisabolol) are solely reported in *P. undulata* essential oils so far and that can be chemical markers for its characterization (Fig. 3).

The VOCs composition of the Italian *P. sicula* essential oil showed a peculiar profile containing around 37 compounds. Among these, borneol was the main compound identified in the *P. sicula* essential oil (Maggio et al. 2015). The structure of borneol is shown in Fig. 4.

The essential oils obtained from Iranian *P. gnaphalodes* have around 22 distinguishable VOCs (Table 2). α-pinene (32.2%) and 1–8-cineole (10.9–22.9%) were the major components in this essential oil (Gandomi et al. 2015; Batoli et al. 2017). However, these two compounds are also reported in the other *Pulicaria* species. In other studies, besides these two, amorpha-4,9-dien-2-ol, calamenene-10-one, longifolol, ar-curcumen-15-al, *trans*-calamenen-10-ol, curcumenol, and cedr-8(15)-en-9-α-ol were also reported as major and distinguishable VOCs (Batoli et al. 2017; Gandomi et al. 2015; Hassanabadi et al. 2022). Of these nine compounds, α-pinene and 1–8-cineole are reported other species as well. Hence, the remaining VOCs can be used as maker compounds for the characterization of *P. gnaphalodes* essential oils (Fig. 5).

Flavonoids and phenolic compounds

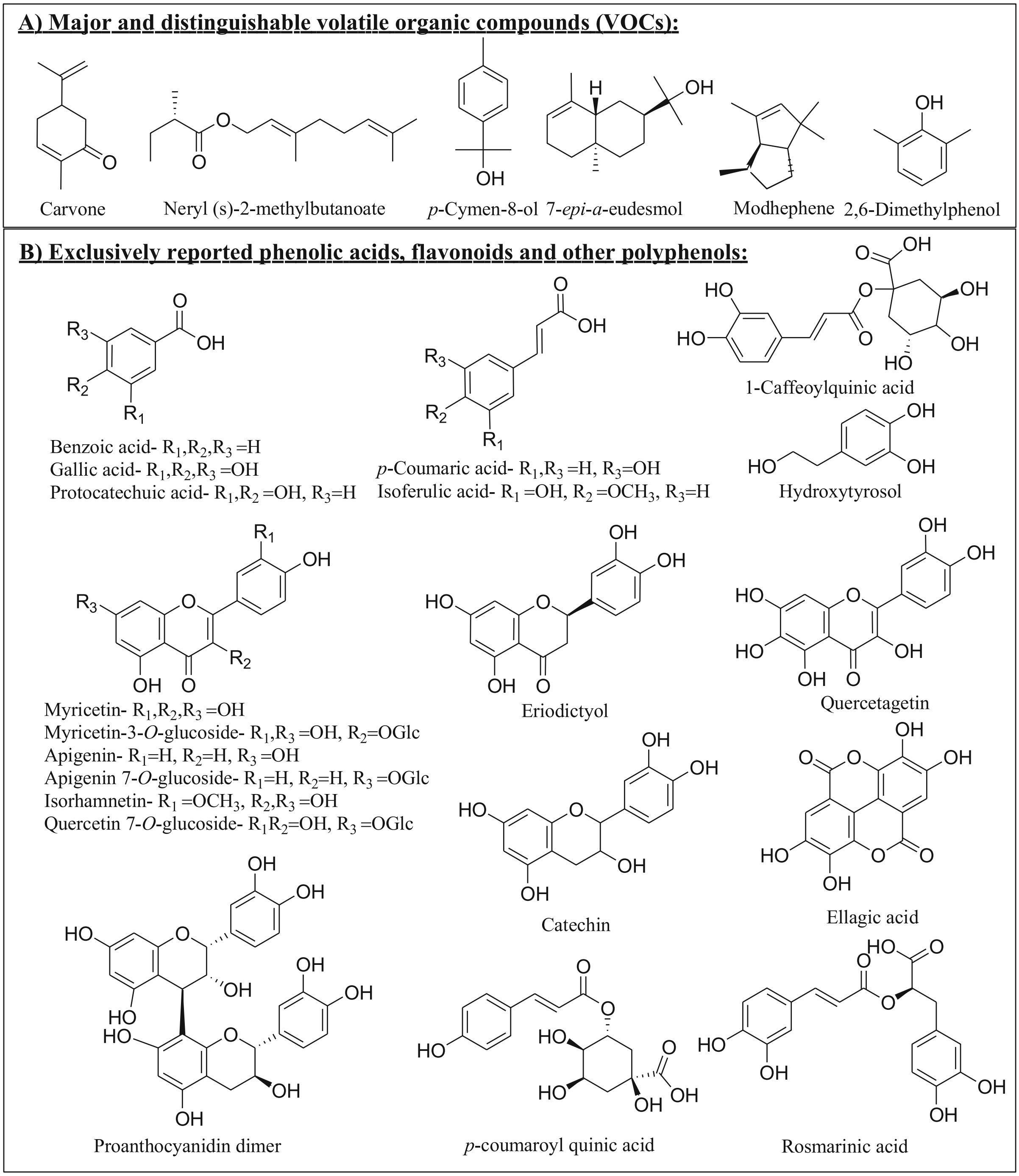
In these *Pulicaria* species, flavonoids and sesquiterpenes are the most studied classes of compounds. So far, nearly or over 45 different flavonoids have been identified in these species (Table 3). Besides this, 9 phenolic acids and other polyphenols are also reported in these species (Table 3).

In *P. crispa*, most of the flavonoids and phenolic compounds have been identified in methanolic extracts of its aerial parts, including Flowers and leaves (Foudah et al. 2015; El-Sabagh et al. 2021; Rizk et al. 1993; Thinina et al. 2020). Around, 29 different flavonoids, phenolic acids, and other polyphenols have been identified in *P. crispa*. Of these, 14 are flavonoids, followed by 8 phenolic acids and 7 other polyphenols (Table 3). Among these reported compounds, 20 flavonoids, phenolic acids, and other polyphenols are only reported in the *P. crispa* (Table 3, Fig. 2). Both flavonoid aglycones and flavonoid glycosides have been reported in *P. crispa* (El-Sabagh et al. 2021; Thinina et al. 2020). Along with phenolic acids,

p-hydroxybenzoic acid, and hydroxycinnamoylquinic acid conjugates such as cafffeoyl-, and *p*-coumaroyl quinic acids were also reported in the methanolic extract of *P. crispa* aerial parts (El-Sabagh et al. 2021). Other reported polyphenols in the methanolic extracts of *P. crispa* aerial parts include tannins, such as ellagic acid and proanthocyanidin dimer (Thinina et al. 2020).

Flavonoids are reported compounds in the different parts of *P. undulata* (whole plant, aerial parts, Flowers, and leaves). Out of 23 reported compounds, 19 are flavonoids. Among these 19 reported flavonoids, 12 are exclusively identified in the *P. undulata*. So far, several flavonoids and their glycosides have been isolated from the aqueous methanolic extract of *P. undulata* (70–95%) (Elhady et al. 2021; Hussien et al. 2016; Hussein et al. 2017; Bishay et al. 1982). Caffeic acid phenethyl ester and caffeic anhydride are the two polyphenolic compounds solely reported in *P. undulata* so far (Abdel Bar et al. 2020; Mohammed et al. 2021). The structures of characteristic flavonoids and polyphenolic compounds exclusively reported in *P. undulata* are shown in Fig. 6.

It has been reported that the occurrence of 6-oxygenation of flavonols is a common feature of *P. sicula* (Wollenweber et al. 2005). Among 11 reported



A) Major and distinguishable volatile organic compounds (VOCs):

B) Exclusively reported phenolic acids, flavonoids and other polyphenols:

Fig. 2 **A** Major and distinguishable volatile organic compounds (VOCs) in the essential oil of *P. cripa*. **B** Exclusively reported phenolic acids, flavonoids, and other polyphenols in the *P. cripa*

flavonoids in aerial parts of *P. sicula*, 10 were quercetagetin derivatives (Wollenweber et al. 2005). Except, quercetagetin 3,6,7,3',4'-pentamethyl ether, all are solely reported in the *P. sicula* that can be used as chemical marker compounds for the characterization of this plant species (Table 3, Fig. 4).

So far, 2 phenolic acids and 10 flavonoids have been isolated from the aerial parts of the *P.*

gnaphalodes (Table 3). Of these, *p*-anisic acid (phenolic acid) and 5 flavonoids are exclusively reported in the *P. gnaphalodes* (Fig. 5).

Non-essential oil fractions sesquiterpenes, diterpenes and triterpenes

Besides essential oil fractions, sesquiterpenes, diterpenes, and triterpenes compounds are isolated from these *Pulicaria* species. Sesquiterpenes are the main reported compounds in the *P. crispa*. Most of these sesquiterpenes were isolated from the methanolic extracts of *P. crispa* aerial parts (El-Sabagh et al. 2021; Stavri et al. 2008a, 2008b; Dendougui et al. 2000; Abdel-Mogib et al. 1990; Bohlmann et al. 1979). So far, 18 sesquiterpenes have been isolated and characterized from aerial parts of *P. crispa*. Of these, 17 sesquiterpenes are exclusively reported in the *P. crispa* (Table 3). Among the 5 reported diterpenes**,** salvicinolide, salvicinolin, and hardwickiic acid were solely isolated diterpenes from the methanolic extracts of *P. crispa* aerial parts.

It has been found that *P. undulata* is rich in sesquiterpene lactones. So far, around 23 sesquiterpenes have been isolated from the whole plant or aerial part of *P. undulata* (Table 3). Interestingly, all are exclusively reported in the *P. undulata* so far (Table 3). Sesquiterpene lactone, 2α-hydroxyalantolactone was one of the major metabolites isolated from the *P. undulata* (Hegazy et al. 2021). Besides this, 5 ditepenes and 4 triterpenes have been isolated from *P. undulata*. Among these, grandifloric acid-15-β-glucoside (diterpenoid), ent-16β,17-dihydroxy-kauran-19-oic acid (diterpenoid), pulicaroside-B (diterpenoid), 13-dihydro-4H-xanthalongin 4-O-β-D-glucopyranoside (triterpenoid), 23hydroxytormenticacid (triterpenoid), and 8-epi-ivalbin (triterpenoid) were exclusively isolated from the *P. undulata* (Abdel Bar et al. 2020; Hussien et al. 2016; Hussein et al. 2017; Hegazy et al. 2015; Rasool et al. 2008, 2013; Elhady et al. 2021; Rustaiyan et al. 1991).

Sesquiterpene lactones such as neryl isobutyrate, thymol derivatives, xanthanolides, and guaianolides were isolated from the Qatari *P. sicula* aerial part (Zdero et al. 1988). Clerodane-type diterpenoid such as salvin, salvinin, casticin, and 7-oxo-15,16-epoxy-trans-cleroda-3,13(14)-dien-19,6-olide have been isolated from the aerial parts of Uzbek *P. gnaphalodes* (Komilov et al. 2019; Eshbakova et al. 2018). Sesquiterpenes such as anabsinthin, isointermedeol, and gnapholide were characteristically isolated from the chloroform extract of Pakistani *P. gnaphalodes* (Ali et al. 2002, 1999; Sarg 1975).

Other compounds

Besides the above class of compounds, organic acids (quinic acid and malic acid) and fatty acids have also been identified in the methanolic extracts of *P. crispa* aerial parts (El-Sabagh et al. 2021). Xanthoxyline (methyl ketone) and stigmasterol (phytosterols) were isolated from the 95% methanolic extract of aerial parts of *P. undulata* (Elhady et al. 2021). Stigmasterol and β-sitosterol have been isolated from the aerial part

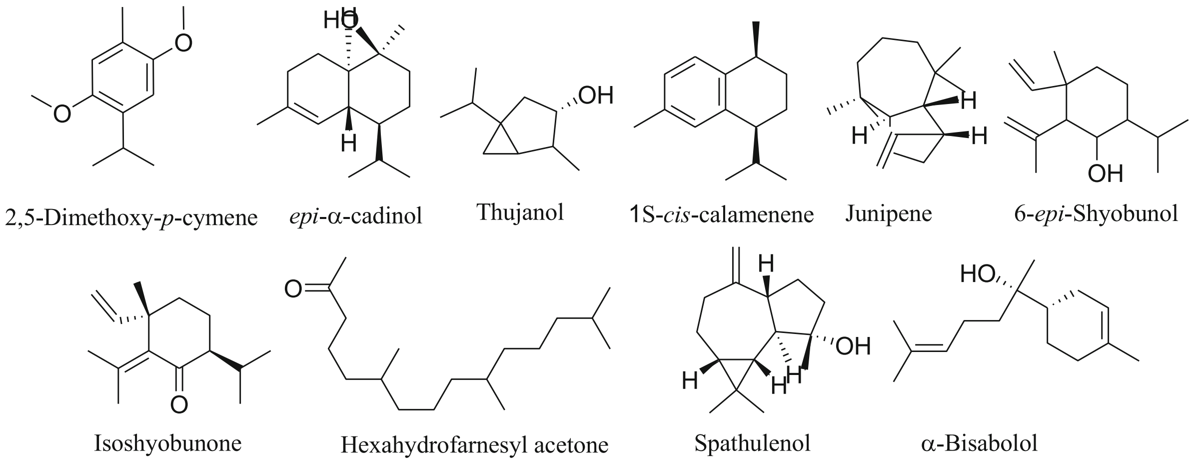
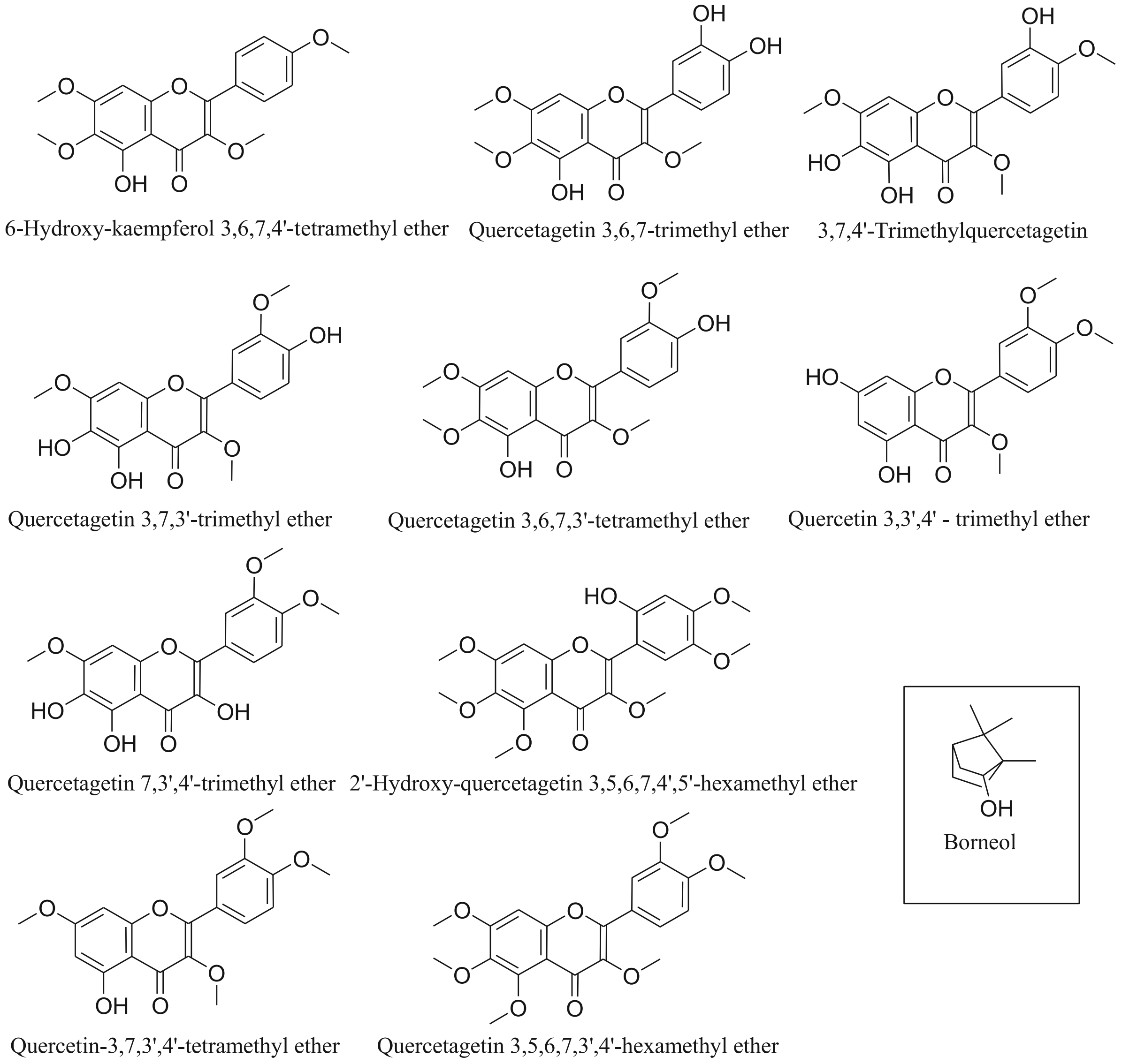


Fig. 3 Major and distinguishable volatile organic compounds in the essential oil of *P. undulata*


6-Hydroxy-kaempferol 3,6,7,4'-tetramethyl ether

Quercetagetin 3,6,7-trimethyl ether

3,7,4'-Trimethylquercetagetin

Quercetagetin 3,7,3'-trimethyl ether

Quercetagetin 3,6,7,3'-tetramethyl ether

Quercetin 3,3',4' - trimethyl ether

Quercetagetin 7,3',4'-trimethyl ether

2'-Hydroxy-quercetagetin 3,5,6,7,4',5'-hexamethyl ether

Borneol

Quercetin-3,7,3',4'-tetramethyl ether

Quercetagetin 3,5,6,7,3',4'-hexamethyl ether

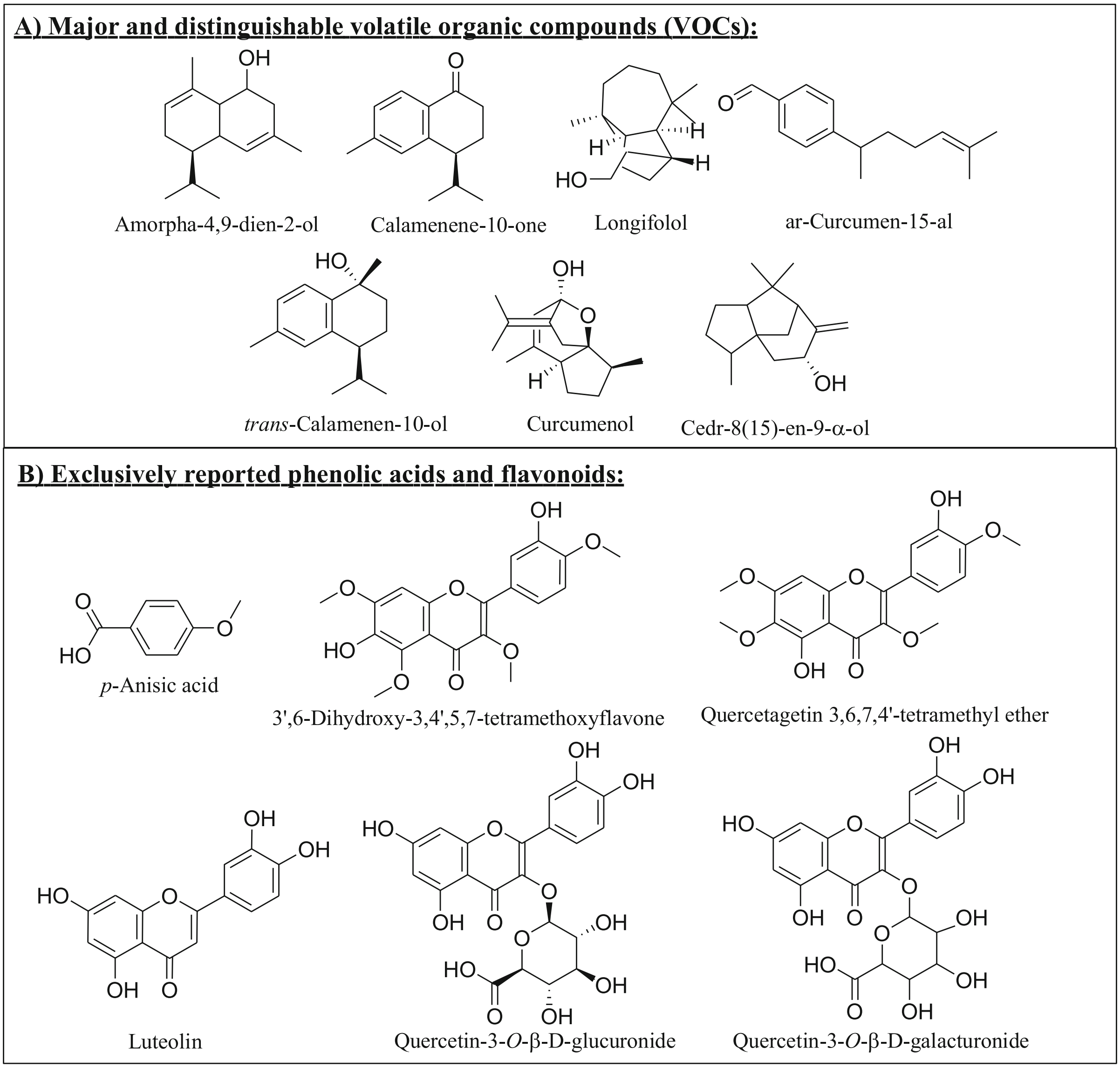
Fig. 4 Structures of borneol (a major volatile organic compound in the essential oil of *P. sicula*) and exclusively reported flavonols in *P. sicula*

of the Pakistani *P. gnaphalodes* (Ali et al. 1999; Sarg 1975).

Biological and pharmacological activities

Antimicrobial activity

Controlling microbial infectious diseases is becoming a major public health concern worldwide, mainly due to the emergence of antibiotic resistance and biofilm-forming microbes, including the limited availability of antibiotics (Kasote et al. 2023). Considering this, these days, extensive research has been undertaken about developing new antibiotics, including exploring new antimicrobials from plants and other natural products. Thus far, these *Pulicaria* species have been extensively investigated for their antimicrobial activity (Table 4). Among these, *P. crispa* and *P. undulata* are the most studied in the context of their antimicrobial activity, followed by *P. gnaphalodes* and *P. sicula*.



A) Major and distinguishable volatile organic compounds (VOCs):

B) Exclusively reported phenolic acids and flavonoids:

Fig. 5 **A** Major and distinguishable volatile organic compounds (VOCs) reported in the essential oil of *P. gnaphalodes*. **B** Exclusively reported phenolic acids and flavonoids in the *P. gnaphalodes*

Essential oils, alcoholic extracts, and their fractions of *P. crispa* whole plant or aerial parts are reported to exhibit antimicrobial activity. The essential oil obtained from *P. crispa* was found to have an antibacterial effect against Gram-positive bacteria such as *Staphylococcus aureus* and methicillin-resistant *S. aureus* (MRSA), but not against Gram-negative bacteria (AlMotwaa and Al-Otaibi 2022). In another study, essential oil and methanol extract of *P. crispa* displayed similar and broad-spectrum antibacterial activity, particularly against Gram-positive bacteria such as *S. aureus*. Significant antifungal activities were observed in essential oil than in methanolic extract (Mohamed et al. 2020). The ethanol and hexane extracts of aerial parts of *P. crispa* were found to be effective against only Gram-positive bacteria (MIC-1–8 mg/ml) and yeast, *Candida albicans* (MIC-1 mg/ml) (Abdelah Bogdadi, 2007). Similarly, different extracts (methanol, chloroform, diethyl ether, acetone, and water) of whole *P. crispa* plants were

Table 3 Flavonoids, phenolic and non-essential oil fractions terpene compounds reported in the Qatari *Pulicaria* species

Compound	Class	Species	Origin	Parts used	References
Benzoic acid	Phenolic acids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
ρ-Coumaric acid	Phenolic acids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Gallic acid	Phenolic acids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Isoferulic acid	Phenolic acids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Protocatechuic acid	Phenolic acids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Apigenin	Flavonoids	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
Apigenin 7-*O*-glucoside	Flavonoids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Eriodyctiol	Flavonoids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Isorhamnetin	Flavonoids	*P. crispa*	Qatar	Flowers, leaves	Rizk et al. (1993)
Myricetin	Flavonoids	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
Myricetin-3-*O*-glucoside	Flavonoids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Quercetagetin	Flavonoids	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
Quercetin 7-*O*-glucoside	Flavonoids	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Cafffeoyl-quinic acid	Other polyphenols	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
Catechin	Other polyphenols	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
p-Coumaroylquinic acid	Other polyphenols	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
Ellagic acid	Other polyphenols	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Hydroxytyrosol	Other polyphenols	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Proanthocyanidin dimer	Other polyphenols	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Rosmarinic acid	Other polyphenols	*P. crispa*	Algeria	Aerial parts	Thinina et al. (2020)
Desacetylxanthanol	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Bohlmann et al. (1979)
5,10-*epi*-2,3-Dihydroaromatin	Sesquiterpenes	*P. crispa*	Kuwait	Aerial parts	Stavri et al. (2008a)
Dihydropulicaric acid	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	El-Sabagh et al. (2021)
1β,4β-Dihydroxy-5α (H)-guaia-10(14),11(13)-dien-8α,12-olide	Sesquiterpenes	*P. crispa*	Algeria	Aerial parts	Dendougui et al. (2000)

Table 3 continued

Compound	Class	Species	Origin	Parts used	References
2α,4α-Dihydroxy-7αH,8αH,10αH-guaia-1(5),11(13)-dien-8β,12-olide	Sesquiterpenes	*P. crispa*	Kuwait	Aerial parts	Stavri et al. (2008a)
10 α,14-Epoxy-8-epiconfertin	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Bohlmann et al. (1979)
1α,2α-Epoxy-4β-hydroxy-5αH,7αH,8αH,10αH-guaia-11(13)-en-8β,12-olide	Sesquiterpenes	*P. crispa*	Kuwait	Aerial parts	Stavri et al. (2008a)
8-Epiconfertin	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Abdel-Mogib et al. (1990)
Grafininacetate	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Bohlmann et al. (1979)
10α-Hydroxy-8-epiconfertin	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Abdel-Mogib et al. (1990)
Pseudoivalin	Sesquiterpenes	*P. crispa*	Algeria	Aerial parts	Dendougui et al. (2000)
Pulicanadiene-C	Sesquiterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
Pulicaric acid	Sesquiterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
Puliglutone	Sesquiterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
Rel-2α,6α-dimethyltetracyclo-decal-3-en-2,12-diol-8α,13-olide	Sesquiterpenes	*P. crispa*	Kuwait	Aerial parts	Stavri et al. (2008b)
Secocrispiolid	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Bohlmann et al. (1979)
Xanthanolacetate	Sesquiterpenes	*P. crispa*	Egypt	Aerial parts	Bohlmann et al. (1979)
Hardwickiic acid	Diterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
Salvicinolide	Diterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
Salvicinolin	Diterpenes	*P. crispa*	Algeria	Aerial parts	El-Sabagh et al. (2021)
β-Amyrin	Triterpenes	*P. crispa*	Saudi Arabia	Aerial parts	Sarg (1975)
Dihydrokaempferol	Flavonoids	*P. undulata*	Egypt	Whole plant	Bishay et al. (1982)
Dihydroquercetin-4′-methyl ether	Flavonoids	*P. undulata*	Egypt	Whole plant	Elhady et al. (2021)
6-Hydroxykaempferol 3-methyl ether-6-*O*-(6’’-*O*-β-glucopyranoside)-β-glucopyranoside	Flavonoids	*P. undulata*	Egypt	Aerial parts	Hussein et al. (2017)
6-Methoxykaempferol	Flavonoids	*P. undulata*	Egypt	Aerial parts	Hussein et al. (2017)
	Flavonoids	*P. undulata*	Egypt		Hussein et al. (2017)

Table 3 continued

Compound	Class	Species	Origin	Parts used	References
Patuletin 3-*O*-β-D-glucopyranoside				Aerial parts	
5,7,2′,3′,4′ Penta hydroxyl isoflavone-4′-*O*-β-glucopyranoside	Flavonoids	*P. undulata*	Egypt	Aerial parts	Hussein et al. (2017)
Patuletin 7-*O*-β-D-glucopyranoside	Flavonoids	*P. undulata*	Egypt	Aerial parts	Hussein et al. (2017)
Quercetagetin 3,6-dimethyl ether	Flavonoids	*P. undulata*	Egypt	Aerial parts	Abdel Bar et al. (2020)
Quercetagetin 6, 7-dimethyl ether	Flavonoids	*P. undulata*	Egypt	Aerial parts	Hussein et al. (2017)
Quercetin 3,7-dimethyl ether	Flavonoids	*P. undulata*	Egypt	Aerial parts, whole plant	Bishay et al. (1982), Hussien et al. (2016)
Quercetin 3-*O*-β-glucoside	Flavonoids	*P. undulata*	Egypt	Whole plant	Bishay et al. (1982)
Rhamnocitrin	Flavonoids	*P. undulata*	Egypt	Whole plant	Bishay et al. (1982)
Salvigenin	Flavonoids	*P. undulata*	Egypt	Whole plant	Elhady et al. 2021)
Caffeic acid phenethyl ester	Other polyphenols	*P. undulata*	Saudi Arabia	Aerial parts	Mohammed et al. (2021)
Caffeic anhydride	Other polyphenols	*P. undulata*	Egypt	Aerial parts	Abdel Bar et al. (2020)
Corchoionol C	Sesquiterpenes	*P. undulata*	Pakistan	Whole plant	Rasool et al. (2008)
1,2-Dehydro-1,10-α-dihydropseudoivalin	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Abdel Bar et al. 2020)
1β-Hydroperoxyl,4α-dihydroxy-5αH,7αH,8β-guaia10(14),11(13)-dien-8b,12-olide	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)
1β-Hydroperoxyl,4α-hydroxy-5αH,7αH,8βH-guaia10(14),11(13)-dien-8α,12-olide	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)
5α-Hydroperoxyivalin	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2012)
2α-Hydroxyalantolactone	Sesquiterpenes	*P. undulata*	Egypt, Pakistan	Aerial parts, whole plant	Hegazy et al. (2012), Rasool et al. (2013)
1 1-Hydroxy-4α,5α-epoxy-lαH,l0αH-13-norguai-7(11)-en-12,8α-olide	Sesquiterpenes	*P. undulata*	Iran	Aerial parts	Rustaiyan et al. (1991)
2α-Hydroxyeudesma-4,11(13)-Dien-8β,12-Olide	Sesquiterpenes	*P. undulata*	Iran	Aerial parts	Rustaiyan et al. (1991)
4α-Hydroxy,10α-hydroperoxyl,5αH,7αH,8β-guaia-1,11(13)dien-8b,12-olide	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)

Table 3 continued

Compound	Class	Species	Origin	Parts used	References
4α-Hydroxy,10β-hydroperoxyl,5αH,7αH,8β-guaia-1,11(13)dien-8b,12-olide	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)
Isoxanthanol	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2012)
8-*epi*-Isoxanthanol	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2012)
Ivalin	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hussien et al. (2016)
1β,2α,3β,19α,23-Pentahydroxy-urs-12-en-28-oic acid	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Abdel Bar et al. (2020)
1β,4β-Peroxide-5αH,7αH,8β,10βH-guaia-2,11(13)-dien-8β,12olide	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)
Pulicaria glaucolide	Sesquiterpenes	*P. undulata*	Iran	Aerial parts	Rustaiyan et al. (1991)
Roseoside	Sesquiterpenes	*P. undulata*	Pakistan	Whole plant	Rasool et al. (2008)
8-*epi*-4H-Tomentosin	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2015)
Xanthanol	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. (2012)
8-*epi*-Xanthanol	Sesquiterpenes	*P. undulata*	Egypt	Aerial parts	Hegazy et al. 2012)
Ent-16β,17-dihydroxy-kauran-19-oic acid	Diterpenes	*P. undulata*	Pakistan	Whole plant	Rasool et al. (2013)
Grandifloric acid-15-β-glucoside	Diterpenes	*P. Undulata*	Egypt	Aerial parts	Abdel Bar et al. (2020)
Pulicaroside-B	Diterpenes	*P. undulata*	Pakistan	Whole plant	Rasool et al. (2008)
13-Dihydro-4H-xanthalongin 4-*O*-β-D-glucopyranoside	Triterpenes	*P. undulata*	Egypt	Aerial parts	Hussien et al. 2016)
23-Hydroxytormenticacid	Triterpenes	*P. Undulata*	Egypt	Aerial parts	Abdel Bar et al. (2020)
8-*epi*-Ivalbin	Triterpenes	*P. undulata*	Egypt	Aerial parts	Hussien et al. (2016)
6-Hydroxy-kaempferol 3,6,7,4'-tetramethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
2'-Hydroxy-quercetagetin 3,5,6,7,4',5'-hexamethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetin 3,3',4'—trimethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetagetin 3,6,7-trimethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetagetin 3,7,3'-trimethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)

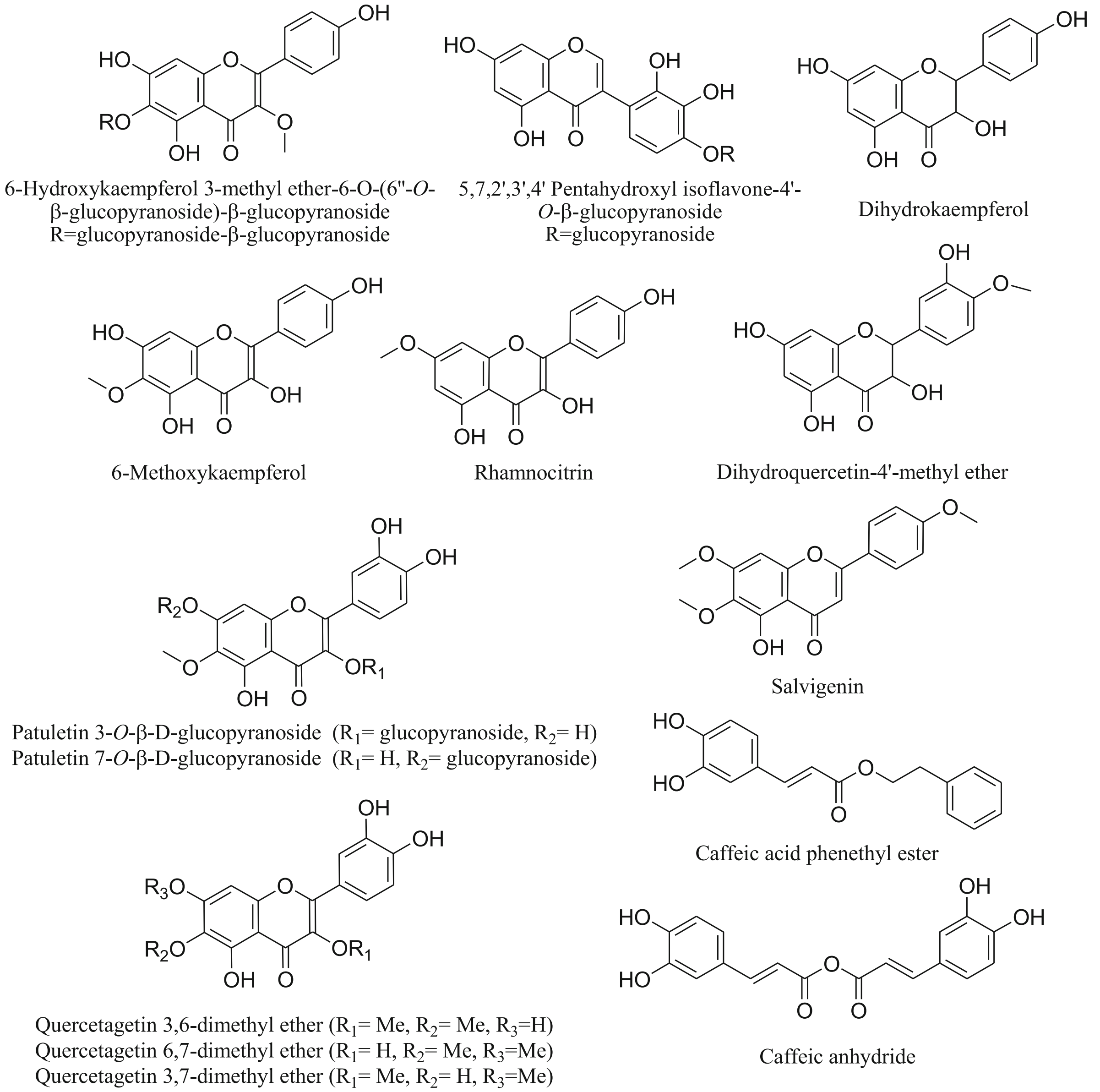
Table 3 continued

Compound	Class	Species	Origin	Parts used	References
Quercetagetin 7,3',4'-trimethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetagetin 3,6,7,3'-tetramethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetagetin 3,7,3',4'-tetramethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Quercetagetin 3,5,6,7,3',4'-hexamethyl ether	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
3,7,4'-Trimethylquercetagetin	Flavonoids	*P. Sicula*	Germany	Aerial parts	Wollenweber et al. (2005)
Guaianolides	Sesquiterpenes	*P. Sicula*	Qatar	Aerial parts	Zdero et al. (1988)
p-Anisic acid	Phenolic acids	*P. gnaphalodes*	Iran	Aerial parts	Pourhossein Alamdary et al. 2023)
3′,6-Dihydroxy-3,4′,5,7-tetramethoxyflavone	Flavonoids	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova (2011)
Luteolin	Flavonoids	*P. gnaphalodes*	Iran	Aerial parts	Pourhossein Alamdary et al. (2023)
Quercetagetin 3,6,7,4'-tetramethyl ether	Flavonoids	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova et al. (2018)
Quercetin-3-*O*-β-D-glucuronide	Flavonoids	*P. gnaphalodes*	Uzbekistan, Iran	Aerial parts	Eshbakova et al. (2018, Pourhossein Alamdary et al. (2023)
Quercetin-3-*O*- β-D-galacturonide	Flavonoids	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova et al. (2018)
Anabsinthin	Sesquiterpenes	*P. gnaphalodes*	Pakistan	Aerial parts	Ali et al. (2002)
Gnapholide	Sesquiterpenes	*P. gnaphalodes*	Pakistan	Aerial parts	Ali et al. (2002)
Isointermedeol	Sesquiterpenes	*P. gnaphalodes*	Pakistan	Aerial parts	Ali et al. (1999)
7-Oxo-15,16-epoxy-trans-cleroda-3,13(14)-dien-19,6-olide	Diterpenes	*P. gnaphalodes*	Uzbekistan	Aerial parts	Komilov et al. (2019)
Salvifolin	Diterpenes	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova et al. (2018)
Salvin	Diterpenes	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova et al. (2018)
Salvinin	Diterpenes	*P. gnaphalodes*	Uzbekistan	Aerial parts	Eshbakova et al. (2018)
Caffeic acid	Phenolic acids	*P. Crispa, P. undulata*	Algeria,Egypt, Saudi Arabia	Aerial parts	Hussien et al. (2016), Mohammed et al. (2021), Thinina et al. (2020)
trans-Ferulic acid	Phenolic acids	*P. crispa, P. undulata*	Algeria, Saudi Arabia	Aerial parts	Mohammed et al. (2021), Thinina et al. (2020)
Salicylic acid	Phenolic acids	*P. crispa, P. gnaphalodes*	Algeria, Uzbekistan	Aerial parts	Eshbakova et al. (2016), Thinina et al. (2020)
Kaempferol	Flavonoids	*P. crispa, P. undulata, P. gnaphalodes*	Egypt, Uzbekistan	Aerial parts	El-Sabagh et al. (2021), Eshbakova et al. (2016), Hussien et al. (2016)

Table 3 continued

Compound	Class	Species	Origin	Parts used	References
Kaempferol 3-*O*-β-glucoside	Flavonoids	*P. undulata, P. crispa*	Egypt, Qatar	Flowers, leaves, whole plant	Hussien et al. (2016), Rizk et al. (1993)
Quercetin	Flavonoids	*P. crispa, P. undulata, P. gnaphalodes*	Algeria, Egypt, Iran, Germany, Saudi Arabia, Qatar	Aerial parts, flowers, leaves	Hussien et al. (2016), Mohammed et al. (2020), Pourhossein Alamdary et al. (2023), Rizk et al. (1993), Thinina et al. (2020), Wollenweber et al. (2005)
Quercetagetin 3,6,7,3',4'-pentamethyl ether	Flavonoids	*P.Sicula, P. gnaphalodes*	Germany, Pakistan	Aerial parts	Ali et al. (1999), Wollenweber et al. (2005)
Quercetin 3-*O*-β-galactoside	Flavonoids	*P. undulata, P. crispa*	Algeria, Egypt	Aerial parts, whole plant	Hussien et al. (2016), Thinina et al. (2020)
Rhamnetin	Flavonoids	*P. crispa, P. undulata*	Egypt	Aerial parts, whole plant	Bishay et al. (1982), El-Sabagh et al. (2021)
Rutin	Flavonoids	*P. crispa, P. undulata*	Algeria, Saudi Arabia	Aerial parts	Mohammed et al. (2021), Thinina et al. (2020)
Xanthanolides	Sesquiterpenes	*P. crispa, P. Sicula*	Algeria, Qatar	Aerial parts, Aerial parts	Dendougui et al. (2000), Zdero et al. (1988)
Crispioside A	Diterpenes	*P. crispa, P. undulata*	Egypt	Aerial parts	Abdel-Mogib et al. (1990), Hussien et al. (2016)
Crispioside B/Paniculoside-IV	Diterpenes	*P. crispa, P. undulata*	Algeria, Egypt, Pakistan	Aerial parts	Abdel Bar et al. (2020), Abdel-Mogib et al. (1990), Hussien et al. (2016)
Oleanolic acid	Triterpenes	*P. crispa, P. undulata*	Algeria, Egypt	Whole plant	El-Sabagh et al. (2021), Elhady et al. (2021)
β-Sitosterol	Sterol	*P. Crispa, P. gnaphalodes*	Saudi Arabia, Pakistan	Aerial parts	Ali et al. (1999), Sarg (1975)

studied for antibacterial activity against Gram-positive and -negative bacteria. All the studied extracts showed activity only against *S. aureus*. However, methanol extract was the most potent among these (Ejaz et al. 2023). In another study, methanol extract of *P. crispa* aerial parts and its fractions (hexane, dichloromethane, ethyl acetate, and water) were investigated against Gram-positive and -negative bacterial isolates and found that the hexane fraction (HF) was the most potent against the studied bacteria, which not only inhibited bacterial growth (minimum inhibitory concentration (MIC)-15.6–125 µg/ml) but also killed the bacteria (minimum bactericidal concentration (MBC)-31.25–250 µg/ml). Based on the observed MBC/MIC ratio, HF had a bactericidal effect against all tested bacteria. The bactericidal effect of HF was linked with its ability to reduce the expression levels of penicillin-binding protein (PBP2A) and DNA gyrase B enzymes in *S. aureus* and *Pseudomonas aeruginosa*, respectively. This observed anti-PBP2A and anti-DNA gyrase B effects of the HF were attributed to its main phytoconstituents such as β-sitosterol, phytol, stigmasterol, and lupeol. Moreover, HF also showed a dose-dependent inhibition of biofilm formation. At a concentration of 250 µg/ml, HF significantly reduced biofilm formation in *Proteus mirabilis*, *S. aureus* (ATCC 25923), *Acinetobacter baumannii* (ATCC 19606), and *P. aeruginosa* by 63.33%, 75.21%, 81.85%, and 85.52%, respectively. Similarly, HF fraction (250 µg/ml) was effective in



6-Hydroxykaempferol 3-methyl ether-6-O-(6''-*O*-β-glucopyranoside)-β-glucopyranoside
R=glucopyranoside-β-glucopyranoside

5,7,2',3',4' Pentahydroxyl isoflavone-4'-*O*-β-glucopyranoside
R=glucopyranoside

Dihydrokaempferol

6-Methoxykaempferol

Rhamnocitrin

Dihydroquercetin-4'-methyl ether

Patuletin 3-*O*-β-D-glucopyranoside (R_1= glucopyranoside, R_2= H)
Patuletin 7-*O*-β-D-glucopyranoside (R_1= H, R_2= glucopyranoside)

Salvigenin

Caffeic acid phenethyl ester

Quercetagetin 3,6-dimethyl ether (R_1= Me, R_2= Me, R_3=H)
Quercetagetin 6,7-dimethyl ether (R_1= H, R_2= Me, R_3=Me)
Quercetagetin 3,7-dimethyl ether (R_1= Me, R_2= H, R_3=Me)

Caffeic anhydride

Fig. 6 Structures of characteristic flavonoids and polyphenolic compounds reported in *P. undulata*

inducing biofilm detachment in all the above-tested bacterial strains (Abo-Elghiet et al. 2023). The antibacterial and antifungal activities of methanol extract of *P. crispa* aerial parts and its fractions (n-hexane, chloroform, ethyl acetate, and n-butanol) were also investigated in another study. It was found that ethyl acetate fraction (EAF) exhibited the strongest antibacterial effect against *Klebsiella pneumonia*, *S. aureus* (animal pathogenic isolate), and *S. aureus* ATCC 29213, with MIC, 5 mg/ml. This activity was even stronger than the reference standard used, ciprofloxacin. The EAF also exhibited the strongest antifungal effect against *C. albicans* (animal pathogenic isolate), *C. albicans* ATCC 60193, and *C. tropicalis* ATCC 66029, with MIC values of 5 mg/ml and 25 mg/ml, respectively (AlZain et al. 2023). Besides this, polyphenolic extract of *P. crispa* Flowersy tops, containing quercetin as a major component, was reported to prevent the formation of biofilms in *K. pneumoniae* and inhibit 80% of planktonic forms. The observed MIC of this extract was in the range of 0.21–3.40 mg gallic acid equivalent (GAE) (Thinina et al. 2020).

Likewise, essential oils, different extracts, and their isolates of *P. undulata* are studied for antibacterial activity, including anti-quorum-sensing activity. Essential oil and the methanolic extract of *P. undulata* inhibited the growth of various tested Gram-positive and -negative bacteria, including fungi (Mohamed et al. 2020). The essential oil obtained from *P. undulata* (L.) C. A. Mey. and *P. jaubertii* E. Gamal-Eldin (syn. *Pulicaria orientalis* Jaub. & Spach) leaves showed strong bactericidal activity against *S. aureus* and MRSA, as well as *C. albicans* with MBC in the range 3.12–6.25 µl/ml (Ali et al. 2012). However, it has been found that the methanolic extract had a significantly higher inhibitory effect on the fungal skin pathogens than the essential oil. These tested strains of dermatophytes were more susceptible to methanolic extract than the opportunistic pathogenic strains of *Candida* and *Aspergillus*. Furthermore, the methanolic extract exhibited higher inhibitory activity against the fungi: *Microsporum boulardii* IFM 56403, *Trichophyton mentagrophytes* AUMC 11661, *Microsporum canis* AUMC 11663, and *C. albicans* AUMC 9142 than the essential oil (Mohammed et al. 2020). Interestingly, a fungicidal effect was only observed for methanolic extract, but not for essential oil (Helal et al. 2019). In general, like *P. crispa*, the alcoholic extract of *P. undulata* was also found to be most effective against Gram-positive bacteria (Elbalola and Abbas 2023). The ethanol extract (95%) of *P. undulata* demonstrated antimicrobial activity only against the Gram-positive bacteria but not against the tested Gram-negative bacteria, or fungi. The observed MICs and MBCs values were 49–1560 µg/ml and 49–3125 µg/ml against the tested Gram-positive bacteria, respectively (Mohammed et al. 2021). In another study, among the different solvent extracts studied, chloroform extract of *P. undulata* aerial parts showed potent activity against Gram-positive bacteria (MIC/MBC: 50–120 µg/ml) (Alshehri and Ghobashy, 2020). It has been reported that the phenolic compounds of *P. undulata* exhibited remarkable antimicrobial and anti-quorum-sensing activities compared to terpenoid compounds, such as sesquiterpenoids and terpenoids (Abdel Bar et al. 2020). The quorum-sensing potential of methylene chloride (CH_2Cl_2) and ethyl acetate extracts, including isolates of *P. undulata* aerial parts were investigated along with their antibacterial and antifungal activities (Abdel Bar et al. 2020). Phenolic compounds viz., caffeic acid, quercetin, and axillarin exhibited strong antibacterial activity against *S. aureus*. However, only axillarin showed pronounced antifungal activity against *C. albicans*. The flavonoids such as axillarin, and quercetin exhibited remarkable quorum-sensing (QS) inhibition (4.5 and 4.0 mm, respectively) comparable to that of the standard compound, catechin (QS 4.8 mm). The predominance of these aglycones in the CH_2Cl_2 extract may account for its higher activity (QS 3.5 mm) compared to the ethyl acetate extract (Abdel Bar et al. 2020).

So far, *P. sicula* has been the least investigated species for its biological and pharmacological activities, compared to the other *Pulicaria* species. There is only one study, in which ethanol extract of *P. sicula* was found to be weakly active against Gram-positive bacteria such as *Bacillus subtilis,* MRSA, and *S. aureus* (Nath et al. 2021).

Essential oils and alcoholic extracts of *P. gnaphalodes* were also investigated for their antimicrobial potential like other species. The essential oil obtained for the aerial parts of *P. gnaphalodes* showed a maximum zone of inhibition against *C. albicans* (23 ± 1.2 mm), which was higher compared to standard, fluconazol (18.0 ± 0.3 mm) (Kazemi et al. 2013). Similarly, the essential oil of *P. gnaphalodes* was found to be effective against *Candida zeylanoides* strains (Shokri 2014). In another study, the essential oil of *P. gnaphalodes* whole plant was found to be more potent against food-borne pathogens bacteria and fungi studied, followed by aqueous and alcoholic extracts (Gandomi et al. 2015). The ethanolic and methanolic extracts of the *P. gnaphalodes* stem were also found to be effective against the *S. aureus* and *B. subtilis* (MICs: 2.8 ± 0.3 and 2.9 ± 0.3 µg/ml, respectively) (Naqvi et al. 2020).

Anticancer activity

Cancer is one of the leading causes of death worldwide, and its global burden is constantly growing. Considering limited therapeutic options, there is a need to undertake extensive research in exploring the utility of different alternative and complementary medicines in the treatment of various cancers. Several studies in the literature confirm the utility of *Pulicaria* species as a promising anticancer agent for the

Table 4 Biological and pharmacological activities of Qatari *Pulicaria* species

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
Antimicrobial	*P. crispa*	Aerial parts (methanol extract and its fractions)	5–125 mg/ml (disc diffusion, agar plate, and microbroth dilution assays)	Bactericidal (MIC: 5 mg/ml), and fungicidal (MIC: 5–25 mg/ml)	Ethyl acetate fraction had the strongest bactericidal and fungicidal effects	AlZain et al. (2023)
	P. crispa	Aerial parts (methanol extract and its fractions)	62.5–1000 µg/ml (microbroth dilution assay)	MIC: 62.5 µg/ml	Hexane fraction (HF) had the strongest antibacterial effects (Gram-positive and negative bacteria, including biofilm producers). HF reduced expression levels of PBP2A and DNA gyrase B enzymes in *S. aureus* and *P. aeruginosa*, respectively	Abo-Elghiet et al. (2023)
	P. crispa	Aerial parts (essential oil)	1.3–83.3 µl/ml (microbroth dilution assay)	*S. aureus* (MIC:0.26 µl/ml, MBC: 0.52 µl/ml), MRSA (MIC: 1.04 µl/ml, MBC: 0.52 µl/ml)	Antibacterial effect only against *Gram-positive bacteria*	AlMotwaa and Al-Otaibi (2022)
	P. crispa	Whole plant (methanol extract and essential oil)	6.25–100 mg/ml (disc diffusion, and microbroth dilution assays)	MIC: 6.25–100 mg/ml	Highest activity against fungus and Gram-negative bacteria	Mohamed et al. (2020)
	P. crispa	Aerial parts (ethanol and hexane extracts)	0.125–16 mg/ml (microbroth dilution assay)	MICs: 1–8 mg/ml	The ethanol extract was most potent against Gram-positive bacteria and *C. albicans*	Abdelah Bogdadi (2007)
	P. crispa	Whole plant (methanol, chloroform, diethyl ether, acetone, and water)	8–200 µg/disc (disc diffusion method)	200 µg/disc	All extracts studied had activity only against *S. aureus*. The methanol extract was the most potent and had growth-inhibitory potential	Ejaz et al. (2023)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
	P. undulata	Whole plant (methanol extract and essential oil)	6.25–100 mg/ml (disc diffusion method)	MIC: 6.25–100 mg/ml	Highest activity against fungus	Mohammed et al. (2020)
	P. undulata	Aerial plants (95% ethanol extract)	0.05 to 25 mg/ml (micro-broth dilution method)	MIC: 49–1563 µg/ml; MBC: 49–3125 µg/ml	Effective only against Gram Gram-positive bacteria	Mohammed et al. (2021)
	P. undulata	Aerial plants (methanol and essential oil extracts)	Serial dilution (micro-broth dilution method)	MIC: 2.12–34 mg/ml; MBC: 4.25–17 µg/ml	Strong fungal inhibitory, including fungicidal effect found in methanol extract	Helal et al. (2019)
	P. undulata	Leaves (essential oil)	0.38 to 100 µl/ml (micro-broth dilution method)	MBC: 3.12 µl/ml	The lowest MBC was for S. *aureus* and MRSA	Ali et al. (2012)
	P. undulata	Aerial parts (chloroform, ethyl acetate, and methanol extracts)	0–1000 µg/ml (broth microdilution assay)	MICs/MBCs: 50–120 µg/ml	Chloroform extract was most potent against Gram-positive bacteria	Alshehri and Ghobashy (2020)
	P. undulata	Aerial parts (extracts such as CH_2Cl_2, and isolates)	19.54 -5000 µg/ml (broth microdilution and anti-quorum-sensing assays)	–	CH_2Cl_2, axillarin, and quercetin showed potent anti-quorum-sensing activity. Caffeic acid and quercetin exhibited strong activity against *S. aureus.* Axillarin showed pronounced antifungal activity against *C. albicans*	Abdel Bar et al. (2020)
	P. sicula	Aerial parts (ethanol extract)	9.76–5000 µg/ml (microbroth dilution assay)	MIC/MBC: 312.5 µg/ml	Most active against MRSA	Nath et al. (2021)
	P. gnaphalodes	Stem (ethanol and methanol extracts)	0.1–500 µg/ml (Agar well dilution method)	MICs: 2.8–3.9 µg/ml	Both extracts were more effective against the *S aureus* and *B subtilis*	Naqvi et al. (2020)
	P. gnaphalodes	Aerial parts (essential oil)	15 µl (disc diffusion method)	–	Potent against Candida albicans	Kazemi et al. (2013)
	P. gnaphalodes	Aerial parts (essential oil)	0–20% *v/v* (DPPH and β-carotene bleaching assays)	Concentration-dependent	Strong DPPH free radical scavenging activity, higher than trolox	Kazemi et al. (2013)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
Anticancer	*P. crispa*	Aerial parts (essential oil)	0.01–14.6 µl/ml (MTT assay)	Concentration-dependent	The highest cytotoxic effect observed on HepG2 cells	AlMotwaa and Al-Otaibi (2022)
	P. crispa	Aerial parts (methanol extract and its fractions)	0–500 µg/ml (MTT assay)	IC50: 229.23–251.09 µg/ml	Ethyl acetate fraction had the highest anticancer activity A549 and MCF-7 cell lines	AlZain et al. (2023)
	P. crispa	Leaves and Flowers (essential oils)	25–500 mg/ml (Giemsa staining and XTT cell viability assay)	IC50: 103–355 µg/ml	Both oils had promising activity against MDA-MB-231 and HL-60 cell lines	Al-Qudah et al. (2022)
	P. crispa	Aerial parts (70% ethanol extract)	Serial dilution (MTT assay)	IC50: 180 µg/ml	Cytotoxicity on MDA-MB-231 breast cancer cell lines was attributed to membrane destruction potential	Barnawi and Ali (2019)
	P. crispa	Aerial parts (80% methanol)	0.33–40 µg/ml (Resazurin reduction assay)	IC50: 1.81 µg/ml	Cytotoxicity on leukemia cell lines and found to induce cell cycle arrest in the G0/G1 phase and apoptosis	Kuete et al. (2013)
	P. undulata	Leaves (essential oil)	50 and 100 µg/ml (MTT assay)	IC50: 64.6 ± 13.7 µg/ml	Moderate activity against MCF-7 breast tumor cells	Ali et al. (2012)
	P. undulata	Aerial plants (95% ethanolic extract)	15.625–1000 µg/ml (MTT and annexin V assay)	IC50: 250 µg/ml	Cytotoxicity on MCF-7 cell lines, and also inhibited and induced apoptosis in MCF-7	Mohammed et al. (2021)
	P. undulata	whole plants (95% methanol extract and isolates)	0–50 µg/mL and 50–200 µg/ml (in vitro and in vivo assays)	IC50: 18–28.10 µg/ml	Crude extract and isolates had promising cytotoxic and antitumor activity. Antiangiogenic activity through the inhibition of VEGF signaling	Elhady et al. (2021)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
	P. undulata	2α-Hydroxyalantolactone	5.91–49.22 µM (Resazurin cytotoxicity assay)	IC50: 5.91–49.22 µM	Inhibited drug-resistant human tumor cell growth through DNA damage, G2/M cell cycle arrest, and apoptosis	Hegazy et al. (2021)
	P. undulata	Aerial parts (essential oil)	Serial dilution (MTT assay)	IC50: 18.53 µg/ml (A375), 40.64 µg/ml (T98G), 22.23 µg/ml (HCT116)	Considerable cytotoxicity against cell lines studied	Mustafa et al. (2020)
	P. undulata	Leafy stems (essential oil)	0.1–400 µg/ml (MTT assay)	IC50: 9.6–18.6 µg/ml	Remarkable anti-proliferative activity	Mohammed et al. (2020)
	P. undulata	Arial parts (methylene chloride: methanol (1:1) extract)	0–10 µg/ml (MTT assay)	IC50: 5.72–6.04 µg/ml	Potent against drug-sensitive CCRF-CEM leukemia cell lines	Hegazy et al. (2019)
	P. undulata	Aerial parts (isolates)	0–100 µg/ml (MTT assay)	IC50: 27.6 µg/ml (MCF-7), 23.5 µg/ml (Hep G2)	Eupatolitin had the highest activity	Hussien et al. (2016)
	P. undulata	Aerial parts (chloroform, ethyl acetate, and methanol extracts)	0–120 µg/ml (MTT assay)	IC50: 3.01 µg/ml (HepG-2), 16.4 µg/ml (MCF-7), 7.4 µg/ml (HCT-116)	The chloroform extract was the most potent	Alshehri and Ghobashy (2020)
	P. undulata	Aerial parts (methanol extract)	0–250 mg/ml (MTT assay)	IC50: 27.7 mg/ml	Induced apoptosis in the HepG2 cells by overexpression of miR-34 at which regulates p53/B-cell lymphoma-2/caspases signaling pathway	Emam et al. (2019)
	P. gnaphalodes	Aerial parts (methanol extracts, and their fractions and isolates)	32–500 µg/ml (MTT assay)	Fraction-IC50: 127 µg/ml (MCF-7) and 210 µg/ml (DU145); Isolates (IC50: 32.23–57.25 µg/ml)	Ethyl acetate was the most potent fraction. Luteolin and quercetin were most promosing isolates	Pourhossein Alamdary et al. (2023)
Anti-oxidant	*P. crispa*	Leaves and Flowers (Essential oils)	0–0.5 mg/ml (DPPH, ABTS, and FIC assays)	Concentration-dependent	Scavenging activity in ABTSassay was more sensitive	Al-Qudah et al. (2022)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
	P. crispa	Aerial parts (70% extract)	10–100 µg/ml (8-OHdG assay assay)	dose-dependent	Decreased level of oxidative DNA damage marker, 8-OHdG	Daradka et al. (2018)
	P. crispa	Aerial parts (methanol extract and its fractions)	0–1000 µg/ml (ABTS assay)	IC50: 333.78 µg/ml	The chloroform fraction had the highest activity	AlZain et al. (2023)
	P. crispa	Aerial parts (methanol extract)	20 mg/kg, b.wt. (CPZ-induced oxidative stress rat model)	20 mg/kg, b.wt	Reversed the modulated MDA and GSH levels due to CPZ toxicity in hepatic tissue	El-Sabagh et al. (2021)
	P. undulata	Aerial parts (essential oil)	0.016–1 mg/ml (DPPH, ABTS, and FRAP assays)	IC50: 7.9 ± 0.2 µg/ml	Comparable antioxidant activity to that of trolox in ABTS assay	Mustafa et al. (2020)
	P. undulata	Whole plant (70% methanol extract, and isolates)	Serial dilution (DPPH and anti-TBHP cytoprotection assays)	DPPH assay-extract (IC50:27.5 µg/ml), isolates (IC50:3.9–252.3 µg/ml); anti-TBHP cytoprotection assays-quercetin 3,7-O-dimethyl ether (EC50 = 33.6 ± 1.7 µM)	Quercetin 3,7-O-dimethyl ether was the most potent isolate	Hussein et al. (2017)
	P. undulata	Aerial parts (isolates)	0–128 µg/ml (DPPH assay)	IC50: 2.3 µg/ml	The most potent was 6-methoxykaempferol	Hussien et al. (2016)
	P. undulata	Aerial plants (95% ethanolic extract)	100–200 µg/ml (DPPH, FRAP, and metal chelating assays)	Concentration-dependent	Ferric-reducing and radical scavenging activities	Mohammed et al. (2021)
	P. undulata	Leafy stems (essential oil)	0.1–400 µg/ml (in vitro DPPH, $ABTS^{\bullet+}$, FRAP and CUPRAC assays)	DPPH: 20.92 ± 0.05 mg/Tes/g; ABTS: 62.36 ± 0.05 mg/Tes/g	Potent radical scavenging activity	Mohammed et al. (2020)
	P. gnaphalodes	Aerial parts (methanol extracts, and their fractions)	5–80 µg/ml (DPPH assay)	IC50: 10.64 ± 1.45 µg/ml)	Ethyl acetate fraction was the most potent	Pourhossein Alamdary et al. (2023)
	P. gnaphalodes	Aerial parts (essential oils)	0.02–80 µg/ml (DPPH assay)	Concentration-dependent (37.1–70.7%)	Considerable radical scavenging activity	Hassanabadi et al. (2022)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
Anti-inflammatory	*P. crispa*	Aerial parts (80% methanol extract)	250 and 500 mg/kg, p.o. (rectal temperature method in rat)	500 mg/kg, p.o	Anti-inflammatory properties in rats by significantly suppressing the edematous response for up to 3 h	Soliman et al. (2022)
	P. undulata	Aerial parts (CH_2Cl_2-MeOH (1:1) extract)	25–400 µg/ml (COX-1, COX-2, and acetylcholinesterase assays)	IC50: 29.06 µg/ml	Moderately inhibited COX-1 and COX-2 enzymes	Shahat et al. (2020)
	P. undulata	Whole plant (chloroform fraction of ethanolic extract, and isolates)	50 − 500 µg/ml of extract and 0.5 − 10 µM of isolates (albumin denaturation inhibitory assay) and 150 and 500 µg of extract (in vivo Carrageenan-induced rat paw model)	IC50: 23.76 µM ((+)-asteriscunolide A), 220.42 µM (methyl pulicaroate)	(+)-asteriscunolide A and methyl pulicaroate showed in vitro anti-inflammatory activity by inhibiting heat-induced albumin denaturation	Boumaraf et al. (2017)
Hepatoprotective	*P. crispa*	Aerial parts (methanol extract)	30 mg/kg (CPZ-induced oxidative stress rat model)	30 mg/kg	Reduced CPZ intoxicated elevated levels of bilirubin, AST, and ALT	El-Sabagh et al. (2021)
	P. crispa	Aerial parts (ethanol extract)	250 mg/kg, b.wt. (CCl_4-induced liver fibrosis rat model)	250 mg/kg, b.wt	Down-regulated hepatic-free radicals' elevation, ameliorate hepatic function enzymes, improve lipid profile, attenuate inflammatory mediators, reduce fibrosis severity, and normalize the hepatic cells architecture	Morsy et al. (2021)
	P. crispa	Aerial parts (80% methanol extract)	250 and 500 mg/kg, p.o. (CCl_4 induced hepatoxicity rat model)	500 mg/kg, p.o	Significantly reduced toxicity linked to elevated liver markers	Soliman et al. (2022)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
Antiviral	*P. crispa*	Whole plant (ethyl acetate extract)	0–100 µg/ml (MTT assay)	IC50: 14.45 µg/ml	Anti-hepatitis B virus (HBV) potential on HepG2.2.15 cells	Arbab et al. (2017)
	P. crispa	Aerial parts (hexane fraction of methanol extract)	Serial dilution (antiviral screening assay)	125 and 250 µg/ml	Virucidal effect	Abo-Elghiet et al. (2023)
Immunomodulatory	*P. crispa*	Aerial parts (Methanol extract)	33 ng/mouse (in vivo mice model)	33 ng/mouse	Stimulated IL2 production and IgG response	Maghraby et al. (2010)
	P. crispa	Whole plant (ethanol extract)	50 and 100 µg/ml (LPS-stimulated human monocytic THP-1 cells assays)	100 µg/ml	Anti-inflammatory, antiproliferative, antimigratory, and antiphagocytic effects	Albrahim et al. (2020)
Antigastric ulcer	*P. crispa*	Aerial parts (ethanol extract)	500 mg/kg, b.wt. (rat model)	500 mg/kg, b.wt	Ameliorated ethanol-induced ulcer by improving antioxidant levels, certain mucosal marker enzymes, inflammatory parameters, and the histopathology of gastric mucosa	Fahmi et al. (2019a)
	P. undulata	Aerial parts (90% ethanol extract)	500 mg/kg, b.wt./day/week (rat model)	500 mg/kg, b.wt	Anti-gastric ulcer protective effect by reversing the ethanol-induced changes in rats	Fahmi et al. (2019b)
Antimalarial	*P. crispa*	Whole plant (aqueous extract)	1: 200 diluted extract (in vitro anti-plasmodial activity)	1: 200 diluted extract	100% inhibition of *P.* falciparum	Sathiyamoorthy et al. (1999)
	P. undulata	*Flowers (70% ethanol and methanol extracts*	0.25–100 µg/ ml (in vitro anti-plasmodial activity)	IC_{50} -18.9 µg/ml	70% ethanol extract was active against *P. falciparum* (3D7)	Abdou et al. (2022)
Nephroprotective	*P. crispa*	Aerial parts (methanol extract)	250 mg/kg, p.o. (CCl_4 induced nephrotoxicity rat model)	250 mg/kg, p.o	Improved kidney function, oxidative stress, inflammatory and nephrotoxicity index, and renal histopathological features	Aziz et al. (2022)

Table 4 continued

Activity	Species	Part used (extract)	Treatment (assay (s)/model(s) used)	Effective concentration/dose	Results and mechanism of action	References
Neuroprotective	*P. undulata*	Aerial parts (essential oil)	50–200 mg/kg (rotenone-induced rat model)	100 and 200 mg/kg	The neuroprotective effect was linked to anti-inflammatory and antioxidant activities, including the ability to reduce α-synuclein gene expression	Issa (2020a; b)
Anticonvulsant	*P. gnaphalodes*	Whole parts (aqueous extract and essential oil)	125–500 µg/rat and 0.125–0.5% (rat model)	dose-dependent	Both extract and oil had anticonvulsant properties	Zendehdel et al. (2013)
Antidiabetic	*P. crispa*	Aerial parts (70% ethanol extract)	50–200 mg/kg, b.wt. (alloxan-induced rat model)	100 and 200 mg/kg, b.wt	Hypoglycaemic effect by improved biochemical parameters related to diabetes	Daradka et al. (2021)
Antipyretic	*P. crispa*	Aerial parts (80% methanol extract)	250 and 500 mg/kg, p.o. (carrageenan-induced hind paw edema rat model)	250 and 500 mg/kg, p.o	Antipyretic activity by blocking the central cyclooxygenase-linked- production of PGE2	Soliman et al. (2022)
Analgesic	*P. crispa*	Aerial parts (Methanol extract)	250 and 500 mg/kg, p.o. (hot plate and acetic acid-induced writhing tests-based mice and rat models)	500 mg/kg, p.o	Inhibited pain sensation through both peripheral and central mechanisms	Soliman et al. (2022)
Antileishmanial and antitoxoplasmal activity	*P. undulata*	Whole plants (methanol extract and fractions)	0.04–100 µg/ml (in vitro assays)	EC50: 1.4–3.9 µg/ml	The chloroform fraction was the most potent	Khan et al. (2021)

eatment of several types of cancers, including, liver, breast, lung, and colon. So far, anticancer activities have been reported in the essential oils, extracts, fractions, and their isolates of *P. crispa*, *P. undulata*, and *P. gnaphalodes* (Table 4).

The essential oil obtained from *P. crispa* aerial parts showed promising cytotoxic activity against several types of cancers including liver, breast, and colon. Following 24 h of incubation, the essential oil of *P. crispa* showed a cytotoxic effect on liver cancerous, HepG2 cells (AlMotwaa and Al-Otaibi, 2022). The essential oil extracted from the leaves and Flowers of *P. crispa* also showed cytotoxic effects on MDA-MB-231 (breast cancer) and HL-60 (human leukemia) cell lines, with IC_{50} ranging from 103 to 355 µg/ml (Al-Qudah et al. 2022). These observed cytotoxic activities were attributed to the monoterpenes, sesquiterpenes, and phenolic compounds of essential oil (Al-Qudah et al. 2022). Besides this, ethanol extract (70%) of *P. crispa* aerial parts also showed cytotoxic activity ($IC_{50:}$ 180 µg/ml) on MDA-MB-231 cell lines, and this observed activity was linked with its membrane destruction potential, more precisely to the loss of cell integrity, shrinkage of cytoplasm, and cell detachment (Barnawi and Ali, 2019). Similarly, cytotoxicity on leukemia CCRF-CEM cell line has been reported to the 80% methanol extract of *P. crispa* aerial parts (IC_{50}: 1.81 µg/ml). This treatment induced cell cycle arrest in the G0/G1 phase, and also induced apoptosis in CCRF-CEM cells with the alteration of the mitochondrial membrane potential (Kuete et al. 2013). In another study, ethyl acetate fraction of methanol extract *P. crispa* aerial parts showed potent anticancer activity against breast (MCF-7) and lung (A549) cancer cells, with IC_{50} values of 229.23 and 251.09 µg/ml, respectively (AlZain et al. 2023).

So far, *P. undulata* has been more extensively studied for its anticancer properties than *P. crispa*. Potent cytotoxic activity has been reported in the essential oils, extracts, and fractions, including isolated compounds of *P. undulata*, against different cancerous cell lines. The essential oil of *P. undulata* aerial parts exhibited promising cytotoxic activity against human malignant melanoma (A375, IC_{50}-18.53 µg/ml), glioblastoma multiform tumor (T98G, IC_{50}-40.64 µg/ml), and human colorectal carcinoma (HCT116, IC_{50}: 22.23 µg/ml) cell lines (Mustafa et al. 2020). Similarly, the essential oil obtained from the *P. undulata* leafy stems also showed anti-proliferative activity (IC_{50}: 9.6–18.6 µg/ml) towards human breast carcinoma (MCF7) and human colon adenocarcinoma (HT29 and HCT116) cell lines (Mohammed et al. 2020). The reported cytotoxicity of the *P. undulata* leaves essential oil against MCF-7 breast tumor cells was attributed to the presence of carvotanacetone (Ali et al. 2012). Besides this, the ethanol extract (95%) of *P. undulata* demonstrated concentration-dependent cytotoxicity in K562 (human leukemia), MCF-7, and PANC-1 (human pancreatic) cancerous cell lines. This treatment inhibited growth and induced late apoptosis in MCF-7 cell lines (Mohammed et al. 2021). Likewise, methanol extract of *P. undulata* aerial part induced apoptosis in HepG2 cells by overexpression of miR-34 that regulates p53/B-cell lymphoma-2/caspases signaling pathway (IC_{50}-27.7 mg/ml) (Emam et al. 2019). In another study, methanol extract (95%) of *P. undulata* and six isolated compounds such as xanthosine (2-hydroxy-4, 6-dimethoxyacetophenone), stigmasterol, oleanolic acid, salvigenin (5-hydroxy-4',6,7-trimethoxyflavone), rhamnetin (5,3',4'-trihydroxy-7 methoxyflavonol) and dihydroquercetin 4 methyl ether were investigated for in vitro and in vivo antiproliferative activity against MCF-7, and Ehrlich's ascites carcinoma (EAC) cell lines, respectively. Extract and isolates showed remarkable in vitro antitumor activity against an MCF-7 (IC_{50}-18–28 µg/ml) and displayed promising in vivo cytotoxic effects against EAC (at 50 and 200 µg/ml of isolates and extracts). This observed antiangiogenic activity was associated with their vascular endothelial growth factor (VEGF) signaling inhibitory potential. In a molecular docking simulation study, alvigenin, rhamnetin, dihydroquercetin-4′-methyl ether, and xanthoxyline showed binding affinity towards VEGFR-2 (Elhady et al. 2021). The sesquiterpenoids, 2α-hydroxyalantolactone isolated from *P. undulata* showed potent cytotoxicity towards the muti drug-sensitive and -resistant cell lines (IC_{50}-5.91–49.22 µM), and also inhibited human tumor cell growth through DNA damage, G2/M cell cycle arrest, and apoptosis. This compound bypasses resistance of multidrug-resistant cancer cells with either overexpression of ABC transporters (P-glycoprotein, BCRP/ABCG2, ABCB5) or deregulated tumor suppressors and oncogenes (TP53, EGFR) (Hegazy et al. 2021). Likewise, eupatolitin isolated from the *P. undulata* aerial part showed considerable cytotoxicity against

MCF-7 and Hep G2 cells, with IC_{50} 27.6 and 23.5 μg/ml, respectively (Hussien et al. 2016). In a comparative study, among different extracts (chloroform, ethyl acetate, and methanol extracts) of *P. undulata*, chloroform extract showed promising anticancer potential on three types of human carcinoma (HEPG-2, MCF-7, and HCT-116) cell lines (Alshehri and Ghobashy, 2020). The CH_2Cl_2:methanol (1:1) extract of *P. undulata* aerial parts also exhibited promising cytotoxic activity against CCRF-CEM leukemia cell lines (IC50: 5.72–6.04 μg/ml) by inducing apoptosis and cell cycle arrest in the G2/M (Hegazy et al. 2019).

Thus far, *P. gnaphalodes* has little been investigated for anticancer potential, compared to *P. crispa* and *P. undulata*. There is one study that investigated the cytotoxicity of ethyl acetate fraction and its isolated compounds (luteolin and quercetin) of methanol extract of *P. gnaphalodes* aerial part on MCF-7 and DU-145 (human prostate) cancerous cell lines (Pourhossein Alamdary et al. 2023). Interestingly, in this study, the observed IC_{50} values for methanol extract and all fractions were much lower than corresponding pure compounds (Pourhossein Alamdary et al. 2023).

Antioxidant activity

Antioxidant activity has been reported in the essential oil and non-essential oil extracts of these *Pulicaria* species in various assays, mainly in vitro assays (Table 4). Essential oil extracted from the leaves and Flowers of *P. crispa* showed good antioxidant activity in in vitro assays. However, the most promising antioxidant activity was found in the ABTS assay for both these essential oils (Al-Qudah et al. 2022). In general, the ABTS assay represents the antioxidant potential of hydrophilic and lipophilic compounds, whereas, the DPPH assay represents the antioxidant activity of more lipophilic compounds. This indicates that the ABTS assay estimates better the antioxidant capacity compared to DPPH (Kasote et al. 2019). The radical scavenging potential of different *P. crispa* extracts (methanol, ethanol, and ethyl acetate) have been investigated in both DPPH and ABTS assays, and the observed results were different in these two assays. Methanol extract of *P. crispa* aerial parts, including its fractions (n-hexane, chloroform, ethyl acetate, and n-butanol) showed radical scavenging activity in the ABTS assay, and the highest activity was reported in the chloroform fraction (IC_{50}: 333.78 μg/ml) (AlZain et al. 2023). In another study, ethyl acetate extract of *P. crispa* showed the most effective anti-oxidant activity in the DPPH test (Feriel et al. 2021). The methanolic extract of *P. crispa* aerial parts was found to be rich in flavonoids (172 mg rutin equivalent/g dry wt.) and showed moderate activity in both DPPH (IC_{50} 0.5123 ± 0.02 mg/ml) and ABTS (IC_{50} 0.733 ± 0.08 mg/ml) assays (El-Sabagh et al. 2021). Besides radical scavenging activity, the potential of *P. crispa* extract in preventing DNA damage as an antioxidant has also been shown in the 8-hydroxy-2'-deoxyguanosine (8-OHdG) assay conducted on cultured human lymphocytes. This study showed that treatment with *P. crispa* extract (100 μg/ml) significantly decreased (36%) the level of 8-OHdG (Daradka et al. 2018). Similarly, the in vivo antioxidant activity of methanol extract of *P. crispa* aerial parts was also investigated in rats against chloropromazine (CPZ) induced oxidative stress. Administration of methanol extract of *P. crispa* (20 mg/kg) in rats following CPZ intoxication significantly decreased the elevated levels of malondialdehyde (MDA) by 46% compared to animals treated with CPZ only (El-Sabagh et al. 2021).

Ethanol extract (95%) of *P. undulata* aerial parts exhibited ferric-reducing and free-radicals scavenging activities in FRAP and DPPH assays, respectively. Observed activities were attributed to the presence of well-known antioxidant phenolics and flavonoids (e.g., trans-ferulic acid, chlorogenic acid, caffeic acid, quercetin, luteolin, rutin, and kaempferol 3-*O*-rutinoside) (Mohammed et al. 2021).

In the available literature, *P. undulata* essential oils and extracts are mainly reported to have radical scavenging activity. The essential oil obtained from *P. undulata* aerial parts had remarkable radical scavenging activity in the ABTS assay, which was comparable to that reported for Trolox (Mustafa et al. 2020). Similarly, essential oil of *P. undulata* leafy stems had considerable radical scavenging ($20.92 \pm 0.05_{DPPH}$ - and $62.36 \pm 0.25_{ABTS}$ mg trolox equivalents (TEs)/g) activities in DPPH and ABTS assays (Mohammed et al. 2020). It has been found that the methanolic extract of *P. undulata* exhibited greater DPPH radical scavenging and total antioxidant activities than those of the petroleum ether extract containing oil (Helal et al. 2019). The isolated compounds from the methanolic extract of *P. undulata* were also investigated for DPPH radical scavenging activity, and the observed activity was in the order of 7,2′,3′,4′ penta hydroxyl isoflavone-4′-*O*-β-glucopyranoside > quercetin > quercetin 3-*O*-galactoside > caffeic acid > quercetin 3,7-*O*-dimethyl ether > kaempferol. Most of these isolates showed more activity than that of crude methanolic extract. Similarly, in the anti-tert-butyl hydroperoxide (anti-TBHP) assay conducted using murine hepatoma Hepa1c1c7 cell line, it was found that TBHP toxicity was completely inhibited by quercetin 3,7-*O*-dimethyl ether ($EC_{50} = 33.6 \pm 1.7$ μM). Interestingly, other tested compounds were not able to protect Hepa1c1c7 cells (Hussein et al. 2017). Similarly, the isolated compound, 6-methoxykaempferol from *P. undulata* aerial parts also had potent radical scavenging activity (IC_{50} 2.3 μg/ml) in the DPPH assay (Hussien et al. 2016). In another study, isolated compounds (6-methoxy-kaempferol 3-*O*-β-D-glucopyranoside, 6-methoxykaempferol, and axillarin) from ethyl acetate soluble fraction of the whole plant of *P. undulata* were also found to have promising superoxide anion scavenging activity (75–92%), at their 100 μM studied concentration (Ahmad et al. 2006).

The essential obtained from the aerial parts of *P. gnaphalodes* had the strongest free radical scavenging activity in the DPPH assay, which was higher than that of trolox. Also, this essential oil showed a high percentage inhibition in β-carotene bleaching test (Kazemi et al. 2013). In another study, the reported DPPH radical scavenging activity to the essential oil of *P. gnaphalodes* (aerial part) was in the range of 37.1–70.7% (Hassanabadi et al. 2022) Hassanabadi et al. 2022). Like essential oil, ethyl acetate fraction of the methanolic extract of *P. gnaphalodes* aerial part also exhibited a promising radical scavenging activity (IC_{50}- 10.64 ± 1.45 μg/ml) in the DPPH assay (Pourhossein Alamdary et al. 2023).

Anti-inflammatory activity

Anti-inflammatory properties are mainly reported in the *P. crispa* and *P. undulata* extracts. The methanol extract (80%) of *P. crispa* aerial parts exhibited ani-inflammatory properties by significantly suppressing the edematous response for up to 3 h in carrageenan-induced paw edema in albino rats at higher doses of 500 mg/kg, p.o. (Soliman et al. 2022). In another study anti-inflammatory property of CH_2Cl_2:methanol (1:1) extract of *P. crispa* aerial parts was linked with its COX-1 and COX-2 inhibitory potential, as these enzymes are generally involved in prostaglandin biosynthesis (Shahat et al. 2020).

In carrageenan-induced paw edema in mice model, the oral administration of the chloroform fraction of ethanolic extract of *P. undulata* (whole plant) at two doses (150 and 300 mg/kg) significantly inhibited inflammatory response in a dose-related manner. Similarly, the isolated pure compounds (+)-asteriscunolide A and methyl pulicaroate showed moderate anti-denaturation activity in albumin denaturation inhibitory assay, and among this, asteriscunolide A was the most effective compound (44.44% inhibition at 10 μM concentration) (Boumaraf et al. 2017). In albumin denaturation inhibitory assay, inhibition of protein denaturation is related to the inhibition of inflammatory activity, as denaturation of protein causes the production of auto-antigens in conditions such as rheumatic arthritis, cancer, and diabetes (Dharmadeva et al. 2018).

Hepatoprotective activity

The hepatoprotective potential has exclusively been reported to the *P. crispa*. The hepatoprotective role of methanol extract (80%) of *P. crispa* aerial parts was investigated in rats against CCl_4-induced hepatotoxicity. This study showed that oral administration of the above extract (500 mg/kg) for seven days before CCl_4 injection significantly attenuated the elevated serum markers of liver toxicity such as AST (aspartate aminotransferase), ALT (alanine aminotransferase), GGT (gamma-glutamyl transferase), and ALP (alkaline phosphatase) compared to the toxic group. Moreover, the above treatment also reversed the altered levels of total protein, MDA, and non-protein sulfhydryls (NP-SH) in the liver tissues of CCl_4-exposed rats (Soliman et al. 2022). In another study, methanol extract of *P. crispa* aerial parts (30 mg/kg) reduced CPZ intoxicated increased levels of bilirubin level by 46%, including AST (10%) and ALT (24%) compared to animals treated with CPZ alone and this effect was similar to the standard hepatoprotective drug, silymarin (El-Sabagh et al. 2021). Similar to methanol extracts, ethanol extract (250 mg/kg, b.wt.) of *P. crispa* aerial parts was also found to have hepatoprotective potential in the CCl_4-induced liver fibrosis rat model. This treatment exerted an antifibrotic effect by downregulating fibrosis and inflammatory signaling pathways in rat liver tissue. Moreover, this treatment significantly suppressed the toxicity-linked elevated levels of AST, ALT, alkaline phosphatase (ALP), total lipids (TP), total cholesterol (TC), triglycerides (TG), low-level glycoprotein-cholesterol (LDL-C), alpha-fetoprotein (AFP), MDA, nitric oxide (NO), tumor necrosis factor-α (TNF-α) and interleukin 6 (IL-6). Conversely, toxicity-linked decreased levels of high-density lipoprotein cholesterol (HDL-C), reduced glutathione (GSH), and superoxide dismutase (SOD) were also increased in treated groups (Morsy et al. 2021).

Antiviral activity

Antiviral activity is also only reported to the *P. crispa*. A study on HepG2.2.15 cells showed promising anti-hepatitis B virus (HBV) potential to the ethyl acetate extract of *P. crispa* (IC_{50}: 14.45 µg/ml). This observed anti-HBV activity was time- and dose-dependent and could be due to its phytochemical composition, which includes flavonoids alkaloids, and tannins (Arbab et al. 2017). Similarly, HF obtained from methanolic extract of *P. crispa* aerial parts also exhibited a potent virucidal effect against influenza A virus at doses 125 and 250 µg/ml. These treatments were found to affect different stages of the virus lifecycle such as pre-treatment, post-infection, and competition (Abo-Elghiet et al. 2023).

Immunomodulatory activity

Like above, immunomodulatory potential has also been solely reported to *P. crispa*. It has been found that mice treated with intra-peritoneal injection of methanolic extract of *P. crispa* (33 ng/mouse) for 10 successive days followed by infecting every mouse with 100 *S. mansoni* cercariae showed significant reduction in *S. mansoni* worm burden and stimulated significant interleukin 2 (IL2) production, including IgG response that reacted in ELISA against bilharzial, *E. coli* and cancer bladder antigens (Maghraby et al. 2010). In another study, the immunomodulatory effect of *P. crispa* extract (ethanol) was investigated in lipopolysaccharide- (LPS-) stimulated human-monocytic THP-1 cells (Albrahim et al. 2020). Results of this study showed that exposure to *P. crispa* extract (100 µg/ml) significantly reduced THP-1cell proliferation, migration, and phagocytosis in LPS-stimulated cells (but not in unstimulated cells). It also significantly reduced the expression of various chemotactic and cell survival-related proteins (Albrahim et al. 2020).

Anti-gastric ulcer potential

Traditionally, *Pulicaria* species are used as anti-gastric ulcer agents (Fahmi et al. 2019a). The ethanol extracts (500 mg/kg b.wt., p.o.) of both *P. crispa* and *P. undulata* aerial parts were found effective in treating gastric ulcers in rats. Treatment with these extracts reversed ethanol-induced ulcer indices, oxidative stress, inflammatory index, and histopathology by improving antioxidant levels, certain mucosal marker enzymes, inflammatory parameters, and the histopathology of the gastric mucosa (Fahmi et al. 2019a, 2019b).

Antimalarial activity

Diluted aqueous extract (1:200) of *P. crispa* whole plant showed strong growth inhibition (100%) of the malaria parasite *Plasmodium falciparum* (Sathiyamoorthy et al. 1999). However, recently in another study, weak activity was also reported in the ethanolic extract (70%) of *P. undulata* against *P. falciparum* (3D7) with IC_{50} -18.9 µg/ml (Abdou et al. 2022).

Analgesic activity

Analgesic activity along with antipyretic effect has only been reported for the *P. crispa*. In a hot plate test, the methanol extract (80%) of *P. crispa* aerial parts showed considerable analgesic effect in mice at the dose of 500 mg/kg, p.o. This effect was comparable to that produced by 4 mg/kg indomethacin and could be due to its central cyclooxygenase-linked production of prostaglandin E2 (PGE2) blocking ability (Soliman et al. 2022).

Antipyretic activity

The antipyretic activity of methanol extract (80%) of *P. crispa* aerial parts was also investigated for antipyretic effects using yeast-induced pyrexia in rats. This extract treatment showed significant protection against hyperthermia at doses studied, 250 and 500 mg/kg, p.o. The observed antipyretic effect could be due to the extract's ability to inhibit the enzyme cyclooxygenase and reduce the levels of PGE2 within the hypothalamus (Soliman et al. 2022).

Nephroprotective activity

The ethanol extract of *P. crispa* aerial parts (at a dose, 250 mg/kg, p.o.) showed a nephroprotective effect in rats against CCl_4-induced nephrotoxicity, mainly by reducing the elevated levels of oxidative stress markers (MDA), interleukin-18 (IL-18), serum creatinine, urea, and uric acid due to CCl_4 toxicity (Aziz et al. 2022). This observed nephroprotective effect was attributed to its anti-oxidant and anti-inflammatory principles (Aziz et al. 2022).

Neuroprotective potential

The essential oil obtained from *P. undulata* aerial parts showed a neuroprotective effect in a rotenone-induced neurotoxicity rat model. The observed neuroprotective activity of *P. undulata* essential oil at doses, 100 and 200 mg/kg was attributed to its anti-inflammatory and anti-oxidant activities. Moreover, studied treatments also mitigated the induced neuroinflammation by various mechanisms such as down-regulating inducible nitric oxide synthase (iNOS) and α-synuclein gene expressions (Issa, 2020).

Antidiabetic activity

The antidiabetic activity of ethanol extract (70%) of *P. crispa* aerial parts was studied in alloxan-induced diabetic rats. The findings of this study showed that akin to antidiabetic medication glibenclamide, the above extract treatments (100 and 200 mg/kg, b.wt.) had a potent hypoglycaemic effect in a dose-dependent manner, and also prevented body weight reduction and significantly decreased cholesterol, urea, and creatinine levels (Daradka et al. 2021).

Antileishmanial and antitoxoplasmal activities

Leishmaniasis and toxoplasmosis are parasitic protozoal diseases that pose serious health concerns, especially for immunocompromised people. The *P. undulata* whole plant methanol extract and its fractions (petroleum ether, chloroform, ethyl acetate, n-butanol, and water) were tested for in vitro antitoxoplasmal (against *Toxoplasma gondii*) and antileishmanial (*Leishmania major* promastigote) activities. Among these, the chloroform fraction was the most potent against *T. gondii* (EC_{50}: 1.4 μg/ml and SI: 12.1), *L. major* promastigotes (EC_{50}: 3.9 μg/ml and SI: 4.4), and amastigotes (EC_{50}: 3.8 μg/ml and SI: 4.5) (Khan et al. 2021).

Anticonvulsant

Intracerebroventricular injection of aqueous extract (125–500 μg/rat) and essential oil (0.125–0.5%) of *P. gnaphalodes* to rats was found to be beneficial in treating myoclonic and tonic–clonic seizures in a dose-dependent manner (Zendehdel et al. 2013).

Other activities

Besides the above biological and pharmacological activities, different enzyme inhibitory activities, especially those that have therapeutic significance in treating metabolic and neurodegenerative disorders have been reported to these *Pulicaria* species. In a recent study, α-amylase and horseradish peroxidase inhibitory activities have been reported to the phenolic extract of *P. crispa*, which suggests its potential in treating diabetes and thyroid diseases (Feriel et al. 2021). Similarly, lipase inhibitory activity (IC_{50}: 1.33 ± 0.03 mg/ml) was also reported in the ethyl acetate fraction of *P. crispa* extract obtained from 70% aqueous acetone (Nia et al. 2014). Besides this, an aqueous extract of *P. crispa* leaves was found to be useful in the biological control of different developmental stages of *Bulinus truncatus*, a major snail intermediate host of urinary schistosomiasis (Ali et al. 2009).

Essential oil of *P. undulata* aerial parts showed a promising anti-acetylcholinesterase activity (IC50 = 139.2 μg/ml) in Ellman method (Mustafa et al. 2020). In another study, essential oil of *P. undulata* leafy stems also showed acetylcholinesterase (0.95 ± 0.06 mg galanthamine equivalents (GALAEs)/g), butyrylcholinesterase (1.19 ± 0.13 mg GALAEs/g) and α-glucosidase (32.59 ± 0.20 mg acarbose equivalents (ACAEs)/g) inhibitory activities, including inhibition of tyrosinase and α-amylase (Mohammed et al. 2020). Paniculoside

IV, an ent-kaurane type diterpene glucoside isolated from *P. undulata* was reported to have α-glucosidase inhibitory activity (Rasool et al. 2008). Similarly, carvotanacetone, separated from the essential of *P. undulata* leaves showed remarkable anticholinesterase activity (Ali et al. 2012).

Toxicity

In the acute toxicity and lethal dose studies, the administration of 5000 mg/kg of ethanolic extract of *P. crispa* did not show any toxicity in mice and it was considered to be safe (Daradka et al. 2021). In another study, the cytotoxicity of whole plant extracts (methanol, chloroform, diethyl ether, acetone, and water) of *P. crispa* was investigated against *Artemia salina* (leach) larvae. Among these, diethyl ether and methanol extract had minimum and maximum toxicity at the highest dose studied of 1000 µg/ml (Ejaz et al. 2023).

Conclusions and future perspectives

Herein, *Pulicaria* species reported in Qatar are comparatively reviewed regarding their traditional uses, phytochemistry, and biological and pharmacological activities. In Qatar, the traditional uses of these species are almost identical and they all are used as herbal tea. Anti-inflammatory agents and insect repellents are some other traditional uses reported for these species in the Arabian/Persian region countries. Of these species, *P. undulata* and *P. crispa* are separately investigated for their phytochemistry, and biological and pharmacological activities in the literature, though *P. crispa* has merged into *P. undulata* decades ago and considered a single species. However, it is noteworthy that *P. crispa* is accepted as a subspecies of *P. undulata*, and it is a synonym of *P. undulata* subsp. *undulata*. The local taxonomists believe that there are two distinct species or perhaps subspecies of *P. undulata* in Qatar, but this has not yet been proven scientifically. After reviewing the literature, we found that traditional uses of both *P. undulata* and *P. crispa* are almost the same. Moreover, *P. undulata* and *P. crispa* can be differentiated at the subspecies level based on the known phytochemistry of their essential oils. In genome analysis studies, *P. undulata* and *P. crispa* are found to be distinct from each other as well (El-Kamali et al. 2010). However, more DNA barcoding and chemometric-based studies are essential to prove this special distinction clearly at the species and subspecies level, including identifying regional hybrids thereof.

Being aromatic plants, the chemical composition of essential oils of these species has been extensively studied. Essential oils are mostly extracted from the aerial parts of these species; however, flowers and leaves are also used. Over 300 VOCs have been reported in the essential oils of these species. Among these, oxygenated monoterpenes and sesquiterpenes are the dominant VOCs. Over 147, 176, 64, and 54 VOCs have been reported in *P. crispa*, *P. undulata*, *P. sicula*, and *P. gnaphalodes*, respectively. Of these, nearly 83, 110, 37, and 22 VOCs are exclusively reported in the essential oils of *P. crispa, P. undulata, P. sicula,* and *P. gnaphalodes*, respectively. These VOCs can be used as marker compounds for the characterization of essential oils of each of these species.

Besides VOCs of essential oils, flavonoids and sesquiterpenes are the most reported classes of compounds in these species. Altogether, over 45 different flavonoids, and nearly 9 phenolic acids and other polyphenols have been identified in these species. Both flavonoid aglycones and flavonoid glycosides have been reported in *P. crispa* and *P. undulata*, and some of them are solely reported in each of these species. The occurrence of 6-oxygenation of flavonols is a unique feature of *P. sicula*. Thus far, *p*-anisic acid and 7 flavonoids are exclusively reported in the *P. gnaphalodes*. Among sesquiterpene, the occurrence of sesquiterpene lactones is a common feature of these species. Along with sesquiterpenes, diterpenes, and triterpenes are reported in these species. Whether these reported flavonoids and sesquiterpenes are exclusively occurring in respective species is not yet clear. Hence, further comparative studies are warranted in this regard.

In view of biological and pharmacological activities, *P. crispa* and *P. undulata* are highly investigated, respectively followed by *P. gnaphalodes*. Interestingly, there is only one reported biological activity of *P. sicula*, which is its antimicrobial activity against MRSA. So far, these species have been reported to exhibit antimicrobial, anticancer, antioxidant, anti-inflammatory, hepatoprotective, antiviral, immunomodulatory, antigastric ulcer, antimalarial, nephroprotective, neuroprotective, anticonvulsant, antidiabetic, antipyretic, analgesic, antileishmanial and antitoxoplasmal activities. Among these, antimicrobial, anticancer, and anti-oxidant activities are mostly investigated for *P. crispa, P. undulata,* and *P. gnaphalodes*. Hepatoprotective antiviral, immunomodulatory, nephroprotective, antidiabetic, antipyretic, and analgesic activities are solely reported in *P. crispa*. These activities are mainly reported to the essential oils, extracts (mainly methanolic extracts), and their fractions, as well as pure compounds isolated from these plants. Antimicrobial and anticancer activities reported to some of the pure compounds such as axillarin, quercetin, and 2α-hydroxyalantolactone, need to be investigated in detail for their potential use as medicine in the future.

At the moment, *Pulicaria* species are confined to very small geographic areas in Qatar due to rapid urbanization and industrial development in the last couple of decades. Moreover, species like *P. sicula* and *P. gnaphalodes* are rapidly becoming rare in Qatar. Considering this, immediate steps in the context of the protection and conservation of these species need to be undertaken.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Abd-ELGawad AM, Al-Rowaily SL, Assaeed AM, Ei-Amier YA, El Gendy AE-NG, Omer E, Al-Dosari DH, Bonanomi G, Kassem HS, Elshamy AI (2021) Comparative chemical profiles and phytotoxic activity of essential oils of two ecospecies of *Pulicaria undulata* (L.) CA Mey. Plants 10:e2366

Abdel-Bari EMM (2012) The Flora of Qatar, the dicotyledons, Vol. 1. Doha: environmental studies centre. Qatar University 2:205–209

Abdel-Mogib M, Jakupovic J, Dawidar AM, Metwally MA, Abou-Elzahab M (1990) Sesquiterpene lactones and kaurane glycosides from *Francoeuria crispa*. Phytochemistry 29:2581–2584. https://doi.org/10.1016/0031-9422(90)85193-J

Abdel Bar FM, Elsbaey M, Taha N, Elgaml A, Abdel-Fattah GM (2020) Phytochemical, antimicrobial and antiquorum-sensing studies of *Pulicaria undulata* L.: a revision on the structure of 1β, 2α, 3β, 19α, 23-pentahydroxy-urs-12-en-28-oic acid. Nat Prod Res 34:804–809. https://doi.org/10.1080/14786419.2018.1503658

Abdelah Bogdadi HA, Kokoska L, Havlik J, Kloucek P, Rada V, Vorisek K (2007) In vitro .Antimicrobial activity of some Libyan medicinal plant extracts. Pharm Biol 45:386–391. https://doi.org/10.1080/13880200701215026

Abdou AM, Seddek AL, Abdelmageed N, Badry MO, Nishikawa Y (2022) Wild Egyptian medicinal plants show in vitro and in vivo cytotoxicity and antimalarial activities. BMC Complement. Med. Ther. 22:e130. https://doi.org/10.1186/s12906-022-03566-5

Abo-Elghiet F, Rushdi A, Ibrahim MH, Mahmoud SH, Rabeh MA, Alshehri SAE, Menofy NG (2023) Chemical profile, antibacterial, antibiofilm, and antiviral activities of *Pulicaria crispa* most potent fraction: an in vitro and in silico study. Molecules e 28:4184. https://doi.org/10.3390/molecules28104184

Ahmad V, Rasool N, Abbasi M, Rashid M, Kousar F, Zubair M, Ejaz A, Choudhary M, Tareen R (2006) Antioxidant flavonoids from *Pulicaria undulata*. Pol J Chem 80:745–751

Al-Haj N, Reem A, Al-Shamahy H, Al-Moyed K, Bahaj SS, Jaber A (2019) Antimicrobial activity of five yemeni medicinal plants against selected human pathogenic bacteria and fungi. Am J Plant Sci 10:1699–1707. https://doi.org/10.4236/ajps.2019.1010121

Al-Qudah MA, Migdadi RS, Mayyas AS, Al-Zereini WA, Al-Dalahmeh Y, Abu Orabi FM, Bataineh TT, Abu-Orabi ST (2022) Chemical composition, cytotoxicity and antioxidant activity of the essential oil from Flowers buds and leaves of the *Pulicaria incisa* (Lam.) DC and Pulicaria crispa (Forskel) Oliver. J Essent Oil-Bear Plants 25:758–772. https://doi.org/10.1080/0972060X.2022.2121618

Alamdary MP, Baharfar R (2023) Phytochemicals and biological activities of *Pulicaria* genus: emphasis on the flavonoids and sesquiterpenoids and cytotoxicity effects. Curr Org Chem 27:526–539. https://doi.org/10.2174/1385272827666230522152708

Alasbahi RH, Groot MJ (2022) Ethnoveterinary uses of certain Yemeni plants: a review of the scientific evidence. Planta Med 88:237–253. https://doi.org/10.1055/a-1612-4556

Albrahim T, Alnasser MM, Al-Anazi MR, ALKahtani MD, Alkahtani S, Al-Qahtani AA (2020) In vitro studies on the immunomodulatory effects of Pulicaria crispa extract on human THP-1 monocytes. Oxid Med Cell Longev. https://doi.org/10.1155/2020/7574606

Ali EA, Bushara HO, Ali FS, Hussein MF (2009) Age-dependent susceptibilities of Bulinus truncatus snails to an aqueous extract of Pulicaria crispa (Forssk.) Oliv. (Asteraceae) leaves. Southeast Asian J Trop Med Public Health 40: 463

Ali MS, Jahangir M, Saleem M, Ahmad VU (1999) Chemical constituents of *Pulicaria gnaphalodes*. Nat Prod Sci 5:134–137

Ali MS, Jahangir M, Uzair SS, Erian AW, Tareen RB (2002) Gnapholide: a new guaiac-dimer from *Pulicaria gnaphalodes* (Asteraceae). Nat Prod 16:179–186. https://doi.org/10.1080/10575630290004260

Ali NA, Sharopov FS, Alhaj M, Hill GM, Porzel A, Arnold N, Setzer WN, Schmidt J, Wessjohann L (2012) Chemical composition and biological activity of essential oil from Pulicaria undulata from Yemen. Nat Prod Commun e7: 1934578X1200700238

AlMotwaa SM, Al-Otaibi WA (2022) Determination of the chemical composition and antioxidant, anticancer, and antibacterial properties of essential oil of *Pulicaria crispa* from Saudi Arabia. J. Indian Chem. Soc. e 99**:** 100341. https://doi.org/10.1016/j.jics.2022.100341

Alshehri KM, Ghobashy MO (2020) Antitumor, antimicrobial activities and phytochemicals constituent of different extracts of *Pulicaria undulata* (Forssk.) Oliver. grown naturally in Saudi Arabia. Int J Res Pharm Sci 11**:** 4889–4901

AlZain MN, Albarakaty FM, El-Desoukey RM (2023) An ethnobotanical, phytochemical analysis, antimicrobial and biological studies of *Pulicaria crispa* as a graze promising shrub. Life e 13:2197. https://doi.org/10.3390/life13112197

Arbab AH, Parvez MK, AlDosari MS, AlRehaily AJ (2017) In vitro evaluation of novel antiviral activities of 60 medicinal plants extracts against hepatitis B virus. Exp Ther Med 14**:** 626–634. https://doi.org/10.3892/etm.2017.4530

Asghari G, Zahabi F, Eskandarian A, Yousefi H, Asghari M (2014) Chemical composition and leishmanicidal activity of *Pulicaria gnaphalodes* essential oil. Res J Pharmacogn 1:27–33

Aziz WM, Hamed MA, Abd-Alla HI, Ahmed SA (2022) *Pulicaria crispa* mitigates nephrotoxicity induced by carbon tetrachloride in rats via regulation oxidative, inflammatory, tubular and glomerular indices. Biomarkers 27:35–43. https://doi.org/10.1080/1354750X.2021.2002412

Barnawi IO, Ali I (2019) Anticancer potential of *Pulicaria crispa* extract on human breast cancer MDA-MB-231 cells. Lett Drug Des Discov 16:1354–1359. https://doi.org/10.2174/1570180816666190712110224

Batoli H, Haghir-Ebrahimabadi A, Karimi E, Mazooch A (2017) The survey of the essential oil composition of *Pulicaria gnaphalodes* (Vent.) Boiss. from Brzok of Kashan at the first report. Eco-Phytochem J Med Plant 5:65–78

Bishay DW, Gomaa CS, Assaf MH (1982) Flavonoids from *Pulicaria undulata* (L.) Kostel grown in Egypt. Bull Pharm Sci Assiut 5:65–71. https://doi.org/10.21608/bfsa.1982.102830

Bohlmann F, Knoll KH, El-Emary NA (1979) Neuartige sesquiterpenlactone aus *Pulicaria crispa*. Phytochemistry 18:1231–1233. https://doi.org/10.1016/0031-9422(79)80146-6

Boumaraf M, Carbone M, Ciavatta ML, Benyahia S, Ameddah S, Menad A, Benayache S, Benayache F, Gavagnin M (2017) Exploring the bioactive terpenoid content of an Algerian plant of the genus *Pulicaria*: The ent-series of asteriscunolides. J Nat Prod 80:82–89. https://doi.org/10.1021/acs.jnatprod.6b00717

Boumaraf M, Mekkiou R, Benyahia S, Chalchat JC, Chalard P, Benayache F, Benayache S (2016) Essential oil composition of *Pulicaria undulata* (L.) DC. (Asteraceae) growing in Algeria. Int J Pharmacogn Phytochem Res 8:746–749

Coutinho AP, Dinis AM (2009) Palynology of the genus *Pulicaria gaertn*. (Asteraceae, Inuleae, Inulinae) in the Iberian Peninsula. Microsc Microanal 15:33–34. https://doi.org/10.1017/S1431927609990626

Daradka HM, Aldhilan AM, Eskandrani AA, Bataineh Y, Alzoubi KH (2021) The effect of *Pulicaria crispa* ethanolic extract on haematological and biochemical parameters in alloxan-induced diabetic rats. Adv Trad Med 21:65–72

Daradka HM, Khabour OF, Alotaibi MK (2018) Potent antioxidative DNA damage of selected Saudi medicinal plants in cultured human lymphocytes. Pak J Pharm Sci e 31

Dendougui H, Benayache S, Benayache F, Connoly JD (2000) Sesquiterpene lactones from *Pulicaria crispa*. Fitoterapia 71:373–378. https://doi.org/10.1016/S0367-326X(00)00133-7

Dharmadeva S, Galgamuwa LS, Prasadinie C, Kumarasinghe N (2018) In vitro anti-inflammatory activity of *Ficus racemosa* L. bark using albumin denaturation method. Ayu e 39:239

Ejaz S, Abdullah I, Rashid S, Ashraf M (2023) Analysis of antibacterial and cytotoxic potential of medicinal plants from Cholistan desert, Pakistan. Saudi J Biol Sci 30:103750. https://doi.org/10.1016/j.sjbs.2023.103750

El-Sabagh OA, El-Toumy SA, Mounir R, Farag MA, Mahrous EA (2021) Metabolite profiles of Pulicaria crispa and P incisa in relation to their in-vitro/in-vivo antioxidant activity and hepatoprotective effect: a comparative mass spectrometry-based metabolomics. J Pharm Biomed Anal 194:113804. https://doi.org/10.1016/j.jpba.2020.113804

Elbalola AA, Abbas ZK (2023) Phytochemical diversity, classification and antibacterial activity of some medicinal plant species from Tabuk (Saudi Arabia). Chem Biodivers 20**:** e202300545. https://doi.org/10.1002/cbdv.202300545

Elhady SS, Abdelhameed RF, Zekry SH, Ibrahim AK, Habib ES, Darwish KM, Hazem RM, Mohammad KA, Hassanean HA, Ahmed SA (2021) VEGFR-mediated cytotoxic activity of *Pulicaria undulata* isolated metabolites: a biological evaluation and in silico study. Life 11:759. https://doi.org/10.3390/life11080759

El-Kamali HH, Habeballa R, Abdalla I, Mohammed AY, Abdelkarim ND, Abbas IM, Ali SM (2010) Genetic relationships of two *Pulicaria* species and identification of their putative hybrids using RAPD markers. World Appl Sci J 8:687–693

Emam MA, Khattab HI, Hegazy MG (2019) Assessment of anticancer activity of *Pulicaria undulata* on hepatocellular carcinoma HepG2 cell line. Tumor Biol. 41:1010428319880080

Eshbakova K (2011) Chemical constituents of *Pulicaria gnaphalodes* Boiss. Med Plants - Int J Phytomed 3:161–163. https://doi.org/10.5958/j.0975-4261.3.2.026

Eshbakova KA, Khasanova KI, Komilov BD, Melieva SO, Aisa HA (2018) Diterpenoids and flavonoids from *Pulicaria gnaphalodes*. Chem Nat Compd 54:360–361. https://doi.org/10.1007/s10600-018-2346-

Eshbakova KA, Toshmatov ZO, Melieva SO, Aisa HA, Abdullaev ND (2016) Secondary metabolites from *Pulicaria gnaphalodes*. Chem Nat Compd 52:713–714. https://doi.org/10.1007/s10600-016-1751-z

Fahmi AA, Abdur-Rahman M, Aboul Naser AF, Hamed MA, Abd-Alla HI, Nasr MI (2019a) *Pulicaria crispa* mitigates gastric ulcer induced by ethanol in rats: role of treatment and auto healing. Biomarkers 24:286–294. https://doi.org/10.1080/1354750X.2018.1556340

Fahmi AA, Abdur-Rahman M, Naser AF, Hamed MA, Abd-Alla HI, Shalaby NM, Nasr MI (2019b) Chemical composition and protective role of *Pulicaria undulata* (L.) CA Mey. subsp. *undulata* against gastric ulcer induced by ethanol in rats. Heliyon 5

Feriel M, Reguia M, Mohamed H, Amar D, Mohamed Y (2021) In vitro antioxidant, α-amylase and Horseradish peroxidase inhibitory potential of phenolics extracts from *Chamomilla pubescens*, *Pulicaria crispa* and *Rhanterium adpressum* growing in Algeria. Curr. Enzyme Inhib 17:175–187. https://doi.org/10.2174/1573408017666210506154339

Foudah AI, Alam A, Soliman GA, Salkini MA, Ahmed EI, Yusufoglu HS (2015) Pharmacognostical, antioxidant and antimicrobial studies of aerial part of *Pulicaria crispa* (Family: Asteraceae). Bull Environ Pharmacol Life Sci 4:19–27

Gandomi H, Abbaszadeh S, Rahimikia E, Shariatifar N (2015) Volatile organic compound from *Pulicaria gnaphalodes* and the antibacterial and antifungal properties of its essential oil and aqueous, ethanolic and methanolic extracts. J Food Process Preserv 39:2129–2134. https://doi.org/10.1111/jfpp.12456

Hassanabadi Z, Mohayeji M, Sharififar F, Mehrafarin A, Mirtadzadini SM (2022) Variability in phenolic compounds, DPPH scavenging activity, and essential oil profile of *Pulicaria gnaphaloides* (Vent.) Boiss. populations: an opportunity for industrial products. J Essent Oil-Bear Plants 25:1096–1108. https://doi.org/10.1080/0972060X.2022.2133974

Hassanabadi Z, Mohayeji M, Sharififar F, Mirtadzadini M, Mehrafarin A (2023) Evaluation of morphologic and genetic diversity of *Pulicaria gnaphalodes* populations collected from south-east of Iran. Agric. Biotechnol. J. 15:145–166

Hegazy ME, Abdelfatah S, Hamed AR, Mohamed TA, Elshamy AA, Saleh IA, Reda EH, Abdel-Azim NS, Shams KA, Sakr M, Sugimoto Y (2019) Cytotoxicity of 40 Egyptian plant extracts targeting mechanisms of drug-resistant cancer cells. Phytomedicine 59:152771. https://doi.org/10.1016/j.phymed.2018.11.031

Hegazy ME, Dawood M, Mahmoud N, Elbadawi M, Sugimoto Y, Klauck SM, Mohamed N, Efferth T (2021) 2α-Hydroxyalantolactone from *Pulicaria undulata*: activity against multidrug-resistant tumor cells and modes of action. Phytomedicine 81:153409. https://doi.org/10.1016/j.phymed.2020.153409

Hegazy ME, Matsuda H, Nakamura S, Yabe M, Matsumoto T, Yoshikawa M (2012) Sesquiterpenes from an Egyptian herbal medicine, *Pulicaria undulate*, with inhibitory effects on nitric oxide production in RAW264. 7 macrophage cells. Chem Pharm Bull 60:363–370. https://doi.org/10.1248/cpb.60.363

Hegazy ME, Nakamura S, Tawfik WA, Abdel-Azim NS, Abdel-Lateff A, Matsuda H, Paré PW (2015) Rare hydroperoxyl guaianolide sesquiterpenes from *Pulicaria undulata*. Phytochem Lett 12:177–181

Helal NM, Ibrahim N, Khattab H (2019) Phytochemical analysis and antifungal bioactivity of *Pulicaria undulata* (L.) methanolic extract and essential oil. Egypt J Bot 59:827–844. https://doi.org/10.21608/ejbo.2019.12259.1308

Hind DJ, Boulos L (2002). Four new combinations in *Pulicaria* (Compositae: Inuleae). Kew Bull, 495–498

Hussein SR, Marzouk MM, Soltan MM, Ahmed EK, Said MM, Hamed AR (2017) Phenolic constituents of *Pulicaria undulata* (L.) CA Mey. sub sp *undulata* (Asteraceae): antioxidant protective effects and chemosystematic significances. J Food Drug Anal 25:333–339

Hussien TA, El-Toumy SA, Hassan HM, Hetta MH (2016) Cytotoxic and antioxidant activities of secondary metabolites from *Pulicaria undulata*. Int J Pharm Pharm Sci 8:150

Issa MY, Ezzat MI, Sayed RH, Elbaz EM, Omar FA, Mohsen E (2020a) Neuroprotective effects of *Pulicaria undulata* essential oil in rotenone model of parkinson's disease in rats: insights into its anti-inflammatory and anti-oxidant effects. S Afr J Bot 132:289–298. https://doi.org/10.1016/j.sajb.2020.04.032

Issa MY, Ezzat MI, Sayed RH, Elbaz EM, Omar FA, Mohsen E (2020b) Neuroprotective effects of *Pulicaria undulata* essential oil in rotenone model of parkinson's disease in rats: insights into its anti-inflammatory and anti-oxidant effects. S Afr J Bot 132:289–298. https://doi.org/10.1016/j.sajb.2020.04.032

Kasote DM, Jayaprakasha GK, Patil BS (2019) Leaf disc assays for rapid measurement of antioxidant activity. Sci Rep 9:1884. https://doi.org/10.1038/s41598-018-38036-x

Kasote DM, Sharbidre AA, Kalyani DC, Nandre VS, Lee JH, Ahmad A, Telke AA (2023P Propolis: a natural antibiotic to combat multidrug-resistant bacteria. In: Wani MY, Ahmad A (eds) Non-traditional approaches to combat antimicrobial drug resistance. Springer, Singapore. https://doi.org/10.1007/978-981-19-9167-7_12

Kazemi M, Ibrahimi Khoram Abadi E, Tohidi R (2022) Nutritional characteristics of some medicinal-range plant species grazed by small ruminants in Torbat-e-Jam region of Iran. J Rangel Sci 13:1–8. https://doi.org/10.57647/J.JRS.2023.1304.33

Kazemi M, Nagafi GR, Azad A (2013) Constituents, antimicrobial and antioxidant activities of *Pulicaria gnaphalodes* (Vent.) Bioss. volatile oil from Iran. Asian J Chem 25:3215

Khan TA, Al-Nasr IS, Mujawah AH, Koko WS (2021) Assessment of *Euphorbia retusa* and *Pulicaria undulata* activity against *Leishmania major* and *Toxoplasma gondii*. Trop Biomed 38:135–141. https://doi.org/10.47665/tb.38.1.023

Komilov BD, Eshbakova KA, Aisa HA (2019) New clerodane diterpenoid from *Pulicaria gnaphalodes*. Chem Nat Compd 55:689–691. https://doi.org/10.1007/s10600-019-02779-4

Kuete V, Wiench B, Alsaid MS, Alyahya MA, Fankam AG, Shahat AA, Efferth T (2013) Cytotoxicity, mode of action and antibacterial activities of selected Saudi Arabian medicinal plants. BMC Complement Altern Med 13:1–11. https://doi.org/10.1186/1472-6882-13-354

Liu L, Yang J, Shi Y (2010) Phytochemicals and biological activities of *Pulicaria* species. Chem Biodivers 7:327–349. https://doi.org/10.1002/cbdv.200900014

Maggio A, Riccobono L, Spadaro V, Campisi P, Bruno M, Senatore F (2015) Volatile constituents of the aerial parts of *Pulicaria sicula* (L.) Moris growing wild in Sicily: chemotaxonomic volatile markers of the genus Pulicaria Gaertn. Chem Biodivers 12:781–799. https://doi.org/10.1002/cbdv.201400255

Maghraby AS, Shalaby N, Abd-Alla HI, Ahmed SA, Khaled HM, Bahgat MM (2010) Immunostimulatory effects of extract of *Pulicaria crispa* before and after *Schistosoma mansoni* infection. Acta Pol Pharm 67:75–79

Mirghani M, j Osman W, Garelnabi EA, Mohammed MS, Ali OH*Pulicaria crispa* (Forssk) Oliv: a review of ethnopharmacology, phytochemistry and biological activities. Khartoum J Pharm Sci 1**:**13–25

Mohamed EA, Muddathir AM, Osman MA (2020) Antimicrobial activity, phytochemical screening of crude extracts, and essential oils constituents of two *Pulicaria* spp. growing in Sudan. Sci Rep 10:1–8. https://doi.org/10.1038/s41598-020-74262-y

Mohammed AB, Yagi S, Tzanova T, Schohn H, Abdelgadir H, Stefanucci A, Mollica A, Mahomoodally MF, Adlan TA, Zengin G (2020) Chemical profile, antiproliferative, antioxidant and enzyme inhibition activities of *Ocimum basilicum* L. and *Pulicaria undulata* (L.) CA Mey. grown in Sudan. S Afr J Bot 132:403–409. https://doi.org/10.1016/j.sajb.2020.06.006

Mohammed HA, Al-Omar MS, Khan RA, Mohammed SA, Qureshi KA, Abbas MM, Al Rugaie O, Abd-Elmoniem E, Ahmad AM, Kandil YI (2021) Chemical profile, antioxidant, antimicrobial, and anticancer activities of the water-ethanol extract of *Pulicaria undulata* growing in the oasis of central Saudi Arabian desert. Plants 10:1811. https://doi.org/10.3390/plants10091811

Morsy BM, Hamed MA, Abd-Alla HI, Aziz WM, Kamel SN (2021) Downregulation of fibrosis and inflammatory signalling pathways in rats liver via *Pulicaria crispa* aerial parts ethanol extract. Biomarkers 26:665–673. https://doi.org/10.1080/1354750X.2021.1970810

Mustafa AM, Eldahmy SI, Caprioli G, Bramucci M, Quassinti L, Lupidi G, Beghelli D, Vittori S, Maggi F (2020) Chemical composition and biological activities of the essential oil from *Pulicaria undulata* (L.) CA Mey. growing wild in Egypt. Nat pro Res 34:2358–2362. https://doi.org/10.1080/14786419.2018.1534107

Naqvi SA, Shah SM, Kanwal L, Saeed M, Atta-ul-Haq NJ, Nisar Z, Akram M (2020) Antimicrobial and antihypercholesterolemic activities of *Pulicaria gnaphalodes*. Dose-Response 18:1559325820904858. https://doi.org/10.1177/1559325820904858

Nath EÖ, Bilgin M, Gurdal B (2021) Antimicrobial activity of *Pulicaria* species from Turkey. Experimed 11:195–199. https://doi.org/10.26650/experimed.2021.986570

Nia S, Benguechoua M, Benarous K, Khacheba I, K Cherif J, Trabelsi-Ayadi M, Yousfi M (2014) Screening of two Algerian spontaneous plants for anti-lipase and antioxidant activities. Curr Enzyme Inhib 10**:**113–120

Norton J, Majid SA, Allan D, Al Safran M, Böer B, Richer R (2009) An illustrated checklist of the flora of Qatar. Browndown Publications, Gosport

Pourhossein Alamdary M, Baharfar R, Tavakoli S (2023) Isolation of secondary metabolites from *Pulicaria gnaphalodes* (Vent.) Boiss. and evaluation of their antiproliferative activity. Polycycl Aromat Compd. https://doi.org/10.1080/10406638.2022.2149933

POWO (2024) Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet. https://powo.science.kew.org/

Rasool N, Ahmad VU, Shahzada N, Rashida MA, Ullah A, Hassan Z, Zubaira M, Tareen RB (2008) New ent–kaurane type diterpene glycoside, Pulicaroside-B, from *Pulicaria undulata L.* Nat Prod Commun. 3: 1934578X0800300206. https://doi.org/10.1177/1934578X0800300206

Rasool N, Rashid MA, Khan SS, Ali Z, Zubair M, Ahmad VU, Khan SN, Choudhary MI, Tareen RB (2013) Novel α-glucosidase activator from *Pulicaria undulata*. Nat Prod Commun 8: 1934578X1300800618. https://doi.org/10.1177/1934578X1300800618

Ravandeh M, Valizadeh J, Noroozifar M, Khorasani-Motlagh M (2011) Screening of chemical composition of essential oil, mineral elements and antioxidant activity in *Pulicaria undulata* (L.) CA Mey from Iran. J Med Plant Res 5:2035–2040

Rizk, Hammouda FM, Ismail SI, Hussiney HA (1993) Constituents of plants growing in Qatar XXIII. Flavonoids of *Francoeuria crispa*. Qatar Univ Sci J 13:51–52. http://hdl.handle.net/10576/9973

Rustaiyan A, Habibi Z, Saberi M, Jakupovic J (1991) A norguaianolide and a glaucolide-like eudesmanolide from *Pulicaria undulata*. Phytochemistry 30:2405–2406. https://doi.org/10.1016/0031-9422(91)83662-5

Salleh W, Kassim H, Tawang A (2021) Volatile components and biological activities of *Pulicaria essential* oils. A review. Riv. Ital. Sostanze Grasse 98:49–58

Sarg T (1975) Phytochemical investigation of *Pulicaria crispa* (Forsk.) Benth and Hook growing in Saudi Arabia. Egypt J Pharm Sci 16:421–427

Sathiyamoorthy P, Lugasi-Evgi H, Schlesinger P, Kedar I, Gopas J, Pollack Y, Golan-Goldhirsh A (1999) Screening for cytotoxic and antimalarial activities in desert plants of the Negev and Bedouin market plant products. Pharm Biol 37**:**188–195. https://doi.org/10.1076/phbi.37.3.188.6298

Shahat AA, Ibrahim AY, Mohamed TA, Elshamy AI, Alqahtani AS, Saleh IA, Hassan EM, Hegazy ME (2020) In vitro anti-inflammatory and acetylcholinesterase inhibition efficiency of plant extracts from Sinai-Egypt. Indian J Tradit Knowl 19:635–641

Shokri H (2014) Genotypic variation and antifungal susceptibly of *Candida zeylanoides* clinical isolates. J Mycol Med 24:179–184. https://doi.org/10.1016/j.mycmed.2014.01.001

Soliman, GA, Ansari, MN, Alqarni, MH, Foudah, AI, Alam, A, Salkini, MA Yusufoglu, HS (2022) Analgesic, antipyretic, anti-inflammatory, and hepatoprotective activities of *Pulicaria crispa* (Forssk.) Oliv.(Asteraceae). Braz J Pharm Sci 58

Stavri M, Mathew K, Gordon A, Shnyder SD, Falconer RA, Gibbons S (2008a) Guaianolide sesquiterpenes from *Pulicaria crispa* (Forssk.) oliv. Phytochem 69:1915–1918. https://doi.org/10.1016/j.phytochem.2008.03.012

Stavri M, Mathew KT, Gibbons S (2008b) A novel sesquiterpene from *Pulicaria crispa* (Forssk.) Oliv Nat Prod Commun 3:1934578X0800300101. https://doi.org/10.1177/1934578X0800300101

Thinina, AC, Karim, H, Alia, MM Karim, A (2020) Evaluation and quantification of the inhibition of biofilm and planktonic forms of Klebsiella pneumoniae by the polyphenolic extract of Pulicaria crispa. J Adv Pharm Technol Res 11: 117. https://doi.org/10.4103/japtr.JAPTR_165_19

Tongnuanchan P, Benjakul S (2014) Essential oils: extraction, bioactivities, and their uses for food preservation. J. Food Sci. 79**:** R1231–R1249. https://doi.org/10.1111/1750-3841.12492

Wollenweber E, Christ M, Dunstan RH, Roitman JN, Stevens JF (2005) Exudate flavonoids in some Gnaphalieae and Inuleae (Asteraceae). Z Naturforsch C 60**:** 671–678. https://doi.org/10.1515/znc-2005-9-1003

Yusufoglu HS, Alqarni MH, Salkini MA, Tabanca N, Demirci B, Kendra PE (2021) Chemical composition of essential oils of *Pulicaria* species growing in Saudi Arabia and activity for Mediterranean fruit fly, ceratitis capitata. Phytochem Lett 46:51–55. https://doi.org/10.1016/j.phytol.2021.08.021

Zdero C, Bohlmann F, Rizk A (1988) Sesquiterpene lactones from *Pulicaria sicula*. Phytochemistry 27**:** 1206-1208. https://doi.org/10.1016/0031-9422(88)80306-6

Zekry SZ, Hassanean H, Abdelhameed RF, Habib ES, Ahmed S (2021) Metabolites and biological activities of some *Pulicaria* species (Asteraceae): mini-review. Rec Pharm Biomed Sci 5:121–132. https://doi.org/10.21608/rpbs.2021.90979.1112

Zendehdel M, Fallah R, Baghbanzadeh A, Pourrahimi M, Shariatifar N, Garavand S (2013) Effect of intracerebroventricular injection of aqueous extract and essential oil of *Pulicaria gnaphalodes* on PTZ-induced seizures in male rat. Physiol Pharmacol 17: 94–100