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Current knowledge on genus *Bassia* All.: a comprehensive review on traditional use, phytochemistry, pharmacological activity, and nonmedical applications

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Abstract *Bassia* All. is a genus from the *Amaranthaceae* family, which was created by merging selected species belonging to the former *Bassia* and *Kochia* genera with those classified to *Chenolea*, *Londesia*, *Kirilowia* and *Panderia.* The reorganised *Bassia* genus currently comprises around 20 species, which are annual herbs or perennial subshrubs native to Eurasia and Africa. *Bassia* plants are well known for their therapeutic applications in folk medicine and traditional medical systems, and they are also used for nonmedical purposes. Some members of this genus, such as *Bassia scoparia* (syn. *Kochia scoparia*) is of great medical importance and economic value. The plant is cultivated in some regions of Asia as a crop to collect *Kochiae fructus,* which is used for both curative and food purposes. Phytochemical studies carried out on *Bassia* species indicate that these plants synthesize metabolites belonging to different groups of compounds (e.g., triterpene saponins, sterols, flavonoids, fatty acids, lignanamides, alkaloids, organic acids). Some of the structures are rarely found in the plant kingdom. Biological activity studies carried out on *Bassia* plants revealed various effects exerted by extracts and isolated compounds, including anti-inflammatory, cytotoxic, antioxidant, antimicrobial, hypoglycemic, anti-obesity, etc. Modern research explained some of the mechanisms of action. This review covers literature from 1935 to 2022, and assembles and discusses data on phytochemistry, biological activity, as well as medical and nonmedical use of the representatives of the genus *Bassia*. In this review we present the current state of knowledge about the plants of the genus.

Keywords *Bassia* · *Kochia* · Phytochemistry · Activity · Medical plant · Saponins

Abbreviations

AAPH	2,2′-Azobis-(2-amidinopropane)
ABTS	2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt
AKT	Protein kinase B
ALI	Acute lung injury
ALS	Acetolactate synthase
ALT	Serum alanine transaminase
ANP	Atrial natriuretic peptide
AST	Aspartate transaminase
BACE-1	β-Site amyloid precursor protein cleaving enzyme 1
Bax	Bcl-2-associated X protein
BDE	Bond dissociation enthalpy

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BHT	Butylated hydroxytoluene
CG	Cathepsin
COX-2	Cyclooxygenase-2
CREB	CAMP response element-binding protein
DCM	Dilated cardiomyopathy
DNCB	2,4-Dinitrochlorobenzene
DNFB	1-Fluoro-2,4,-dinitrofluorobenzene
DPAR	Direct passive arthus reaction
DPPH	2,2′-Diphenyl-1-picrylhydrazyl
dw	Dry weight
ERK	Extracellular-signal-regulated kinase
FA	Fatty acid
FoxO	Forkhead family of transcription factors O
FRAP	Ferric reducing antioxidant power
GAE	Gallic acid equivalents
HIF-1α	Hypoxia-inducible factor 1-α
HNE	Human neutrophil elastase
HO	Heme oxygenase
i.p.	Intraperitoneally
ICAM-1	Intercellular adhesion molecule-1
IL-1β	Interleukin-1β
IL-4,	Interleukin-4
IL-5	Interleukin-5
IL-6	Interleukin-6
IL-10	Interleukin-10
INF-γ	Interferon-gamma
iNOS	Inducible NO synthase
i.v.	Intravenous
JNK	C-Jun N-terminal kinases
LC_{50}	Lethal dose 50%
LDH	Lactic dehydrogenase
LPS	Lipopolisaccharide
MAE	Microwave-assisted extraction
MAO-B	Monoamine oxidase-B
MAPK	Mitogen-activated protein kinases,
MCP-1	Monocyte chemotactic protein-1
MIC	Minimal inhibitory concentration
MPO	Myeloperoxidase
MMP-9	Matrix metalloproteinase-9
mTOR	Mechanistic target of rapamycin
NET-DNA	Net-like structures of nuclear DNA
NF-κB	Nuclear factor kappa B
NOS	Nitric oxide synthase
OVA	Ovalbumin
PCA	Passive cutaneous anaphylaxis
p.o.	Per os
p38	P38-mitogen activated protein kinase
PARP	Poly (ADP) ribose polymerase
PGC-1α	Peroxisome proliferator-activated receptor-γ coactivator
PGE_2	Prostaglandin E
PI3K	Phosphoinositide 3-kinase
PPAR	Peroxisome proliferator-activated receptors
RCA	Reversed cutaneous anaphylaxis
ROS	Reactive oxygen species
SAR	Structure activity-relationship
SENP	SUMO-specific proteases
SUMO	Small ubiquitin-like modifier protease
TAC	Total antioxidant capacity
TFC	Total flavonoid content
TLR	Toll-like receptor
TPC	Total phenolic content
TBARS	Thiobarbituric acid reactive substances
TCM	Traditional Chinese Medicine
TEAC	Trolox equivalent antioxidant capacity
Th	Helper T cells
TNF-α	Tumor necrosis factor α
TrkA	Tropomyosin receptor kinase A
VCAM-1	Vascular cell adhesion molecule-1
VLCFA	Very-long-chain fatty acids
VEGF	Vascular endothelial growth factor
VEGFR	Vascular endothelial growth factor receptor

Introduction

The genus *Bassia* All. is one of the genera found in the *Amaranthaceae* family. The taxonomy of these plants is problematic, but according to a new reclassification, the genus *Bassia* comprises circa 20 species (Kaderit and Freitag 2011). *Bassia* plants are annual herbs or perennial subshrubs native to Eurasia and Africa. As members of the *Amaranthaceae* family, these species operate C4 photosynthesis, which evolved in dicots to facilitate their growth in arid ecosystems. Therefore, *Bassia* plants can be found in semideserts or dry steps, and, as halophytes, can exist also in habitats characterized by high salinity. Due to adaptation to different environmental conditions, *Bassia* species have attracted attention as plants that can be cultivated in regions where other

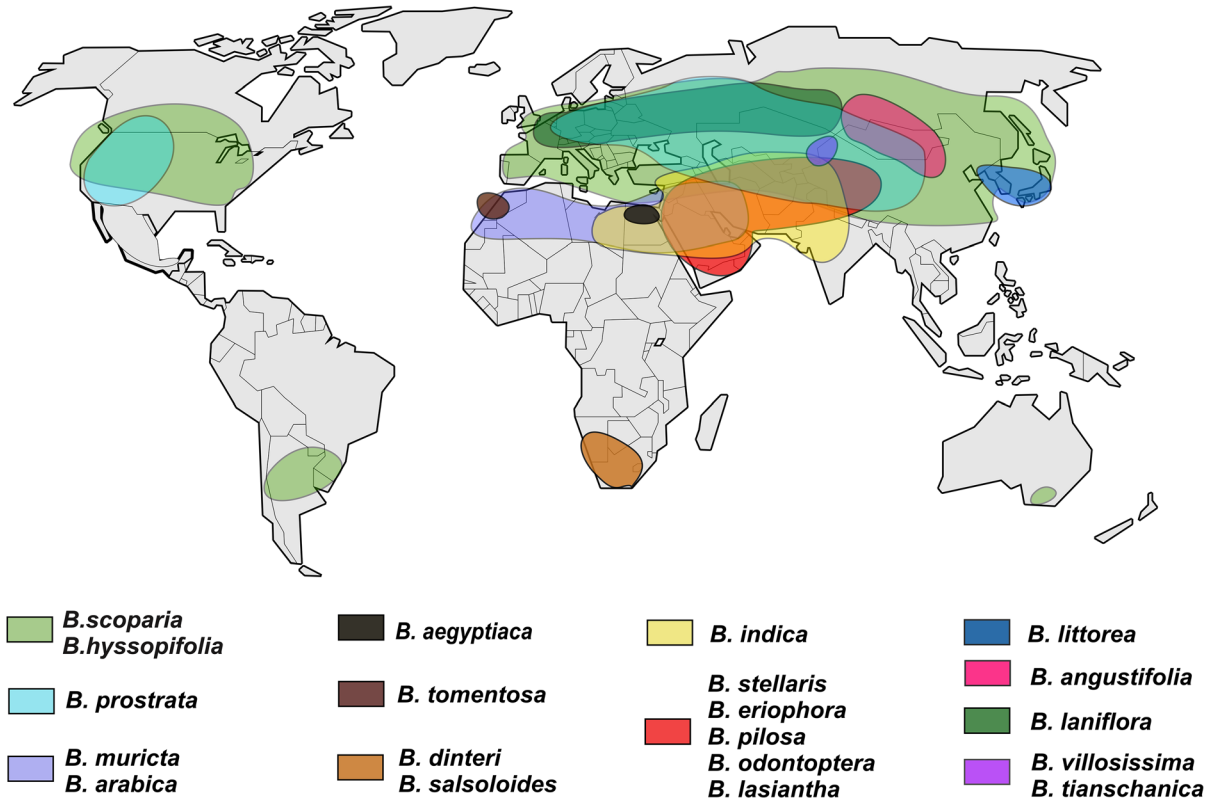

Fig. 1 The distribution range of plants in the genus *Bassia*

plant species cannot be planted (Al-Ahmadi et al. 2007; Kaderit and Freitag 2011; Orlovsky et al. 2011; Shelef et al. 2012; Abideen et al. 2015). Today, as can be seen in Fig. 1, *Bassia* plants are distributed from the Mediterranean region (Europe and North Africa) up to Japan (*B. scoparia*, *B. prostrata*, *B. hyssopifolia*). Several species are characteristic of the arid regions of the Middle East, India, and steps of Central Asia (*B. odontoptera*, *B. indica*, *B. eriophora*, *B. stellaris*). Some grow in North Africa, in the Sahara region (*B. arabica*, *B. muricata*) and South Africa (*B. salsoloides, B. dinteri*) (Kaderit and Freitag 2011; GBIF 2022). Plants of the *Bassia* genus, such as *B. scoparia, B. prostrata* and *B. hyssopifolia,* have been introduced to North America as high-yielding forage plants with nutritional value or for ornamental purposes. They spread quickly and are currently naturalized in both North and South America (Lauriault et al. 2020; Torbiak et al. 2021; Brignone et al. 2021; Ravet et al. 2021). *B. scoparia* and *B. hyssopifolia* have also been introduced to Australia. However, due to the high invasive potential of *B. scoparia*, a year after introduction, work on the eradication of this plant species began. The elimination process proved successful, and no *B. scoparia* have been observed in Australia since 2000. In turn, there are some records that *B. hyssopifolia* still occurs in southeastern Australia, but only in a small area of north-western Victoria state (POWO 2022; Panetta 2015).

In Asia, *B. scoparia* (syn. *Kochia scoparia*) has great medical importance and economic value. At present, it is cultivated in China and Japan as a crop for both curative and food purposes (Tashiro et al. 2019; Chen et al. 2021; Zou et al. 2021). *B. scoparia* is a plant recorded in the Chinese Pharmacopeia (Chen et al. 2021), which provides dried fruits (*Kochiae fructus, Di-Fu-Zi*) which is a TCM product very popular in different parts of Asia. Currently, due to globalization, *Kochiae fructus* is commercially available worldwide. Given that *B. scoparia* has well-documented pro-health effects and is also used as a food, some authors suggest that its fruit should be

considered for the development of functional foods (Chen et al 2017).

Apart from *B. scoparia,* other *Bassia* species have also been recommended in traditional medical systems, especially in regions where they grow as wild plants (Hammiche and Maiza 2006; Khare 2007; Altundag and Ozturk 2011; Youssef 2013; Moein et al. 2015; Umair et al. 2017). In addition to the therapeutic value of these plants, they have also been used for nonmedical purposes. For example, some plants of the genus *Bassia* are being appreciated as human food and livestock feed because of their nutritional value. (Nadelcheva et al. 2007; El Shaer 2010; Khan et al. 2013; Youssef 2013; Akhtar et al. 2018).

In recent years, several studies have provided new data on the chemistry and biological activity of *Bassia* species (Xiae et al. 2018; Houlihan et al. 2019; Abd-ElGawad et al. 2020; Gancheva et al. 2020; Othman et al. 2021a; 2021b; Othman et al. 2022; Said et al. 2021; Petruk et al. 2021). It is noteworthy that not only *B. scoparia* but also other hitherto unexplored *Bassia* species attracted scientific attention. Modern research also investigated the potential for new applications of plants from this genus (Abideen et al. 2015; Athinarayanan et al. 2018; Aihemaiti et al. 2018; El-Katori and Al-Mhyawi 2019; Song et al. 2021; Shi et al. 2022; Hozhabralsadat et al. 2022).

To the best of our knowledge, there are no papers reviewing available scientific data on the *Bassia* genus. Although there are some reviews devoted to *B. scoparia*, they focused exclusively on one part of this plant, namely *Kochiae fructus* (Al-Sanafi et al. 2018; Zou et al. 2021). Therefore, the main objective of the current review is to provide the first comprehensive overview of the Bassia genus, including the latest information on its phytochemistry, biological activity, as well as its medical and nonmedical use.

Methods

The search of scientific literature was carried out in various databases including PubMed, Scopus, Google Scholar, Science Direct, and Embase, and covered the period up to 2022 June 17. The key words (as individuals and their different combinations) used to search were: Bassia, Kochia, "phytochemistry", "phytochemical", "taxonomic", "distribution", "saponins", "phenolics", "triterpenes", "fatty acids", "flavonoids", "quantification", "sterol", "alkaloid", "terpenes", "compound", "nitrates", "organic acid", "oil", "essential oil", "monosaccharides", "carotenoids", "activity", "pharmacological", "extract", "anti-inflammatory", "inflammatory", "oedema", "anti-allergic", "psoriasis", "eczema", "wound healing", "traditional medicine", "food", "ethnobotany", "TCM", "animal model", "antibacterial", "antifungal", "antiparasitic", "phytoremediation", "gastric", "hypoglycemic", "antioxidant", "toxicity", "cytotoxicity", "cancer cell", "mechanism". As key words, the full Latin name of representatives of the genus *Bassia* (according to the new classification proposed by Kaderit and Freitag (2011), as well as their synonyms and former Latin name (according to the previous taxonomic classification) (as individual or in combination with the above-mentioned keywords) were used. According to the rules of the specific databases, Boolean operators were also used. No filters or time restrictions were applied for publications during the search. Furthermore, the reference lists of all selected reports were searched to identify potentially eligible publications. Only publications that had available full texts were included. Conference communications, posters, and the thesis were excluded. The available information on *Bassia* species has been divided into several sections, i.e. taxonomy, distribution, phytochemistry, biological activity, medical use, nonmedical use, and toxicology. Publications outside the scope of these thematic sections were rejected. Moreover, publications on the phytochemistry of *Bassia* species were thoroughly checked, and articles that contained information on preliminary phytochemical analyses of extracts, based only on characteristic reactions of groups of compounds (e.g. foam test), which are not specific, were excluded from the phytochemistry section.

ChemDraw 19.0 software was used to draw the chemical structures of compounds. The graphs were performed using Excel 365 software (Microsoft Office) software. The illustrations were made with CorelDraw 2021.5 software.

Taxonomy

Species of the genus *Bassia* were previously classified to the *Chenopodiaceae* family. However, the *Chenopodiaceae* family is currently included in the *Amaranthaceae* family, which is taxonomically complicated. According to a new classification, proposed by Kadereit and Freitag (2011) based on molecular phylogeny and morphological studies, species belonging to the *Bassia* and *Kochia* genera were combined in a subclade renamed *Bassia* All., which is part of the *Bassia/Camphorosma* clade. The reorganized genus *Bassia* All. comprises currently circa 20 species: *B. aegyptiaca* Turki, El Shayeb & F. Shehata, *Bassia angustifolia* (Turcz.) Freitag & G. Kadereit, *Bassia arabica* (Boiss.) Maire & Weiller, *Bassia dinteri* (Botsch.) A.J. Scott, *Bassia eriophora* (Schrad.) Asch., *Bassia hyssopifolia* (Pall.) Kuntze, *Bassia indica* (Wight) A.J. Scott, Bassia laniflora (S. G. Gmel.) A.J. Scott, *Bassia lasiantha* Freitag & G. Kadereit, *Bassia littorea* (Makino) Freitag & G. Kadereit, *Bassia muricata* (L.) Asch., *Bassia odontoptera* (Schrenk) Freitag & G. Kadereit, *Bassia pilosa* (Fisch. & C.A. Mey.) Freitag & G. Kadereit, *Bassia prostrata* (L.) A.J. Scott, *Bassia salsoloides* (Fenzl) A.J. Scott, *Bassia scoparia* (L.) A.J. Scott, *Bassia stellaris* (Moq.) Bornm., *Bassia tianschanica* (Pavlov) Freitag & G. Kadereit, *Bassia tomentosa* (Lowe) Maire & Weiller, *Bassia villosissima* (Bong. & C.A. Mey.) (Kadereit and Freitag 2011; Hernández-Ledesma et al. 2015). Although some authors indicate ambiguities in the proposed classification, and distinguish more species, for example *Bassia eriantha* and *Kochia monticola*, nevertheless these species are denoted in the current classification *B. eriophora* and *B. pilosa*, respectively (Akhani and Khoshravesh 2013; Sukhorukov and Kushunina 2020). Apart from *Kochia/Bassia* species, plants from *Chenolea*, *Londesia,* as well as *Kirilowia* and *Panderia* have also been transferred into *Bassia* taxonomic group and renamed *Bassia*. On the other hand, after taxonomic reorganisation, some formerly known *Bassia* or *Kochia* species were excluded from *Bassia* subclade and grouped in new genera; *Eokochia* (*K. saxicola*), *Spirobassia* (*B. hirsuta*), *Sedobassia* (*K. sedoides*) and *Grubovia* (*B. dasyphylla, K. melanoptera*, *K. krylovii*). Additionally, two perennial species native to the United States, formerly known as *Kochia americana* S. Watson and *Kochia californica* S. Watson are now included in the genus *Neokochia* as *Neokochia americana* (S. Watson) G.L. Chu & S.C. Sand and *N. californica* (S. Watson) G.L. Chu & S.C. Sand (Kaderit and Freitag 2011; Kadereit et al. 2014; Hernández-Ledesma et al. 2015).

Despite the new classification and nomenclature proposed by Kaderit and Freitag, both new names and their synonyms coexist in the scientific literature. Interestingly, for some species, such as *Bassia scoparia*, the term *Kochia scoparia* is used even more frequently. This may be related to the fact that *K. scoparia* is a plant commonly used in TCM, and according to Flora of China records, *Kochia* and *Bassia* were not merged but are still treated as separate genera (Chen et al. 2021).

Therefore, in order to avoid any confusion, in the current review, the new terminology according to Kadereit and Freitag (2011) is used for all species of the genus *Bassia.*

The importance of plants of the genus *Bassia*

Numerous ethnobotanical surveys carried out in different regions of Asia and Europe, records found in herbal books referring to traditional medicinal systems, and scientific literature reports, all underline that *Bassia* plants have been intensively used by humans for therapeutic purposes and as nonmedical products (Hammiche and Maiza 2006; Khare 2007; Nadelcheva et al. 2007; Altundag and Ozturk 2011; Umair et al. 2017; Lin et al. 2021) (see Table 1). It should be mentioned that modern research revealed some new potential applications of *Bassia* plants, which are currently being investigated.

Medical uses of *Bassia* species

Representatives of the genus *Bassia* have been used in traditional medicine to treat various aliments (see Table 1). One of the most important species from the therapeutic point of view is *B. scoparia*. The dried fructus of *B. scoparia*, known as Di-Fu-Zi, has been valued in Traditional Chinese Medicine (TCM). Its application is based on ethnopharmacological data, and modern scientific research (Zou et al. 2021). Today, *Kochiae fructus* is recommended for urinary system disorders, such as frequent urination or

Table 1 The ethnobotanical importance of *Bassia* plants and their use in medical systems, including TCM

Plant name	Usage	Plant part/Form	Country (Region)	References
B. scoparia (syn. *K. scoparia*)	Cardiac tonic	Fruits, leaves/ oral	China	Kirtikar and Basu (1935), Khare (2007),
	Tonic, hypotensive and breath stimulating agent	Undef	Armenia, Uzbekistan	Akopian et al. (2020)
		Undef		
	Diuretic	Fruits, leaves/oral	China	Kirtikar and Basu (1935), Khare (2007),
	Urinary system disorders (frequent urination, urinary incontinence) Gonorrhea	Fruit	China	Zou et al. (2021)
		Fruit/seed/ decoction	China (Gaomi)	Lin et al. (2021)
		Fruit	Korea	Im et al. (2016), Whang and Hahn (1991)
	Skin diseases (itching, eczema, sores), swelling, urticaria	Fruit	China	Chien et al. (2013), Chen et al. (2015)
			Taiwan	
	Dermatitis	Fruit	Korea	Whang and Hahn (1991)
	Atopic dermatitis	Fruit	Taiwan	Chen et al. (2016)
	Psoriasis	Fruit	Taiwan	Weng et al. (2016)
	Male impotence, vaginal discharge, vaginal fungal infections, leucorrhea	Fruit	China	Liu et al. (2012), Zou et al. (2021)
	Improvement of eyesight, hearing, pain in head, eyes, ears	Fruit	China	Zou et al. (2021)
	Food/vegetable	Aerial parts/ fried/ steamed with flour	China (Inner Mongolia)	Sachula et al. (2020)
		Shoots and tender leaves	Myanmar	Shin et al. (2018)
		Aerial parts	China (Heihe valley)	Kang et al. (2012)
	Food (Tonburi)	Fresh fruits	Japan	Tashiro et al. (2019)
	Medicinal use household items,	Undef	South Korea	Lee et al. (2017)
				Chung et al. (2016)
	Brooms	Aerial parts	Bulgaria, Romania, Macedonia, Italy	Nedelcheva et al. (2007)
		Aerial parts	Spain	Gras et al. (2020)
	Fodder	Fresh/ dry aerial parts	Pakistan (Gilgit-Baltistan)	Khan et al. (2013)
	Ornamental, fibres (mats, baskets)	–	Pakistan	Khan and Qaiser (2006)
B. eriophora	Antirheumatic, snake bite, vermifugal	Whole plant, seed oil	Saudi Arabia (Onaizah province)	Youssef (2013)
	Food/vegetables and fodder	Leaves, stem	Pakistan (Karak district)	Akhtar et al. (2018)
	Alzheimer, gingivitis, hair loss	Leaf, twig/ infusion	Iran (Darab region)	Moein et al. (2015)
	B. muricata			
	Kidney diseases, antirheumatic, ulcers	Seeds, leaves, flowers, seed oil/gargle	Saudi Arabia (Onaizah province)	Youssef (2013)
	Analgesic, antiseptic, anti-inflammatory	Undef	Algiers (Sahara, Oued Righ)	Lakhdari et al. (2016)
	Skin diseases	Leaf/cataplasm aerial parts/infusion/oral	Morocco (Tata Province)	Abouri et al. (2012)
	hypoglycaemic			
	Skin diseases: boils, dermatosis, pustules, infected wounds	Leaf/poultice	Algeria (Tassili N'Ajjer's)	Hammiche and Maiza (2006)
	Diarrhoea	Aerial parts/infusion/ internal	Algeria (Tassili N'Ajjer's)	Hammiche and Maiza (2006)
	Birds appetizer agent	Seeds and fruits	Saudi Arabia (Riyadh)	Sher and Aldosari (2013)

Table 1 The ethnobotanical importance of *Bassia* plants and their use in medical systems, including TCM

Plant name	Usage	Plant part/Form	Country (Region)	References
	Skin diseases: sores	Seed oil	Saudi Arabia (Tabuk)	Al-Harbi (2017)
	Fodder	Seeds, leaves, flowers, seed oil, gargle	Saudi Arabia (Onaizah)	Youssef (2013)
		Whole plant	Libya (Mediterranean Coast)	Louhaichi et al. (2011)
	Sand fixation	Whole plant		
	Fuel	Seeds, leaves, flowers, seed oil, gargle	Saudi Arabia (Onaizah)	Youssef (2013)
B. indica	Heart tonic, cardiac stimulant (weak and irregular heart)	Whole plant/ decoction, oil, gargle	Saudi Arabia (Onaizah)	Youssef (2013)
		Undef	India	Khare (2007)
		Undef	India	Kirtikar and Basu (1935)
		Undef	India (Rajasthan)	Tripathi et al. (1996)
		Roots, whole plant/ extract	Pakistan (Faisalabad)	Ahmad et al. (2015)
	Diuretic	Fruits, leaves/ decoction, oil; oral, gargle	Pakistan (Hafizabad)	Umair et al. (2017)
	Toothache	Fruits, leaves/ decoction, oil; oral, gargle		
		Roots, whole plant/ tooth brushes, extract	Pakistan (Faisalabad)	Ahmad et al. (2015)
	Blood pressure, constipation, vomiting, internal worms	Whole plant/decoction	Pakistan (Karak)	Khan et al. (2018)
	Fodder	Fresh/ dry aerial parts	Pakistan (Karak)	Rashid and Marwat (2006)
		Fresh/ dry aerial parts	Pakistan (Tank)	Badshah et al. (2012)
		Fresh/ dry aerial parts	Pakistan (Gilgit-Baltistan)	Khan et al. (2013)
		Fresh/ dry aerial parts	Pakistan (Charsadda)	Khan and Badshah (2019)
		Whole plant	Libya (Mediterranean Coast)	Louhaichi et al. (2011)
		Fresh/ dry aerial parts fresh	Pakistan (Muzaffar Garh)	Ajaib et al. (2015)
	Ornamental	Fresh/ dry aerial parts fresh		
	Fuel	Fresh/ dry aerial parts	Pakistan (Karak)	Rashid and Marwat (2006)
		Fresh/ dry aerial parts	Pakistan (Tank)	Badshah et al. (2012)
	Sand fixation	Whole plant	Libya (Mediterranean Coast)	Louhaichi et al. (2011)

Table 1 continued7

Plant name	Usage	Plant part/Form	Country (Region)	References
B. prostrata	Urinary system disorders	Aerial parts/ decoction/ internal	Turkey, (Anatolia)	Altundag and Ozturk (2011)
	Anthelminthic	Undef.	Armenia, Uzbekistan	Akopian et al. (2020)
	Soap for washing utensils	Undef.	Pakistan (Karak)	Khan et al. (2011)
	Fodder	Aerial parts	Kazakhstan	Ryabushkina et al. (2008)
		Whole plant	Pakistan (Gilgit)	Khan and Khatoon (2008)
	Toothache	Roots/tooth brush, whole plant		
	Brooms	Aerial parts	Bulgaria	Nedelcheva, et al. (2007)
		Branches	Pakistan (Baltistan)	Abbas et al. (2019)
	Fuel	Branches		
*B.odontoptera (*former name: *K. iranica)*	Fodder, fuel wood	Undef.	Pakistan (Balochistan)	Durrani et al. (2010)
	Ornamental, fibres (mats, baskets)	Undef.	Pakistan	Khan and Qaiser (2006)

undef. The plant part and the form of application were not specified

urinary incontinence, and as a remedy in vaginal discharge. *Kochiae fructus* is also applied in skin, eyes, and ear diseases (Im et al. 2016; Lin et al. 2021; Zou et al. 2021). Recent studies have shown that Di-Fu-Zi is one of the most prescribed single herbal preparations in traditional Chinese medicine to treat dermatological problems such as eczema, urticaria, psoriasis, and pediatric atopic dermatitis (Chien et al. 2013; Chen et al. 2015, 2016; Weng et al. 2016). The fruit is also used as a key ingredient in herbal formulas to reduce itching, swelling, and sores (Chien et al. 2013; Chen et al. 2015; Weng et al. 2016). In China, the fruits and leaves of *B. scoparia* have been known as cardiac tonics (Kirtikar and Basu 1935). People in Armenia and Uzbekistan have also used *B. scoparia* as a breath stimulator and hypotensive agent (Akopian et al. 2020). In addition to *B. scoparia*, other species of the genus have also been valued as medicinal plants. In the Middle East, as well as in India, the decoction of the entire plant of *B. indica* has been recommended as a cardiac stimulant (Khare 2007; Youssef 2013; Umair et al. 2017). Ethnobotanical surveys revealed that aerial parts of *B. muricata*, and *B. prostrata* have been used by inhabitants of Saudi Arabia and Turkey to treat kidney diseases and as antirheumatic agents (Altundag and Ozturk 2011; Youssef 2013). Furthermore, *B. muricata* leaves poultices have been applied to the skin as a remedy for boils, ulcers, dermatosis, pustules, and infected wounds in folk medicine of different regions of North Africa and Saudi Arabia (Hammiche and Maiza 2006; Abouri et al. 2012; Al-Harbi 2017). *B. eriophora* has traditionally been used in Iran as an infusion of leaves or twigs in the treatment of gingivitis, hair loss, and the symptoms of Alzheimer's disease (Moein et al. 2015). Furthermore, recent research has revealed some new applications for *Bassia* species. *B. eriophora* was studied as a natural material to obtain cellulose nanofibers. Such structures can be used in various sectors of industry and medicine. Because the produced nanofibers along with their very good mechanical properties were also biocompatible and biodegradable, the possibility of using them in regenerative medicine and tissue engineering should be considered (Athinarayanan et al. 2018).

Nonmedical applications of *Bassia* species

In addition to medical applications, *Bassia* species are also valued as nonmedical products. Fresh fruits of *B. scoparia* are very popular in Asian cuisine as a

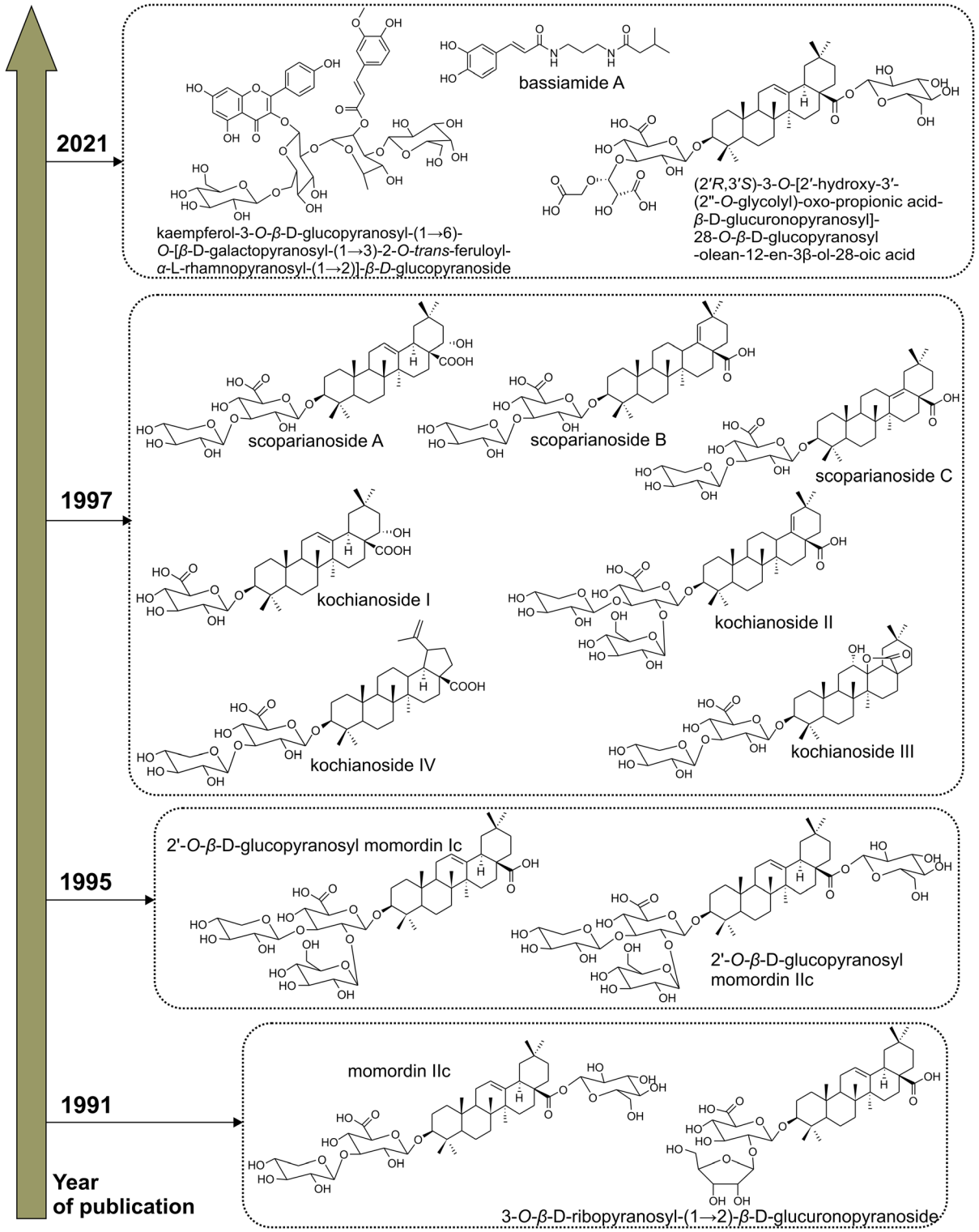

Fig. 2 Chemical structures of new compounds (at the time of publication) isolated from the genus *Bassia*

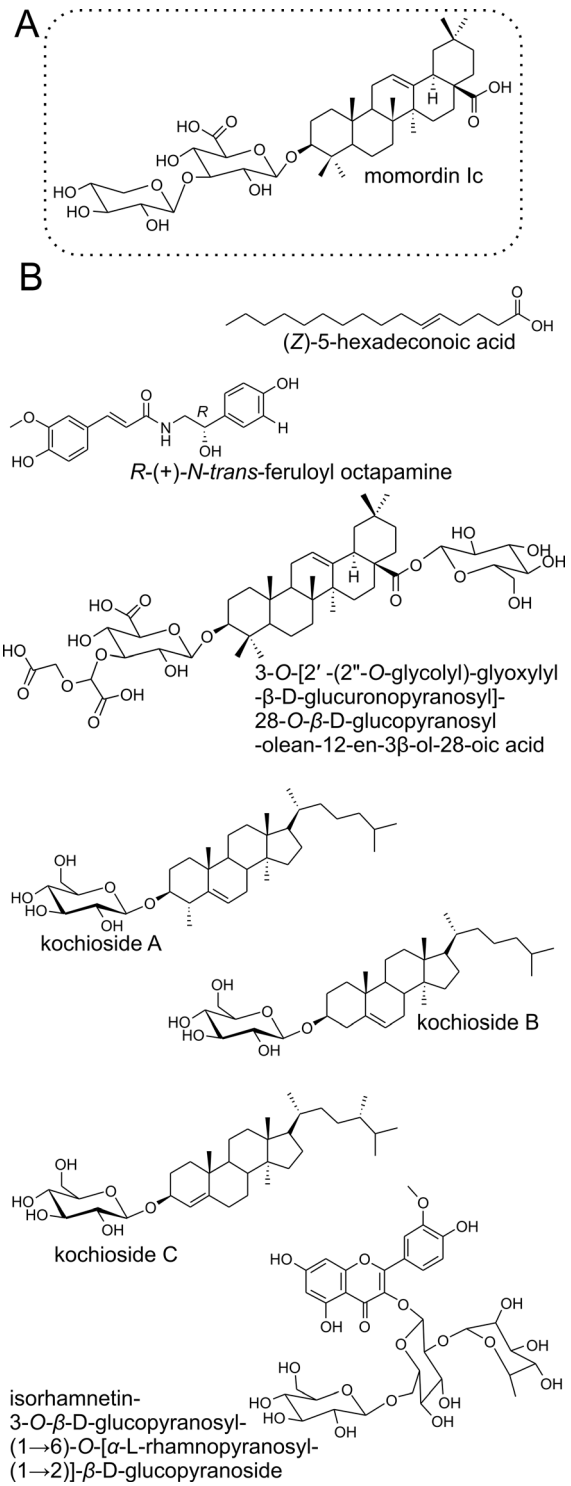

Fig. 3 Chemical structures of compounds isolated from the genus *Bassia*: characteristic compound (A), rarely found compounds in the plant kingdom (B)

food garnish called Tomburi or 'plant caviar' (Tashiro et al. 2019). Some authors also highlight the potential of *Kochiae* fruits in the development of functional foods (Chen et al. 2017). The shots and tender leaves of *B. scoparia* are eaten as a vegetable by people from Myanmar and inhabitants of the Heihe valley in China (Kang et al. 2012; Shin et al. 2018). In the inner Mongolian region, aerial parts of the plant are consumed fried or steamed with flour (Sachula et al. 2020). *Bassia* plants, including *B. prostrata*, *B. scoparia*, *B. muricata*, *B. eriophora* and *B. indica,* are also valued as feed for livestock in various districts of Pakistan, Saudi Arabia, and Kazakhstan due to the nutritional values of aerial parts, but equally important to the possibility of their cultivation under unfavourable climatic conditions, even in arid areas (see Table 1) (Khan and Khatoon 2008; Khan et al. 2013; Youssef 2013; Akhtar et al. 2018). In the western United States and the Near East, *B. prostrata* and *B. indica* are gaining increasing importance as high-yielding forage plants for grazing (Waldron et al. 2010; El Shaer 2010).

Furthermore, ethnobotanical surveys revealed that *B. muricata* and *B. indica* have been used by inhabitants of Pakistan and some regions of Saudi Arabia as fuel and firewood (Badshah et al. 2012; Youssef 2013). On the other hand, there are some reports from the USA that another *Bassia species*, *B. prostrata,* may be used as a green firebreak, a management tool for wildfires (Harrison et al. 2002). Some reports indicate that aerial parts of *B. scoparia* have been used in different countries of Europe to produce household items, such as brooms (Nadelcheva et al. 2007; Gras et al. 2020). In turn, the people of Karak district in Pakistan produced a soap-like product from *B. prostrata* (Khan et al. 2011). *B. scoparia*, commonly called summer-cypress, is also cultivated as an ornamental plant. Currently, research is being carried out on the possibility of using various species of *Bassia* (*B. indica*, *B. scoparia*) in the phytoremediation of salt- and metal-contaminated soils (Shelef et al. 2012; Moubasher et al. 2015; Aihemaiti et al. 2018; Shi et al. 2022). The possibility of using *B. scoparia* and its associated rhizosphere microflora is also being considered in the degradation of aromatic hydrocarbons in soils contaminated with crude oil (Moubasher et al. 2015; Song et al. 2021). Furthermore, new potential applications such as the

Table 2 Saponins isolated from plants of the genus *Bassia*

Aglycone	Sugar part	Common name of saponin*	Species (plant part)	References
OA	C-3: Xyl-(1→3)-GlcA	Momordin Ic	*B. scoparia* (FR)	Wen et al. (1995), Yoshikawa et al. (1997a, b), Han et al. (2006), Lu et al. (2012b)
OA	C-3: Xyl-(1→3)-[Glc (1→2)]-β-D-GlcA	2′-*O*-β-D-glucopyranosyl momordin Ic	*B. scoparia* (FR)	Wen et al. (1995), Yoshikawa et al. (1997a, b), Han et al. (2006)
OA	C-3: Xyl-(1→3)-6-Me-GlcA	Momordin Ic methyl ester	*B. scoparia* (FR)	Wen et al. (1995), Yoshikawa et al. (1997a), Han et al. (2006), Lu et al. (2012b)
OA	C-3: Xyl-(1→3)-Et-GlcA	Momordin Ic ethyl ester	*B. scoparia* (FR)	Han et al. (2006)
OA	C-3: Xyl-(1→3)-GlcA C-28: Glc	Momordin IIc	*B. scoparia* (FR)	Whang and Hahn (1991), Wen et al. (1995), Yoshikawa et al. (1997a), Han et al. (2006), Lu et al. (2012b)
OA	C-3: Xyl-(1→3)-6-Me-GlcA C-28: Glc	Momordin IIc methyl ester	*B. scoparia* (FR)	Han et al. (2006)
OA	C-3: Xyl-(1→3)-[Glc (1→2)]-β-D-GlcA C-28: Glc	2′-*O*-β-D-glucopyranosyl momordin IIc	*B. scoparia* (FR)	Wen et al. (1995), Yoshikawa et al. (1997a), Han et al. (2006), Lu et al. (2012b)
OA	C-3: Rib-(1→2)-GlcA	Oleanolic acid 3-*O*-β-D-ribopyranosyl-(1→2)-β-D-glucuronopyranoside	*B. scoparia* (FR)	Whang and Hahn (1991)
OA	C-3: Ara-(1→3)-GlcA	Momordin I	*B. scoparia* (FR)	Yoshikawa et al. (1997a)
OA	C-3: Ara (1→3)-GlcA C-28: Glc	Momordin IIa[a]	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-3: GlcA	Oleanolic acid-3-*O*-glucuronide (Calenduloside E)	*B. scoparia* (FR)	Yoshikawa et al. (1997a), Lu et al. (2012b)
OA	C-3: Glc	Oleanolic acid-3-*O*-β-glucopyranoside	*B. muricata* (WP)	Kamel et al. (2001)
OA	C-3: GlcA	Chikusetsusaponin IVa	*B. muricata* (WP)	Kamel et al. (2001)
OA	C-28: Glc		*B. indica* (AP)	Mohamed et al. (1998)
			B. scoparia (FR)	Lu et al. (2012b)
OA	C-3: Glc-(1→2)-GlcA C-28: Glc	Chikusetsusaponin V	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-3: 6‘-Me-GlcA C-28: Glc	Chikusetsusaponin IVa methyl ester	*B. muricata* (AP)	Kamel et al. (2001)
OA	C-3: Glc C-28: Glc	Oleanolic acid-3,28-β-diglucopyranoside	*B. muricata* (AP)	Kamel et al. (2001)
OA	C-3: [3-R1]-6-GlcA C-28: Glc	Betavulgaroside III[a]	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-3: [3-R2]-GlcA C-28: Glc	(2′*R*,3′*S*)-3-*O*-[2′-hydroxy-3′-(2-*O*-glycolyl)-oxo-propionic acid-β-D-glucuronopyranosyl]-28-*O*-β-D-glucopyranosyl-olean-12-en-3β-ol-28-oic acid	*B. indica* (AP)	Othman et al. (2021b)

Table 2 continued

Aglycone	Sugar part	Common name of saponin*	Species (plant part)	References
OA	C-3: [3-R2]-6-GlcA C-28: Glc	3-*O*-[2′-(2-*O*-glycolyl)-glyoxylyl-β-D-glucuronopyranosyl]-28-*O*-β-D-glucopyranosyl-olean-12-en-3β-ol-28-oic acid[a]	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-3: [3-R1]-6-GlcA	Betavulgaroside IV[a]	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-3: [Glc(1→2)]- [3-R1]-GlcA C-28: Glc	Betavulgaroside V	*B. indica* (AP)	Othman et al. (2021b)
OA	C-3: [Glc(1→2)]- [3-R1]-6-GlcA C-28: Glc	Betavulgaroside V[a]	*B. indica* (AP)	Mohamed et al. (1998)
OA	C-28: Glc	Oleanolic acid-28-*O*-β-D-glucopyranosyl ester	*B. prostrata* (WP)	Seitimova et al. (2018)
OA	C-3: sugar part (Glc)	Undef.	*B. muricata* (WP)	El-Sayed (1993)
OA	C-3: sugar part (Glc, Ara)	Undef.	*B. muricata* (WP)	El-Sayed (1993)
OA	C-3: sugar part (Glc, Ara, Rha)	Undef.	*B. muricata* (WP)	El-Sayed (1993)
HE	C-3: sugar part (nd)	Undef.	*B. muricata* (WP)	El-Sayed (1993)
22α-*hydroxyoleanolic acid*	C-3: GlcA	Kochianoside I	*B. scoparia* (FR)	Yoshikawa et al. (1997a)
C-3: Xyl-(1→3)-GlcA	Scoparianoside A	*B. scoparia* (FR)	Yoshikawa et al. (1997b)	
Morolic acid	C-3: Glc-(1→2)-Xyl (1→3)-GlcA	Kochianoside II	*B. scoparia* (FR)	Yoshikawa et al. (1997a)
	C-3: Xyl-(1→3)-GlcA	Scoparianoside B	*B. scoparia* (FR)	Yoshikawa et al. (1997b)
3β,12α-*dihydroxyolean-28,13*α-*olide*	C-3: Xyl-(1→3)-GlcA	Kochianoside III	*B. scoparia* (FR)	Yoshikawa et al. (1997a)
Betulinic acid	C-3: Xyl-(1→3)-GlcA	Kochianoside IV	*B. scoparia* (FR)	Yoshikawa et al. (1997a)
3β-hydroxyolean-13(18)-en-28-oic acid	C-3: Xyl-(1→3)-GlcA	Scoparianoside C	*B. scoparia* (FR)	Yoshikawa et al. (1997b)

*In the absence of a common name, a chemical term was used

[a] Saponins obtained by Mohamed et al. (1998) as their methyl esters after methylation using ethereal diazomethane; Undef.–undefined—the identity of the saponin cannot be determined due to the lack of a precise compound structure

OA Oleanolic acid, *HE* Hederagenin, *FR* Fruit, *AP* Aerial parts, *WP* Whole plant, *Glc* β-D-glucoopyranose, *GlcA* β-D-glucuronopyranose, *Ara* α-L-arabinopyranose, *Xyl* β-D-xylopyranose, *Rib* β-D-ribopyranose, *Et* Ethyl moiety, *Me* Methyl moiety, *R1* 2′-hydroxy-3′-(2-*O*-glycolyl)-oxo-propionic acid, *R2* 2′-(2-*O*-glycolyl)-glyoxylyl

use of ethanol extract from fresh parts of the *B. muricata* as an eco-friendly and effective inhibitor of the corrosion process of the aluminium alloy are also investigated (El-Katori and Al-Mhyawi 2019).

Phytochemistry

The phytochemical studies of representatives of the genus *Bassia* have been conducted for many years. Notwithstanding, the chemical compositions of only few species of the genus have been investigated so far. Initially, the analyses focused mainly on *B. scoparia*, but in recent years there has been an increased research interest in phytochemistry of other species of the genus. Until now, more than 300 compounds have been identified in the genus, and some of them were new compounds at the time of publication (Fig. 2). Moreover, several rarely occurring phytochemicals have been detected, including some saponins, flavonoids, steroidal glycosides, or fatty acids. Examples of compounds characteristic of the genus *Bassia* and at the same time rarely found in the plant kingdom are shown in Fig. 3.

Triterpene saponins and triterpenes

From a pharmacological point of view, triterpenoid saponins are one of the most important groups of metabolites found in *Bassia* plants. However, until now, saponins have been isolated solely from three species, *B. scoparia*, *B. indica,* and *B. muricata*. So far, phytochemical studies of *Bassia* species have led to the isolation of thirty-three different saponins, while twenty-eight of them have been fully characterized by structural studies. These saponins are listed in Table 2. Interestingly, twelve saponins were novel compounds at the time of publication (see Fig. 2).

Among saponins, structures with an oleanane skeleton dominated. Within this group, the highest number of saponins represented oleanolic acid glycosides, while compounds with rearranged double bond positions, such as morolic acid and 3β-hydroxyolean-13(18)-en-28-oic acid were less common (Fig. 4). Interestingly, lupane-type saponin was also detected, as well as a fairly rare type of 13,28-epoxyoleanane saponins. Sapogenins found in *Bassia* species are presented in Fig. 4. Almost half of *Bassia* saponins (42.4%) are bidesmosides, the remaining 57.6% are classified as monodesmosides, usually bearing a sugar chain at C-3 of sapogenin. The sugar part is composed of β-D-glucuronic acid (GlcA), β-D-xylopyranose (Xyl), β-L-arabinofuranose (Ara) and β-D-glucopyranose (Glc). It should be noted that the vast majority (81.8%) of saponins have β-D-glucuronic acid units in the sugar chain attached to C-3 of the aglycone. Among them, 34.4% can be classified as the GOTCAB group (glucuronide oleanane-type triterpenoid carboxylic acid 3, 28-*O*-bidesmosides). It is also worth mentioning that one new saponin (Fig. 2) and five rarely occurring seco-glycosidic oleanane saponins, containing acidic constituents at C-3 of glucuronic acid, have been isolated so far exclusively from the aerial parts of *B. indica* (Mohamed et al. 1998; Othman et al. 2021b).

Quantitative research on the content of saponins in *Bassia* species is limited to *Kochiae fructus*. Analysis of fruit from various regions of China using the HPLC-ELSD method showed that the saponin level ranges from 3.0 to 5.8% (Xia et al. 2002a; Wang et al. 2014a). In another study, qualitative gas–liquid chromatographic analysis (GLC) of methyl esters of triterpene sapogenins (methyl oleanolate) demonstrated that the sapogenin content ranges from 0.95 to 2.09% in a single seed of *B. scoparia*, reflecting the content of oleanolic acid-type saponins in plant material (Kernan et al. 1973).

Although various saponin compounds have been found in plants of the genus *Bassia*, the quantitative determination focused on momordin Ic, which is the main saponin of *Kochiae fructus* (Fig. 3A). Various reports indicate that momordin Ic content in plant material ranges from 0.85 to 3.5% (Xia et al. 2002a; b; Belsevich et al. 2009). According to Hong Kong Chinese Materia Medica Standards, the content of momordin Ic in *Kochiae fructus* should not be less than 2.3% (HKCMMS 2012).

In addition to qualitative studies of the plant material, which reflect the quality of the product, investigations on momordin Ic content were also carried out on various extracts of *Kochiae fructus*. It can be seen that the amount of momordin Ic in the extract varies greatly depending on the extraction method (Choi et al. 2014; Wang et al. 2014a; Yoo et al. 2017). For example, Wang et al. (2014a), using the HPLC-ELSD method, found that the momordin content in the water extract (under infusion condition for 4 h at room temperature) was 2.88%, while in the

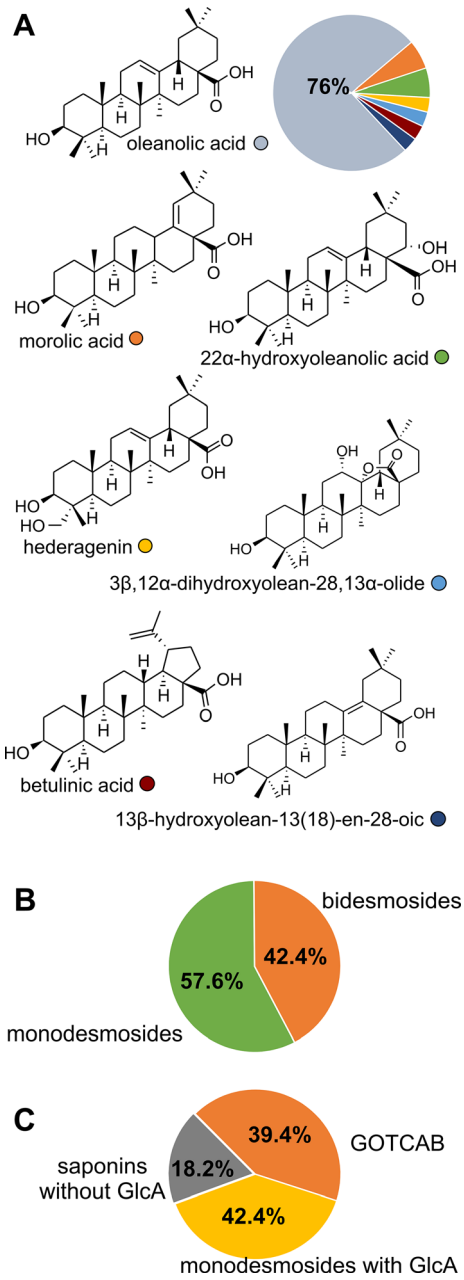

Fig. 4 Types of sapogenins and their share (%) in saponins found in the genus *Bassia* (graph A), the share (%) of *Bassia* saponins depending on amount of sugar chains (graph B), the share (%) of *Bassia* saponins with a specific sugar moiety (graph C)

50% ethanol extract prepared under reflux conditions (4 h) it reached a higher value of 5.75%.

In addition to triterpene saponins, free triterpenes have also been reported in *Bassia* plants. Various types of pentacyclic triterpenes, including oleanolic acid, gypsogenin, hederagenin (Setimova et al. 2018; Imran et al. 2017), betulin, betulinic acid and ursolic acid (Imran et al. 2017) were detected in *B. prostrata*. Oleanolic acid, (Lu et al. 2012b; Zhang et al. 2013) β-amyrin and lupeol were also found in *B. scoparia,* along with some tetracyclic triterpenes such as cycloartenol, 31-norcykloartenol and cycloeucalenol that were detected in *Kochiae fructus* (Narumi et al. 2001).

Sterols, steroidal glucosides and phytoecdysteroids

Some species of *Bassia* were analysed for the presence of sterols, and to date, more than 25 sterols have been identified in representatives of the genus (see Table 3). Reports indicate that the most abundant group of sterols were 4-desmethylsterols, but 4α-monomethylsterols were also detected (Narumi et al. 2001). In most of studied species, among 4-desmethylsterols, both Δ^5-sterols and Δ^7-sterols coexist. The exception was *B. indica* where exclusively Δ^5-sterols were found (Othman et al. 2021b; Javed et al. 2018a, b). Sitosterol and stigmasterol were the main sterol components in all species studied. GC–MS-identification of sterols revealed that fruits of *B. scoparia* were also abundant in 24-ethyllathosterol (Narumi et al. 2001). In turn, Javed et al. (2018a) underlined that γ-sitosterol was present in considerable amounts in the stem of *B. indica*. In addition to free sterols, their glycosides have also been reported in some of the *Bassia* species, including three novel kochiosides A,B,C, belonging to the class of 14α-methylated steroidal glucosides, which are rarely encountered in nature (Fig. 3B) (Imran et al. 2007). It is interesting that some structures containing the 14α-methyl group were found in sea cucumbers (Cordeiro and Djerassi 1990). To date, kochiosides have been isolated solely from *B. prostrata* (Imran et al. 2007; 2017).

Phytoecdysteroids are polyhydroxylated plant sterols that occur in several species from the *Amaranthaceae* family (Dinan et al. 1998; Das et al. 2021). In the genus *Bassia*, they were found exclusively in *B. scoparia* (Dinan et al. 1994). The species was reported to contain 20-hydroxyecdysone and polypodine B (5β,20-dihydroxyecdysone) but the level of phytoecdysteroids varied considerably

Table 3 Sterols detected in the genus *Bassia*

Species	Compound	References
B. prostrata	*Sterols:*	Imran et al. (2007, 2017), Seitimova et al. (2018)
	β-sitosterol (AP), stigmasterol (AP), spinasterol (AP)	
	Steroidal glucosides:	
	stigmasterol 3-*O*-β-D-glucopyranoside (AP), β-sitosterol 3-*O*-β-D-glucopyranoside (AP); kochioside A, kochioside B, kochioside C (WP)	
B. indica	*Sterols:*	Othman et al. (2021b), Javed et al. (2018a, b)
	β-sitosterol (AP, L, S), γ-sitosterol (S), stigmasterol (S)	
B. scoparia	*Sterols:*	Salt and Adler (1985), Narumi et al. (2001), Lu et al. (2012b), Zhang et al. (2013)
	stigmasterol (L,FR), β-sitosterol (L, FR), 24α-methylcholesterol (L), cholesterol (FR), lathosterol (FR), campesterol (FR), 24-methyllathosterol (FR), isofucosterol (FR), 24-ethyllathosterol (FR), avenasterol (FR); 31-norlanosterol (FR), lophenol (FR), obtusifoliol (FR), 4α-methylfecosterol (FR), gramisterol (FR), 4α-methyl-5α-cholest-8-en-3β-ol (FR), citrostadienol (FR)	
	Steroidal glucosides:	
	daucosterol, (L,FR);	
	Phytoecdysteroids:	Dinan et al. (1994)
	20-hydroxyecdysone (FR, R, L, S, FL)	
	polypodine B (5β,20-dihydroxyecdysone) (FR, R, F, S, FL)	
	unidentified ecdysteroid (WP)	

AP Aerial parts, *FR* Fruit, *L* Leaves, *S* Stem, *R* Root, *FL* Flos, *WP* Whole plant

between the different morphotic parts of *B. scoparia*. The radioimmunoassay using DBL-1 antiserum revealed that the highest content of ecdysteroids was found in the roots (143 µg ecdysone equivalents/g dw). Lower levels were observed in leaves, flowers, stems, and seeds (44–112, 56, 26–37 and 30 µg ecdysone equivalents/g dw, respectively) (Dinan et al. 1994).

Phenolics

Phenolics, including flavonoids and phenolic acids, are one of the most widely distributed metabolites in the plant kingdom. So far, phytochemical studies of *Bassia* species have led to the detection of nearly 60 flavonoids. Thirty-one of them were unambiguously identified following structure elucidation of isolated compounds (Lu et al. 2012b; Shaker et al. 2013; Musa et al. 2016; Kamel et al. 2001; Xu et al. 2014; Othman et al. 2021b). The identification of the remaining flavonoids was performed directly in *Bassia* plant extracts using HPLC with UV detection (Rakhmankulova et al. 2015; Xiao et al. 2018; Petruk et al. 2021) and by combination of chromatographic technique coupled with tandem mass spectrometry. Said et al. (2021) have recently evaluated the flavonoid profile in aerial parts of *B. eriophora* using LC–ESI–MS/MS in negative-ion mode, which led to tentative detection of 28 compounds (Said et al. 2021). In turn, Xiao et al. (2016) analyzed flavonoids in *B. scoparia* pollen using atmospheric solid analysis probe mass spectrometry (ASAP-MS) (Xiao et al. 2016).

As shown in Table 4 various flavonoids, including flavonols, flavones, and a flavanone, were detected in the *Bassia* genus. It is interesting to note that free sugar isoflavones have also been found, but so far only in *B. scoparia* (Zhang et al. 2013).

Most of the flavonoids identified in the *Bassia* genus are glycosidic (75%). Flavonol glycosides, including mainly derivatives of quercetin (35%), kaempferol (15%) and isorhamnetin (15%), are definitely the most abundant. It should be noted that acylated compounds account for 30% of flavonoid glycosides. Their presence was found exclusively in the aerial parts of *Bassia* species. Kamel et al. (2001)

Table 4 Flavonoids of the genus *Bassia*

Compound	Species (plant part)	References
Flavonols and dihydroflavonols:		
Quercetin	*B. scoparia* (FR)	Lu et al. (2012b)
		Xiao et al. (2018)
	B. eriophora (AP)	Musa et al. (2016)
3′-methylquercetin	*B. muricata* (AP)	Shaker et al. (2013)
Isorhamnetin	*B. scoparia* (FR)	Lu et al. (2012b)
Morin	*B. prostrata* (AP)	Rakhmankulova et al. (2015)
Fisetin	*B. prostrata* (AP)	Rakhmankulova et al. (2015)
Dihydroquercitin	*B. prostrata* (AP)	Rakhmankulova et al. (2015)
Flavones:		
Luteolin	*B. prostrata* (AP)	Petruk et al. (2021)
	B. eriophora (AP)	Musa et al. (2021)
5, 7, 4′-trihydroxy-6,3’-dimethoxyflavone	*B. scoparia* (FR)	Lu et al. (2012b)
4′,5, 7-trihydroxy-6-methoxyflavone (Hispidulin)	*B. scoparia* (FR)	Lu et al. (2012b)
Isoflavones		
Tectorigenin	*B. scoparia*	Zhang et al. (2013)
Pratensein	*B. scoparia*	Zhang et al. (2013)
Iriflogenin	*B. scoparia*	Zhang et al. (2013)
5,2′-dihydroxy-6,7-methylenedioxyisoflavone (Irisone B)	*B. scoparia*	Zhang et al. (2013)
5-hydroxy-6,7-methylenedioxyflavone (Cochliophilin A)	*B. scoparia*	Zhang et al. (2013)
Quercetin glycosides:		
Quercetin-3-*O*-galactoside	*B. scoparia* (FR)	Xu et al. (2012)
Quercetin 3-*O*-β-D-glucoside (Isoquercitrin)	*B. prostrata* (AP)	Petruk et al. (2021)
Quercetin 7-*O*-β-D-glucopyranoside	*B. scoparia*	Xu et al. (2014)
	B. eriophora (AP)	Musa et al. (2016)
Quercetin-3,7-*O*-β-diglucopyranoside	*B. muricata* (AP)	Kamel et al. (2001)
Quercetin-3-*O*-rutinoside (Rutin)	*B. scoparia* (FR)	Lu et al. (2012b)
		Wang et. al. (2018)
		Xiao et al. (2018)
	B. prostrata (AP)	Rakhmankulova et al. (2015)
	B. eriophora (AP)	Musa et al. (2021)
Quercetin-7-*O*-β-D-sophoroside	*B. scoparia* (FR)	Xu et al. (2014)
Quercetin-3-*O*-sophoroside	*B. muricata* (AP)	Kamel et al. (2001)
Quercetin-3-*O*-(6″-caffeoyl)-sophoroside	*B. muricata* (AP)	Kamel et al. (2001)
Quercetin-3-*O*-(6″-feruloyl)-sophoroside	*B. muricata* (AP)	Kamel et al. (2001)
Quercetin-3-*O*-(feruloyl)-*O*-sophoroside	*B. eriophora* (AP)	Said et al. (2021)
Quercetin-3-*O*-(sinapoyl)-sophoroside	*B. eriophora* (AP)	Said et al. (2021)
Quercetin-3-*O*-β-D-apiofuranosyl-(1→2)-β-D-galactopyranoside	*B.scoparia* (FR)	Xu et al. (2014)
Quercetin 3-*O*-β-D-galactopyranosyl-7-*O*-β-D-glucopyranoside	*B. scoparia* (FR)	Xu et al. (2014)
Quercetin 3-*O*-β-D-apiofuranosyl-(1→2)-β-D-galactopyranosyl-7-*O*-β-D-glucopyranoside	*B. scoparia* (FR)	Xu et al. (2014)

Table 4 continued

Compound	Species (plant part)	References
Quercetin 3-*O*-α-L-rhamnopyranosyl-(1→6)-β-D-galactopyranosyl-7-*O*-β-D-sophoroside	*B. scoparia* (FR)	Xu et al. (2014)
3′-methylquercetin 3-*O*-α-L-arabinopyranosyl-(1→2)-L-α-*arabinopyranoside*	*B. muricata* (AP)	Shaker et al. (2013)
Quercetin-3-*O*-sophoroside-7-*O*-hexoside	*B. eriophora* (AP)	Said et al. (2021)
Quercetin-3-*O*-sophoroside-7-*O*-dihexoside	*B. eriophora* (AP)	Said et al. (2021)
Quercetin-3,7-di-*O*-glycopyranoside	*B. eriophora* (AP)	Said et al. (2021)
Quercetin-3-*O*-(feruloyl)-*O*-trihexosides	*B. eriophora* (AP)	Said et al. (2021)
Other glycosides:		
Isorhamnetin-3-*O*-β-D-glucopyranoside	*B. scoparia* (FR)	Lu et al. (2012b)
	B. eriophora (AP)	Musa et al. (2016), Said et al. (2021)
	B. indica (AP)	Othman et al. (2021b)
Isorhamnetin-3-*O*-β-D-rutinoside	*B. prostrata* (AP)	Petruk et al. (2021)
Isorhamnetin-3-*O*-β-D-glucopyranosyl-(1→6)-*O*-[α-*L-rhamnopyranosyl-(1→2)]*-β-*D-glucopyranoside*	*B. indica* (AP)	Othman et al. (2021b)
Isorhamnetin-3-*O*-sophoroside	*B. eriophora* (AP)	Said et al. (2021)
Isorhamntin-3-*O*-(feruloyl)-sophoroside	*B. eriophora* (AP)	Said et al. (2021)
Isorhamnetin-3-*O*-(feruloyl)-*O*-hexuronide-*O*-hexoside	*B. eriophora* (AP)	Said et al. (2021)
Isorhamntin-3-*O*-sophoroside-7-*O*-hexoside	*B. eriophora* (AP)	Said et al. (2021)
Isorhamnetin-3-*O*-(feruloyl)-trihexoside	*B. eriophora* (AP)	Said et al. (2021)
Isorhamnetin-3-*O*-(feruloyl)-*O*-tetrahexoside	*B. eriophora* (AP)	Said et al. (2021)
Kaempferol-3-*O*-β-D-glucopyranoside (Populin)	*B. prostrata* (AP)	Petruk et al. (2021)
Kaempferol-3-*O*-rutinoside	*B. indica* (AP)	Othman et al. (2021b)
	B. eriophora (AP)	Musa et al. (2021)
		Said et al. (2021)
Kaempferol-3-*O*-β-d-glucopyranosyl-(1→6)-*O*-[β-D-galactopyranosyl-(1→3)-2-*O*-*trans*-feruloyl-α-*L-rhamnopyranosyl-(1→2)]*-β-*D-glucopyranoside*	*B. indica* (AP)	Othman et al. (2021b)
Kaempferol-3-*O*-dihexoside-7-*O*-dihexoside	*B. eriophora* (AP)	Said et al. (2021)
Kaempferol-3-*O*-(caffeoyl)-*O*-trihexoside	*B. eriophora* (AP)	Said et al. (2021)
Kaempferol 3-*O*-(feruloyl)-*O*-trihexoside	*B. eriophora* (AP)	Said et al. (2021)
Kaempferol-3-*O*-(caffeoyl)-sophoroside	*B. eriophora* (AP)	Said et al. (2021)
Kaempferol-7-*O*-hexoside-3-*O*-dihexosides	*B. eriophora* (AP)	Said et al. (2021)
Kaempferide-3-*O*-trihexoside	*B. eriophora* (AP)	Said et al. (2021)
Naringenin 7-*O*-neohesperidoside (Naringin)	*B. prostrata* (AP)	Rakhmankulova et al. (2015)
Acacetin-7-*O*-β-D-glucoside	*B. eriophora* (AP)	Musa et al. (2021)
Diosmetin 7-rutinoside	*B. eriophora* (AP)	Musa et al. (2021)
Apigenin 6,8-di-*C*-hexosides	*B. eriophora* (AP)	Said et al. (2021)
Apigenin 6-*C*-pentoside-8-*C*-hexoside or	*B. eriophora* (AP)	Said et al. (2021)
Apigenin 8-*C*-pentoside-6-*C*-hexoside		

FR Fruit; *AP* Aerial parts

established the structure of quercetin sophorosides that contained the feruloyl and caffeoyl moiety that were isolated from *B. muricata*. Furthermore, Said et al. (2021) detected several acylated flavonol glycosides in *B. eriophora* using the LC–ESI–MS/MS method. Recently, a novel flavonol tetraglycoside with feruloyl moiety (kaempferol-3-*O*-β-D-glucopyranosyl-(1→6)-*O*-[β-D-galactopyranosyl-(1→3)-2-*O*-*trans*-feruloyl-α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranoside) (Fig. 2) were isolated from the aqueous methanol extract of the aerial parts of *B. indica* (Othman et al. 2021b).

Although the research on flavonoids of the *Bassia* genus has been carried out intensively for several years, most quantitative studies focused on determining the total flavonoid content (TFC) or even the total phenolic content (TPC) (see Table S1, Supplementary information). Only a few reports on the quantitative determination of individual compounds have been published (Xiao et al. 2018; Rakhmankulova et al. 2015; Wang et al. 2018; Petruk et al. 2021). Wang et al (2018) measured the content of rutin (0.115 mg/g dw) in *B. scoparia* fruits by capillary electrophoresis. Rakhmankulova et al. (2015) revealed that naringin (5.03–13.53 mg/g dw) and rutin (1.71–8.13 mg/g dw) were dominant flavonoids in aerial parts of *B. prostrata*, while free-sugar flavonols, such as isorhamnetin, fisetin, and morin, were found in a lower content (0.11–0.75 mg/g dw, 0.01–0.76 mg/g dw, 0.01–0.03 dw, respectively) (Rakhmankulova et al. 2015). Petruk et al. (2021) also highlighted the high content of rutin (4.96–8.13 mg/g dw) and the presence of luteolin (0.1–3.0 mg/g), populin (0.1–6.4 mg/g), and isoquercitrin (0.1–3.4 mg/g) in the aerial parts of *B. prostrata* (Petruk et al. 2021). The authors suggest that cytotype and habitat can influence the content of flavonoids in plant species (Rakhmankulova et al. 2015; Petruk et al. 2021).

Although phenolic acids appear to be widely distributed in plants, data on their occurrence in the genus *Bassia* are limited. So far, several phenolic acids from both hydroxybenzoic and hydroxycinnamic groups have been detected only in the aerial parts of the species. Chlorogenic acid, caffeic acid, and ferulic acid were determined in shoots of *B. scoparia* (Lodhi 1979). Seitimova et al. (2016) detected protocatechuic, vanillic, isovanillic, and *p*-coumaric acids in aerial parts of *B. prostrata*. The latest report indicates that vanillic acid, *o*-hydroxybenzoic acid, *p*-hydroxybenzoic acid, caffeic acid, and methyl caffeate are present in *B. indica* (Othman et al. 2021b). Some phenolic acids may occur not as a free form, but as part of more complex structures. As mentioned above, flavonoid glycosides bearing feruloyl and caffeoyl moiety have been reported in *B. muricata*, *B. indica* and *B. eriophora* (Kamel et al. 2001; Said et al. 2021; Othman et al. 2021b). Recently, five lignanamides containing the feruloyl moiety were isolated from aerial parts of *B. indica* (Othman et al. 2021a).

Other phenolics reported in the *Bassia* genus include 6,7-dihydroxycoumarin and tachioside, which were detected in aerial parts of *B. indica* (Othman et al. 2021b).

Fatty acids

Some *Bassia* species were analysed for the presence of oil and fatty acids. The percentage content of oil in the seeds of *B. scoparia* ranges from 9.7 to 16% (Hegnauer 1964; Weber et al. 2001; Abideen et al. 2015). Due to the fact that seeds are abundant in lipids, most of the studies focused on the identification and quantification of FA in various *Bassia* seed oils (Kleiman et al. 1972; Escudero et al. 1999; Weber et al. 2001). Data on the analysis of other morphotic parts are scarce and limited to the aerial parts of *B. prostrata, B. indica,* and *B. muricata* (Seitimova et al. 2016; Imran et al. 2017; Bibi et al. 2021; Abu Ziada et al. 2015). The reports indicate that *Bassia* species are the source of saturated and unsaturated fatty acids, especially FA with chain lengths of 16 to 18 carbons. GC–MS analysis revealed that *Bassia* seed oil contained 54% to 89% linoleic acid (Kleiman et al. 1972; Escudero et al. 1999; Weber et al. 2001; Abideen et al. 2015). Significant amounts of palmitic acid (9%–68%) and oleic acid (4%–17%) were also observed (Kleiman et al. 1972; Weber et al. 2001; Abideen et al. 2015). Similarly, oleic acid (64.9%) and linoleic acid (22.0%) are reported to be the main FA in aerial parts of *B. prostrata* (Seitimova et al. 2016). It is interesting that very long-chain fatty acids (VLCFA–FA with more than 22C), have been identified in *B. scoparia seeds* and aerial parts of *B. prostrata* (Table 6) (Imran et al. 2017; Weber et al. 2001; Abideen et al. 2015). Furthermore, reports revealed

that members of the *Bassia* genus accumulate Δ^5 unsaturated fatty acids, such as 16:1Δ^5, 18:1Δ^5, 18:2$\Delta^{5,9}$, 18:3$\Delta^{5,9,12}$, 20:4$\Delta^{5,8,11,14}$ (Kleiman et al. 1972; Escudero et al. 1999; Olagbemiro et al. 1999; Whitney et al. 2004). (*Z*)-5-hexadecenoic acid (16:1Δ^5) (Fig. 3B) is an unusual monounsaturated FA that is considered a potentially useful substance in the control of the mosquito *Culex quinquefasciatus*, a vector of filariasis in humans. This is since 16:1Δ^5 can serve as an intermediate in the production of an insect oviposition pheromone (Olagbemiro et al. 1999; Whitney et al. 2004). (*Z*)-5-hexadecenoic acid was reported to constitute 12% of the seed oil of *B. prostrata* and around 5% of the oils of the seeds of *B. scoparia* as well as *B. hyssopifolia* (Kleiman et al. 1972). Fatty acids detected in *Bassia* species are listed in Table 5.

Nitrogen-containing compounds

Phytochemical analyzes conducted in the 1960s suggested that some *Bassia* species contain alkaloids. Borkowski and Drost (1965) showed the presence of four compounds in the herb of *B. scoparia* and *B. laniflora* (formerly classified as *B. arenaria*) (Borkowski and Drost 1965). *B. indica* was also reported to contain three alkaloids, which accumulate in seeds (512 mg/100 g dw), pericarp (387 mg/100 g dw), shoot (up to 294 mg/100 g dw) and roots (85 mg/100 g dw) (Zahran et al. 1982). The research carried out at that time was mainly based on the reaction of the isolated substances with Dragendorff's reagent and did not lead to the determination of the structure of alkaloids (Zahran and Wahid 1982). Only Drost-Karbowska (1978) on the basis of spectroscopic techniques (UV, MS, NMR) showed that compounds found in aerial parts of *B. scoparia* are harman and harmine, belonging to the indole alkaloids with β-carboline skeleton (Drost-Karbowska et al. 1978). It is interesting that the most recent studies revealed the presence of a novel alkaloid named bassiamide A (*N*-[(3-(3-methyl-1-oxo-butyl)amino)propyl]-3-(3,4-dihydroxyphenyl)prop-2-enamide in aerial parts of *B. indica* (Fig. 2) (Othman et al. 2021a).

Other constituents reported in the *Bassia* genus include lignanamides. The presence of *N-trans*-feruloylmethoxytyramine and *N-trans*-feruloyltyramine were investigated in *B. scoparia* (Zhang et al. 2013) and *B. indica* (Othman et al. 2021a, 2022). *N-trans*-feruloyltyramine derivative was also tentatively detected by LC–ESI–MS/MS in *B. eriophora* (Said et al. 2021). Recently, several lignanamides including *S*-(-)-*N-trans*-feruloyl nor-metanephrine, *S*-(-)-*N-trans*-feruloyl octopamine, and rarely occurring *R*-(+)-*N-trans*-feruloyl octopamine were isolated from aerial parts of *B. indica* (Fig. 3B) (Othman et al. 2021a, 2022).

Species of *Bassia* genus have been reported to contain proteins and multiple amino acids, and several studies have considered their potential nutritional and feeding value (Davis 1979; Riasi et al. 2008; Waldron et al. 2006, 2020; Seitimova et al. 2016; Houlihan et al. 2019; Nair et al. 2021). For example, Waldron et al. (2006) showed that the crude protein content in *B. prostrata* ranges from 44.6 to 116.5 g/kg of aerial parts. A similarly high protein content was found in aerial parts of *B. scoparia* (117 g/kg) (Riasi et al. 2008). El-Adawy et al. (2020) reported a crude protein concentration in aerial parts of *B. indica* at 12.6%. Some reports underlined that protein content depended on the maturity stage of the plant (Knipfel et al. 1989; Waldron et al. 2006; Nair et al. 2021). Differences in protein level were also observed between various parts of the plant. Seeds, leaves, and stems of *B. prostrata* were reported to contain 190.6 g, 123.2 g and 55.1 g of protein per kg, respectively (Waldron et al. 2006). Waldron et al. (2020) also observed that protein levels decrease with increasing salinity in the soil (Waldron et al. 2020). Seitimova et al. (2016) revealed that the main amino acids in aerial parts of *B. prostrata* were glutamic acid (23.46%), alanine (5.82%), proline (3.35%), arginine (3.32), leucine (3.20%) and isoleucine (3.03%) (Seitimova et al. 2016). Houlihan et al. (2019) identified 18 amino acids in water-soluble exudates from *B. scoparia seeds* with tyrosine and glutamic acid as predominant compounds. It should be noted that some of the *Bassia* (Kochia) biotypes are resistant to sulfonylurea herbicides (ALS-inhibiting herbicides) (Kumar et al. 2019). Because the acetolactate synthase enzyme (ALS) is the key step in the biosynthesis of branched chain amino acids, some differences in the valine and leucine content were observed between biotypes resistant and susceptible to herbicides. The level of free valine and leucine was elevated in seeds and aerial parts of the resistant *Bassia* biotype compared to susceptible plants (Dyer et al. 1993; Chodová and Mikulka 2000).

Table 5 Fatty acids in *Bassia* sp

Fatty acid		Species						
		B. scoparia	*B. prostrata*		*B. indica*		*B. muricata*	*B. hyssopifolia*
Abb	Trivial name	FR/SE	SE	AP	SE	AP	AP	SE
11:0	Undecylic						$+^{z}$	
12:0	Lauric acid						$+^{z}$	
14:0	Myristic acid			$+^{s,i}$			$+^{z}$	
15:0	Pentadecanoic acid			$+^{s}$			$+^{z}$	
16:0	Palmitic acid	$++^{k,w,e,an}$	$+^{k}$	$++^{s}$	$+++^{j,b}$	$+^{a}$	$+^{z}$	$++^{k}$
16:1Δ^{5}	(*Z*)-5-hexadecenoic acid	$++^{k,o,}$	$++^{k}$	$+*^{s}$				$+^{k}$
16:1Δ^{9}	Palmitoleic acid	$+^{k,}$	$\pm^{k}$					$+^{k}$
17:0	Margaric acid	$+^{w}$						
18:0	Stearic acid	$++^{k,l,w,an}$	$+^{k}$	$+^{s}$	$+^{b}$	$+^{a}$		$+^{k}$
18:1Δ^{5}		$+^{k,}$	$+^{k}$					$+^{k}$
18:1Δ^{9}	Oleic acid	$++^{k,e}$	$++^{k}$	$+++^{s}$	$+^{b}$	$+^{a}$	$+^{z}$	$++^{k}$
18:2Δ^{5,9}		$+^{k}$	$\pm^{k}$					$+^{k}$
18:2Δ^{9,12}	Linoleic acid	$+++^{k,e,an}$	$+++^{k}$	$++^{s}$	$+^{j}$	$+^{a}$	$+^{z}$	$+++^{k}$
18:3Δ^{5,9,12}		$+^{k}$	$+^{k}$	$+*^{s}$				$+^{k}$
18:3 Δ^{9,12,15}	α-linolenic acid	$+^{k,e}$	$+^{k}$				$+^{z}$	$+^{k}$
20:0	arachidic acid	$+^{w,an}$				$+^{a}$		
20:1Δ^{11}	11-eicosenoic acid	$+^{w,\ an}$						
20:4Δ^{5,8,11,14}	Arachidonic acid	$+^{e}$				$+^{a}$	$+^{z}$	
22:0	Bohenic acid	$+^{w,\ an}$						
22:1Δ^{13}	13-docosenoic acid	$+^{w,\ an}$						
24:0	Lignoceric acid	$+^{w}$		$+^{i}$			$+^{z}$	
24:1Δ^{15}	15-tetracosenoic acid	$+^{w,\ an}$						
26:0	Cerotic acid	$+^{w,\ an}$						
28:0	Montanic acid			$+^{i}$				
32:0	Lacceroic acid			$+^{i}$				

FA Fatty acid;+ + +dominant FA;+ +main (relevant) FA;+present FA;±traces of FA;+* the location of the double bonds have not been determined; *a* Abeer et al. (2015); *z* Abu Ziada et al. (2015), *an* Abideen et al. (2015); *b* Bibi et al. (2021); *e* Escudero et al. (1999); *i* Imran et al. (2017); *j* Javed et al. (2018a); *k* Kleiman et al. (1972); *l* Lu et al. (2012b); *o* Olagbemiro et al. (1999); *s* Seitimova et al. (2016); *w* Weber et al. (2001)

Furthermore, the concentration of these amino acids decreased in the susceptible *Bassia* population after herbicide treatment (Chodová and Mikulka 2000).

It is well known that plants of the *Amaranthaceae* family can accumulate nitrates (Salehi et al. 2019; Liubertas et al.2020; Munekata et al. 2021). Several works have been devoted to quantification of nitrates in *Bassia* species, especially in *B. scoparia* (Finley and Sherrod 1971; Steppuhn et al. 1994; Escudero et al. 1999; López-Aguilar et al. 2013). The studies revealed that the content of nitrates in the aerial parts of *B. scoparia* decreases during the growing season (Finley and Sherrod 1971; López-Aguilar et al. 2013). Steppuhn et al. (1994) also observed that the amount of nitrates can increase from 0.01 to 0.04 g/kg to 0.5 g/kg after the addition of nitrogen fertilizer. Among other members of the *Bassia* genus, nitrates were detected also in *B. hyssopifolia* but only in traces (James et al. 1976). It is interesting that the accumulation of nitrates was not observed in *B. prostrata,* which is a perennial plant (Waldron et al. 2010; Acar et al. 2016).

Other compounds

Representatives of the genus *Bassia* can also accumulate organic acids. Among carboxylic acids, oxalic acid was the most common compound. Other compounds such as tartaric acid, malic acids, citric acid, succinic acid, lactic acid, acetic acid, formic acid, and L-ascorbic acid were also detected (Hong et al. 2006; Ma et al. 2011, 2016; López-Aguilar et al. 2013).

A low glycolic acid content was found in the root of *B. scoparia* (Ma et al. 2011). Gluconic acid, citric acid, and oxalic acid were the major organic acids detected in the water-soluble exudates from the seeds of the species. Other acids identified in small amounts in seed exudates included: threonic acid, malic acid, malonic acid, glucaric acid, fumaric acid, lactic acid, ribonic acid, galacturonic acid, 2-ketogluconic acid, glucuronic acid and glucuronic acid 1,5-lactone (Houlihan et al. 2019).

It is noteworthy that the level of carboxylic acids varies between the species, its morphotic parts, and maturity stage and depends on environmental factors. *B. prostrata* is considered a species with a low level of oxalic acid accumulation. The content of oxalates in aerial parts of the species averaged 1.2% (Davis 1979). In turn, studies on organic acid content in aerial parts of *B. scoparia* provide diverse data, which may result from differences in habitat conditions of the analyzed plants. *B. scoparia* is an alkali resistant forage plant and is able to survive in extremely unfavourable environments with a pH greater than 10. Several studies indicate that the accumulation of organic acids in the aboveground parts is probably the way to adapt to ecological conditions (Yang et al. 2007; Ma et al. 2011, 2016). The oxalate concentration in *B. scoparia* shoots (1.4–2.6% of dry weight) can be defined as moderate (Cohen et al. 1989; López-Aguilar et al. 2013). In other studies, the oxalic acid content was much higher and was estimated to be in the range of 12%–17.8% of the dry weight of aerial parts (Yang et al. 2007; Ma et al. 2011, 2016).

Hong et al. (2006) revealed that the roots of *B. scoparia* accumulate higher amounts of oxalic acid (26.76 µmol/g) than the shoots (4.305 µmol/g). A similar relationship was found for other acids, such as malic acid (6.60 µmol/g roots; 1.93 µmol/g shoots), tartaric acid (15.04 µmol/g roots; 1.29 µmol/g shoots) and succinic acid (4.70 µmol/g roots; 2.03 µmol/g shoots) (Hong et al. 2006). It is interesting that, in contrast to control conditions, the concentrations of oxalic acid, succinic acid, malic acid, and tartaric acid were higher in shoots (71.99 µmol/g, 66.73 µmol/g, 45.99 µmol/g, 44.60 µmol/g, respectively) under alkaline stress than in roots of the plant (67.39 µmol/g, 64.0 µmol/g, 26.89 µmol/g, 40.99 µmol/g, respectively) (Hong et al. 2006). Contrary to research reported by Hong et al. (2006), Ma et al. (2011) observed that under control conditions mature leaves contain the highest amount of oxalic acid (8% dry weight), followed by young leaves, old stem, and roots (1% of dry weight), while under salt and alkali stress, the concentration of oxalic acids in mature leaves reached 10% and 12% of their weight, respectively (Ma et al. 2011).

Although members of the *Bassia* genus are not considered aromatic plants, several studies indicate that some of them can produce essential oils (El-Shamy et al. 2012; Kianinodeh et al. 2017; Abd-ElGawad et al. 2020). Recently, thirty-four compounds were identified by the GC–MS method in the essential oil of the aerial parts of *B. muricata*. The study revealed that the essential oil is rich in terpenes, including sesquiterpenes, oxygenated monoterpenes and diterpenes, which constitute 58.21%, 9.77%, and 1.19% of the oil, respectively. Aromatic compounds (21.92%) and hydrocarbons (8.91%) were also detected. Hexahydrofarnesyl acetone (47.34%) was the main compound of the essential oil of *B. muricata*, followed by 6-methoxy-1-acetonaphthone (19.92%), *n*-dotriacontane (3.58%) and endo-borneol (3.24%) and methyl-ionone (3.04%). The other volatile compounds constituted less than 3% of the essential oil (Abd-ElGawad et al. 2020). Thirty-one volatile components were also identified in essential oil from shoots of *B. scoparia* growing in Egypt. GC–MS analysis revealed that terpenes represented the dominant class of compounds (58.54%), but aliphatic and aromatic hydrocarbons were also present (29.18%). The main compounds were α-thujaplicin (22.91%), phytone (8.66%), dictamnol (7.98%), butylated hydroxytoluene (7.49%), phytol (6.57%) and camphenolone (3.84%) (El-Shamy et al. 2012). Kianinodeh et al. (2017) observed a similar qualitative composition of the essential oil of *B. scoparia*. However, the essential oil obtained from the fruits of the plant that grows in Iran differed in its quantitative composition because it contained alkanes (*n*-

Table 6 Anti-inflammatory activity of extracts and isolated substances of *Bassia* sp

Species; extract	Tested doses; Administration	Model or assay	Effect	References
B. scoparia 70% ethanol extract from fruits	50, 200, 500 mg/kg; p.o	Acetic acid- induced vascular permeability in ddY mice positive control: indomethacin (10 mg/kg; p.o.)	(-) ↑ of vascular permeability induced by acetic acid (effect at 200, 500 mg/kg comparable to positive control)	Matsuda et al. (1997a)
		Carrageenan-induced paw edema in Male Wistar rats positive control: indomethacin (10 mg/kg; p.o.)	Prevention ↑ of paw edema (at 200, 500 mg/kg–significant effect)	
		Compound 40/80 induced edema in ddY mice positive control: diphenhydramine (50 mg/kg; po)	Prevention ↑ of paw edema (at 500 mg/kg–weak effect)	
		Histamine/serotonin/bradykinin -induced edema in ddY mice positive control: diphenhydramine (50 mg/kg; po)	Prevention ↑ of paw edema induced by histamine (significant effect) and serotonin or bradykinin (weak effect)	
		Arachidonic acid-induced ear swelling in ddY mice positive control: phenidone 20 mg/kg (i.v.)	Prevention ↑ of paw edema (dose-dependent, significant effect, at 500 mg/kg comparable to positive control)	
	10—300 μg/mL	Histamine-induced contraction in isolated guinea pig ileum (ex vivo)	(-) of contraction of isolated ileum with IC_{50} value of 220 μg/mL	
	10—300 μg/mL	Prekallikrein enzyme activity assay (in vitro)	Not active in concentration 100—500 μg/mL	
B. scoparia aqueous infusion of seeds	*ad libidum*; p.o	Carrageenan-induced paw edema in an experimental model of metabolic syndrome in male Wistar rats	Prevention ↑ of paw edema (short-lived effect)	Abtulov et al. (2020)
B. scoparia methanol extract, fractionated:→ chloroform extract, ethyl acetate extract, butanol extract,	150, 250 mg/kg; p.o	Carrageenan-induced paw edema Sprague–Dawley male rats positive control: indomethacin (100 mg/kg; p.o.)	Prevention ↑ of paw edema	Choi et al. (2002)
		Freud's complete adjuvant-induced arthritis in Sprague–Dawley male rats positive control: methotrexate (10 mg/kg; i.p.)	Anti-edema effect (exception: chloroform fraction – not active)	
B. scoparia 1% water extract from fructus	Topical application	2,4-dinitrochlorobenzene (DNCB)-induced contact dermatitis in female BALB/mouse model; Histopathological analysis, Western blot analysis	↓ hyperplasia of dermis and epidermis vs. DNCB group; Extract ↓ contact dermatitis (via inhibition of the production of inflammatory mediators)	Choi et al. (2014)
B. scoparia methanol extracts from fruit	30, 100 or 300 μg/ear	1-fluoro-2,4-dinitrofluorobenzene (DNFB)-induced contact dermatitis mice in BALB/mouse model; Histopathological analysis positive control: dexamethasone (75 μg/ear)	Prevents histopathological changes; ↓ ear swelling;↓ production of IL-6, IFN-γ; at 300 μg/ear effect similar to dexamethasone	Jo et al. (2016)

Table 6 continued

Species; extract	Tested doses; Administration	Model or assay	Effect	References
B. scoparia ethanol extract from fruits	100, 200 mg/kg; (*p.o.*)	OVA induced mouse asthma model; biochemical assay—ELISA	↓ levels of IL-4 and IL-5 in a dose-dependent manner	Lee et al. (2011)
B. scoparia methanol extract from fruits	7.5, 13, 30 μg/mL	LPS-induced raw 264.7 cells in vitro	(-) of NO production; ↓ PGE_2 and TNF-α release (via blocking NF-kB activation)	Shin et al. (2004)
B. scoparia water extract from fruits		Serine proteases inhibitory assay in vitro*;* positive control: elaspol; CG inhibitor	Cathepsin G (CG) (-): $IC_{50} > 300$ μg/mL*;* CG inhibitor*:* IC_{50}=0.29 μM proteinase 3 (-): $IC_{50} > 300$ μg/mL elaspol: IC_{50}=0.63 μM	Chen et al. (2017)
		Human neutrophil elastase (HNE) inhibition assay positive control: elaspol	Selective inhibitory activity: IC_{50}=79.53 μg/mL elaspol: IC_{50}=0.04 μM	
B. scoparia 70% ethanol extract from fruits	50, 200, 500 mg/kg; p.o	Type I allergic model: - forty-eight-h homologus Passive Cutaneous Anaphylaxis (PCA) in Wistar rats positive control: DSCG (5 mg/kg, i.v.) one and a half-h heterologous PCA in ddY mice; prednisolone (20 mg/kg; p.o)	at 200, 500 mg/kg: significant ↓ of dye leakage caused by PCA	Matsuda et al. (1997b)
		Type II allergic model: - reversed cutaneous anaphylaxis (RCA) in JW rabbits; positive control: dexamethasone (10 mg/kg)	Not active	
		Type III allergic model: - direct passive arthrus reaction (DPAR) in JW rabbits positive control: prednisolone (25 mg/kg; p.o.)	At 500 mg/kg: ↓ of paw swelling	
		Type IV allergic model: - sheep red blood cell- induced delayed hypersensivity in ICR mice (SRBC-DTH model) positive control: prednisolone (10 mg/kg; p.o.) - picryl chloride-induced contact dermatitis in ICR mice (PC-DT model) positive control: prednisolone (20 mg/kg; p.o.)	At 500 mg/kg: ↓ of paw swelling (SRBC-DTH model) and ear swelling (PC-DT model)	

Table 6 continued

Species; extract	Tested doses; Administration	Model or assay	Effect	References
B. scoparia 70% ethanol extract from fruits	200, 500 mg/kg; p.o	Compound 48/80-induced pruritogenic model in male ddY mice positive control: diphenhydramine (50 mg/kg; p.o.)	(-) of scratching behaviour by 50% vs. control group positive control: inhibition by 74—90%	Kubo et al. (1997)
B. scoparia water extract	0.15 g/mL, 0.3 g/mL, 0.6 g/mL; topical application	Itching guinea pig model caused by histamine; Itching mice model	(-) of scratching behaviour	Zou et al. (2021)
B. eriophora ethanol extract from aerial parts	250, 500, 750 mg/kg; (i.p.)	Carrageenan-induced paw edema in Male Wistar rats control: diclophenac 10 mg/mL; i.p	Prevention ↑ of paw edema; significant ↓ of the edema thickness (1.92±0.067, 1.69±0.112 and 1.58±0.096, respectively) compared to carrageenan injected group with value of 2.404±0.14	Musa et al. (2016)
Fractions and compounds from Bassia species:				
Polysaccharide fraction isolated from water extract from *Kochiae fructus* (molecular weight > 300 kDa)	125, 250 mg/kg; (through gavage)	LPS-induced ALI model in male ICR mice (post tests: measurement of MPO activity; neutrophil tissue elastase activity in tissue; protein and pro-inflammatory cytokines in BALF; quantification of NET-DNA) positive control: dexamethasone (10 mg/kg; i.p.)	Protective activity against acute lung injury (ALI); ↓ levels of TNF-α and IL-6 ↓ MPO activity ↓ neutrophil infiltration ↓ HNE activity: IC_{50}=3. 74 μg/mL ↓ NET-DNA formation	Chen et al. (2017)
		Serine proteases inhibitory assay in vitro; positive control: elaspol; CG inhibitor	Cathepsin G (CG) (-): IC_{50} > 300 μg/mL; CG inhibitor: IC_{50}=0.29 μM proteinase 3 (-): IC_{50} > 300 μg/mL elaspol: IC_{50}=0.63 μM	
		Human neutrophil elastase (HNE) inhibition assay positive control: elaspol	Selective inhibitory activity: IC_{50}=79.53 μg/mL elaspol: IC_{50}=0.04 μM	
Flavonoid fraction isolated from 80% ethanol extract of *Kochiae fructus*	100, 200 mg/kg Topical application (2x/24 h)	2,4-dinitrochlorobenzene- (DNCB)-induced ACD Sprague–Dawley rats; Histopathological analysis; biochemical assay—ELISA; Western blot; paraffin section immunohistochemical method positive control: prednisolone acetate (2.5 mg/kg)	↓ ear swelling (no significant differences vs. positive control group; significant effect) ↓ levels TNF-α and IL-6, IL-18, INF-γ ↑ levels of IL-10 ↓ levels of $pERK_{1/2}$, TLR4, NFκB	Xiao et al. (2018)

Table 6 continued

Species; extract	Tested doses; Administration	Model or assay	Effect	References
Momordin Ic oleanolic acid (OA) 20-hydroxyecdysone	6.25, 12.5, 25 μg/mL	LPS-induced raw 264.7 cells in vitro	Momordin Ic: ↓ production of TNF-α, IL-6, PGE_2; OA, 20-hydroxyecdysone -not active	Yoo et al. (2017)
Momordin Ic oleanolic acid (OA)	5, 10 mg/kg; i.p	Freund's adjuvant-induced arthritis in Sprague–Dawley male rats positive control: aminopyrine (100 mg/kg; p.o.)	Anti-edema effect	Choi et al. (2002)
Momordin Ic	20, 50, 100 mg/kg; p.o	Type I allergic model: - forty-eight-h homologus Passive Cutaneous Anaphylaxis (PCA) in Wistar rats positive control: DSCG (5 mg/kg, i.v.)	Significant ↓ of dye leakage caused by PCA	Matsuda et al. (1997b)
		- one and a half-h heterologous PCA in ddY mice; prednisolone (20 mg/kg; p.o.)	Significant ↓ of dye leakage caused by PCA (at 100 mg/kg effect comparable to positive control)	
		Type IV allergic model: - picryl chloride-induced contact dermatitis in ICR mice (PC-DT model) positive control: prednisolone (20 mg/kg; p.o.)	At 50, 100 mg/kg: ↓ of ear swelling	
	Momordin 20,50 100 mg/kg; p.o	Carrageenan-induced paw edema in Male Wistar rats positive control: indomethacin (10 mg/kg; p.o.)	Prevention ↑ of paw edema (significant effect); at 50 and 100 mg/kg, after 1 h, the effect comparable to positive control	Matsuda et al. (1997a)
	20, 50,100 mg/kg; p.o	Compound 48/80-induced pruritogenic model in male ddY mice positive control: diphenhydramine (50 mg/kg; p.o.)	At 50 mg/kg (-) of scratching behaviour by 50% vs. control group	Kubo et al. (1997)

(–) inhibition; ↑ the increase; ↓ reduction/descrease; *ALI* Acute lung injury; *CG* Cathepsin; *DNCB* 2,4-dinitrochlorobenzene; *DNFB* 1-fluoro-2,4,-dinitrofluorobenzene; *DPAR* Direct passive arthus reaction; *DSCG* sodium cromoglicate; *ELISA* Enzyme-linked immunosorbent assay; *ERK* Extracellular-signal-regulated kinase; *HNE* Human neutrophil elastase; *i.v.* Intravenous; *IL-10* Interleukin-10; *IL-4* Interleukin-4; *IL-5* Interleukin-5; *IL-6* Interleukin-6; *INF-γ* Interferon-gamma; *MPO* Myeloperoxidase; *NET-DNA* Net-like structures of nuclear DNA; *NF-κB* Nuclear factor kappa B; *p.o.* Per os; *PCA* Passive cutaneous anaphylaxis; *PCA* Passive cutaneous anaphylaxis; *PGE_2* Prostaglandin; *RCA* Reversed cutaneous anaphylaxis; *TLR* Toll-like receptor; *TNF-α* Tumor necrosis factor α

tetracosane, *n*-tricosane, *n*-docosane, *n*-henicosane, *n*-eicosane) as the main constituents (Kianinodeh et al. 2017). Hydrocarbons such as heptacosane, pentacosane, hexacosane, tetracosane, tricosane, and 9-tricosene were also detected in aerial parts of *B. indica*. In addition, phytol, verbenone, heptanone, p-methoxy acetophenone, phenyl benzene, 2-pentanoyl thiophene and β-ionone were identified as the main volatile compounds (Abou Zeid and El-Khayat 2000).

Recently, the polysaccharide rich fraction (KSWP), consisting of carbohydrates (81.82%), uronic acid (6.63%), and protein (8.71%), was isolated from the water extract of the *B. scoparia* fruit. HPLC analysis revealed that among the monosaccharides in KSWP mannose, rhamnose, glucuronic acid, glucose, galactose, and arabinose were present. Glucose was found to be the predominant sugar in the polysaccharide fraction (Chen et al. 2017). In turn, Houlihan et al. (2019) detected free monosaccharides in water-soluble exudates from seeds of *B. scoparia*. Among them, fructose, galactose, glucose, and sorbitol were the main compounds. Other sugars, identified in a low amount, included: trehalose, *scyllo*-inositol, sucrose, mannitol, mannose, rhamnose, melibiose, maltitol, ribitol, xylulose, erythritol, and glucosamine (Houlihan et al. 2019).

Other constituents reported in the *Bassia* genus include macroelements (Na, K, Mg, Ca, P) and microelements (Fe, Cu, Se). These plant species are able to accumulate ions, but the amount depends on various factors, such as soil composition or environmental contamination (Karimi et al. 2005; Yang et al. 2007; Riasi et al. 2008; Ma et al. 2011; Endo et al. 2014; Yamada et al. 2016). Environmental factors, such as salinity and cadmium stress, also affected the content of carotenoids in the *Bassia* genus. Seasonal variations in the level of carotenoids were also observed (Davis 1979). The published reports indicate that the carotenoids content ranged from 0.13 to1.06 mg/g of fresh aerial parts of the analysed species: *B. scoparia*, *B. prostrata,* and *B. indica* (Karimi et al. 2005; Abeer et al. 2015; Hashem et al. 2019; Ghaffarian et al. 2020).

In addition to the phytoconstituents mentioned above, syringaresinol, a compound of the lignan group, was recently isolated from aerial parts of *B. indica* (Othman et al. 2021a).

Biological activity

The biological activity studies conducted on the representatives of the genus *Bassia* focused on several plant species, including *B. scoparia*, *B. eriophora*, *B. muricata*, *B. indica,* and *B. prostrata*. It is interesting that most of the studies on *B. scoparia* were carried out on fruits or seeds of the plant, while the investigations of the other species were mainly focused on the other aerial parts. The various activities of extracts of *Bassia* species were evaluated, including anti-inflammatory, cytotoxic, hypoglycemic, antioxidant, antimicrobic and tissue-protective potential. However, it should be mentioned that published data on anti-inflammatory hypoglycemic and anti-obesity activity were limited almost completely to *Kochiae fructus*.

It should be noted that not only in vitro tests, but also in vivo studies were conducted. Additionally, in several investigations, an attempt was made to determine which components are responsible for the observed activity of the extract.

Anti-inflammatory activity

The dried fruit of *Bassia scoparia* is commonly used in traditional Chinese medicine (TCM) as an anti-inflammatory agent, especially in skin disorders (Chien et al. 2013; Chen et al. 2015, 2016; Weng et al. 2016). The anti-inflammatory activity of *Kochiae fructus* has been well documented in both in vitro studies and in various animal models (see Table 6). In most of the studies, acute inflammation models were performed, including those of edema. Due to the fact that skin inflammation often manifests itself by itching, antipruritic activity was also investigated. The water and ethanol extracts of *Kochiae fructus* were found to demonstrate the ability to inhibit scratching behavior in animal models (see Table 6). It should be noted that the extracts demonstrated their anti-inflammatory activity in vivo after oral administration and external application.

The effect of *Kochiae fructus* on various types of hypersensitivity was also investigated in animal models (see Table 6). It was found that 70% extract exhibited inhibitory activity in models of I, III and IV-type of allergy (Matsuda et al. 1997b). The activity of extracts in contact allergic dermatitis,

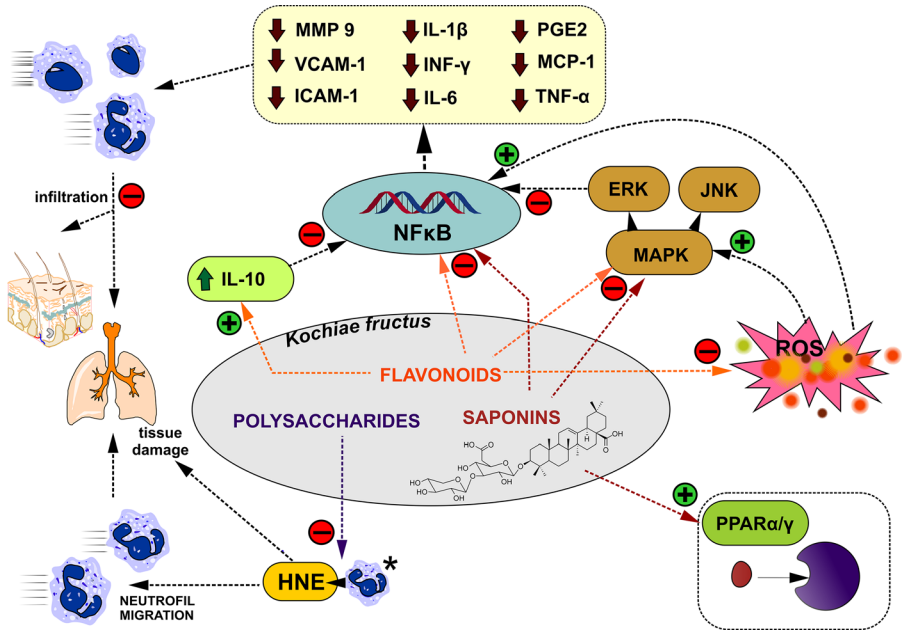

Fig. 5 The main pathways involved in the anti-inflammatory activity of extracts and compounds from *Kochiae fructus.* Abbreviations: ERK extracellular signal-regulated kinase; HNE human neutrophil elastase; ICAM-1 intercellular adhesion molecule-1; IL-1β interleukin-1β; IL-6 interleukin-6; IL-10 interleukin-10; INF-γ interferon-gamma; JNK c-Jun N-terminal kinases; MAPK mitogen-activated protein kinases; MCP-1 monocyte chemotactic protein-1;MMP-9 matrix metalloproteinase-9; NFκB nuclear factor kappa B;PGE_2 prostaglandin E; PPAR peroxisome proliferator-activated receptors; ROS reactive oxygen species; TNF-α tumor necrosis factor α; VCAM-1 vascular cell adhesion molecule-1

which can be classified as type IV hypersensitivity, has been one of the most intensively studied. External application of methanol or water extracts significantly inhibited inflammation in animal contact dermatitis models (Choi et al. 2014; Jo et al. 2016). Choi et al. (2014), revealed that 1% water extract significantly reduced hyperplasia and thickening of the dermis and epidermis (by 35.6% and 39.2%, respectively) of mice in DNCB-induced dermatitis model compared to the animal group without treatment. Furthermore, histological examination by Jo et al. (2016), demonstrated that repeated topical application of methanol extract inhibited epidermal acanthosis, spongiosis and immune cell infiltration (Jo et al. 2016) in mice with DNFB-induced contact dermatitis model. The observed anti-inflammatory effect as inhibition of ear swelling was comparable to dexamethasone (Jo et al. 2016).

Matsuda (1997b) observed that, in addition to antiallergic activity in type IV hypersensitivity, *Kochiae fructus* also influenced direct passive arthus reaction (DPAR) in rats, which is a type III allergic model. In another study, Choi et al (2002) demonstrated the potential of methanol extract in Freund's complete adjuvant-induced arthritis in Sprague–Dawley rats (Choi et al. 2002).

In addition, *B. scoparia* extracts also showed antiallergic potential in IgE-mediated hypersensitivity (type I). This type of allergy is associated with eczema and asthma (Matsuda et al. 1997b; Lee et al. 2011). Ethanol extracts from fruits reduced the level of interleukins (IL-4, IL-5) and the migration of inflammatory cells into the lungs in the OVA-induced asthma model in BALB/c mice. The effect may be the result of inhibition of matrix metalloproteinase-9 (MMP-9) inhibition and reduction in the expression of adhesive molecules (VCAM-1 and ICAM-1) in lung tissue (Lee et al. 2011).

The published research postulates that *Kochiae fructus* extracts exerted anti-inflammatory effects by influencing various factors involved in the inflammatory response. *Kochiae fructus* methanol extract

decreased the level of INF-γ, TNFα, IL-1β and MCP-1 in the mouse model with DNCB-induced contact dermatitis (Jo et al. 2016). The methanolic extract was also observed to be a potent inhibitor of LPS-induced TNF-α, NO and PGE_2 production in LPS-induced RAW cells 264.7 in vitro. The effect was associated with LPS-induced iNOS and COX-2 gene expression by blocking nuclear factor kappa beta (NFκB) activation (Shin et al. 2004). Furthermore, Choi et al. (2014) point out that the anti-inflammatory activity of *B. scoparia* can be regulated via NFκB and MAP kinase pathways, such as ERK1/2, p38 and JNK (Choi et al. 2014). Furthermore, recently, *Kochiae fructus* was found to exert peroxisome proliferator activated receptors (PPAR) α/γ dual agonistic activity, which can alleviate the inflammation process (Jeon et al. 2016). Furthermore, the water extract showed the ability to inhibit human neutrophil elastase (HNE) (IC_{50}=79.53 μg/mL), the hydrolytic enzyme that can cause damage to elastase-rich tissue, and also promote inflammatory cell migration (Chen et al. 2017).

The search for active compounds revealed that various phytochemicals of *Kochiae fructus* could be associated with an anti-inflammatory effect. Several studies indicated that activity is related to saponins, mainly momordin Ic (Fig. 3B) (Matsuda et al. 1997a, b). This monodesmosidic saponin suppressed the production of pro-inflammatory cytokines, including TNF-α, IL-6 as well as PGE_2 in RAW 264.7 cells stimulated with LPS (Yoo et al. 2017). Furthermore, the anti-inflammatory, antiarthritic, and antiallergic potential of the compound was demonstrated in several animal models as well (see Table 6) (Kubo et al. 1997; Matsuda et al. 1997a, b). Furthermore, the antipruritic effect of *Kochiae fructus* was also attributed to saponins. However, it should be noted that the structure of a particular saponin affected the observed activity. Monodesmosides such as momordin Ic and oleanolic acid 3-*O*-glucuronide were observed to alleviate scratching behavior, while bidesmosides such as momordin IIc (Fig. 2) were almost ineffective against itching induced using compound 48/80 (Kubo et al. 1997; Matsuda et al. 1998a). However, Xiao et al. (2018) underlined that anti-inflammatory activity is related to the flavonoid fraction which was demonstrated using an animal model of DNCB-induced contact dermatitis. The flavonoid fraction, isolated from *Kochiae fructus*, containing rutin (24 mg/g) and quercetin (18 mg/g), after topical application, was found to reduce the level of pro-inflammatory cytokines and simultaneously increase the level of anti-inflammatory interleukin IL-10. Additionally, a significant decrease in tissue monocyte infiltration was observed. These effects could be the result of NFκB suppression via the ERK/TLR4 pathway. It should be mentioned that the flavonoid fraction exerted an effect comparable to a positive control (prednisolone acetate; 2.5 mg/kg) (Xiao et al. 2018).

In turn, Chen et al. (2017) with the use of bioactivity-guided fractionation revealed that the effect of the water extract of *Kochiae fructus* should be attributed to the polysaccharide fraction. It significantly reduced the activity of human neutrophil elastase with an IC_{50} value of 3.74 μg/mL. Furthermore, the polysaccharide rich fraction was also active in the LPS–induced acute lung injury model in mice (Chen et al. 2017).

Summarizing the current state of art, the postulated main pathways involved in the anti-inflammatory activity of the extracts and compounds from *Kochiae fructus* are presented in Fig. 5.

To our knowledge, in addition to anti-inflammatory investigations on *B. scoparia*, there is only one report devoted to another species of *Bassia*. Musa et al. 2016, demonstrated that the ethanol extract of aerial parts of *B. eriophora* (250, 500 and 750 mg/kg; i.p.) possessed the ability to inhibit swelling in the carrageenan-induced model of paw edema in rats (Musa et al. 2016).

Antinociceptive activity

The antinociceptive potential of some *Bassia* species was investigated using an acetic acid-induced writing test and a hot-plate test. The 90% ethanol extract of aerial parts from *B. eriophora* (250 and 500 mg/kg, p.o.) was found to cause an analgesic effect in both tests. The animals were treated with the extract after 90 min. and showed an increase in reaction time, which was comparable to indomethacin (4 mg/kg) (8.1±0.18; 8.1±0.12; 9.18±0.22, respectively) [control: 5.82±0.13]. In the writhing method, extracts (250 and 500 mg/kg, p.o) also demonstrated significant antinociceptive activity (55.14% and 68.38%) when compared to the control vehicle group, however the effect was slightly worse than

observed for indomethacin (86%) (Yusufoglu 2015a). Musa et al. (2016) also confirmed the antinociceptive activity of the ethanol extract of the aerial parts of *B. eriophora* using the hot plate test, but the significant effect was observed only at high doses (500 mg/kg and 750 mg/kg, p.o) (Musa et al. 2016). In turn, Matsuda et al. (1997a, b) revealed that 70% extract of *Kochiae fructus* (500 mg/kg) demonstrated activity only in the acetic acid-induced writhing model (Matsuda et al. 1997a). Different results were provided by Choi et al. (2002), who investigated the activity of the ethanolic extract of *Kochie fructus* and fractions (chloroform, ethyl acetate, butanol) derived from the extract. All extracts (100 and 200 mg/kg; p.o.) revealed an analgesic effect in both hot plate and writhing tests in male Sprague–Dawley rats (Choi et al. 2002). Furthermore, the triterpenes isolated from the extract, such as momordin Ic and oleanolic acid (5, 10 mg/kg, i.p.) were also active in both models (Choi et al. 2002). Further studies revealed that momordin Ic (20,50,100 mg/kg, p.o.) alleviated the pain response but only in the second (late) phase of the formalin test, suggesting that its antinociceptive activity is mainly associated with anti-inflammatory activity (Matsuda et al. 1997a). On the other hand, *Bassia* extracts also showed activity in the hot plate test, which is considered to integrate supraspinal pathways (Deuis et al. 2017). This suggests that apart from anti-inflammatory activity, other mechanisms may also be involved in antinociceptive effect, but this issue requires in-depth research.

Cytotoxic activity

Most published studies on the cytotoxic activity of the *Bassia genus* concern *B. scoparia* species, while two articles describe the activity of *B. indica* (Abdel-Hamid et al. 2017; Aboul-Enein et al. 2012) and one *B. muricata* (Al-Barri et al. 2021). Interestingly, only two of the reviewed papers defined, at least partially, the chemical content of the extracts studied (Cho et al. 2019; Wang et al. 2014a) and one paper provided a full chemical characterization of the essential oil of *B. scoparia* seeds which was the object of the study (Kianinodeh et al. 2017). Most of the results indicate a rather weak cytotoxic potential of *Bassia* extracts.

The weak cytotoxic activity of the water and ethanol extract prepared from *B. indica* whole plant against Ehrlich ascites carcinoma cells was observed, with a decrease of 2.88 and 1.6% decrease in cell viability (Abdoul-Enein et al. 2012). A similar weak activity of the ethanolic extract of the whole plant of *B. indica* was described for HepG2 cells, with IC_{50} 120.5 µg/mL, while for the control cytostatic 5-FU, the IC_{50} value was 237.56 µg/mL. The extract was combined with 5-FU, and the most effective ratio, namely 5-FU/*Bassia* 1:2, decreased cell viability up to 48%, with a combination index of 0.996, suggesting a synergistic effect (Abdel-Hamid et al. 2017). In another study, a similar weak effect of *Kochiae fructus* aqueous and 50% ethanol extracts was investigated on the same HepG2 cells, after 4 and 24 h. Despite the difference in momordin Ic content, both extracts revealed a comparable, weak cytotoxic activity. Extracts at the dose of 1 mg/mL for 4 h or 0.1 mg/mL for 24 h decreased cell viability to approximately 60–70%, while almost total inhibition of cell viability was observed at doses as high as 5 mg/mL (Wang et al. 2014a). The methanolic extract of *B. scoparia* seeds revealed only weak cytotoxic activity in human lung A549 and colon Col2 cancer cells, with an IC_{50} exceeding 20 µg/mL (Nam and Lee 2000). Other studies present the cytotoxic impact of ethanolic extract of *B. scoparia* seeds on human neuroblastoma N-2A cells, with LC_{50} 0.147 mg/mL. Although the authors classified the effect as strong, the value seems to indicate rather weak activity (Mazzio et al. 2009). *B. scoparia* seed ethanolic (80%) extract was evaluated for the possibility of its use in psoriasis. The in vitro experiment was carried out on HaCaT cells and proliferation was measured by SRB and MTT assays. The extract revealed a rather weak effect in decreasing keratinocyte proliferation, with IC_{50} 185.7 and 125.0 µg/mL for the SRB and MTT assay, respectively (Tse et al. 2006).

B. muricata whole plant was extracted with different solvents, namely methanol, ethanol, or the combination of methanol:chloroform:water (12:5:1), and the cytotoxicity of the extracts was examined against human lymphocytes and Chinese hamster ovary CHO cells. Not only was none of the extracts toxic to the tested cells, but an increase in cell viability was also observed during exposure at concentrations of up to 2 mg/mL (Al-Barri et al. 2021).

Several reports provide data on the mechanism of action of *Bassia* extracts. The cytotoxic potential of the methanolic extract of *B. scoparia* seeds was evaluated in a panel of prostate cancer cells, differing in metastatic potential: LNCaP, PC-3, RC-58 T, but also normal prostate epithelial cells RWPE-1, with IC_{50} 89.25, 123.41,141.62 and > 250 µg/mL, respectively. The subtoxic dose of the extract (20 µg/mL) significantly suppressed VEGF-induced migration, invasion and formation of capillary-like structures of human umbilical vein endothelial cells (HUVECs) and micro vessels that sprout from rat aortic rings. The extract also downregulated the phosphorylation of VEGFR2 and the level of PI3K/AKT/mTOR, which resulted in decreased angiogenesis in HUVECs (Cho et al. 2019). Similar results on the antiangiogenic effect of *Kochiae fructus* extract were published by Na et al. (2006). The extract decreased the expression of the antiangiogenic protein HIF-1α (hypoxia-inducible factor 1-α) in HepG2 and HaCaT cells, and also reduced the level of VEGF and iNOS in HaCaT cells. The results indicate that the extract may be an antiangiogenic and anti-inflammatory agent useful in decreasing tumor progression (Na et al. 2006).

The methanolic extract of *B. scoparia* mature fruits was found to influence proliferation rate, cell cycle arrest, the generation of reactive oxygen species (ROS) and the stimulation of apoptosis in human breast MDA-MB-231 cancer cells. The results showed a dose-dependent decrease in cell proliferation, with IC_{50} 36.2 µg/mL. Furthermore, the extract at 25 µg/mL significantly increased the sub-G1 DNA content in cells to 44.7%, when compared to untreated cells, and also increased pro-apoptotic proteins such as cleaved caspase 3, cleaved caspase 8, cleaved caspase 9 and cleaved Poly (ADP-ribose) polymerase (PARP), leading to cell apoptosis (Han et al 2014). In their further studies, the authors examined the effect of *Bassia scoparia* mature fruit methanolic extract on human (Ca9-22 and HSC-4) and murine (AT-84) oral squamous cell carcinoma, and also on human HaCaT keratinocytes. The extract arrested cancer cells in the sub-G1 phase, and also led the cells to apoptosis, by activating caspase-3 and -9 through the p38 MAPK pathway. Importantly, normal HaCaT cells were not affected (Han et al. 2016).

To our knowledge, there is only one report devoted to evaluating the cytotoxic potential and mechanism of action of essential oil from *Bassia* plants. The essential oil from mature fruits of *B. scoparia*, obtained by the Clevenger apparatus, which contained alkanes as main constituents (*n*-tetracosane, *n*-tricosane, *n*-docosane, *n*-henicosane, *n*-eicosane), was tested in human breast cancer MCF-7 and normal HU02 fibroblast cells after 24, 48 and 72 h of incubation. The substance tested inhibited the viability of MCF-7 cells, with IC_{50} 125 µg/mL (72 h), while normal cells were not affected. Furthermore, incubation of MCF-7 cells with essential oil resulted in changes in cellular morphology, manifested as star-shaped cells, vacuolation, cytoplasmic and cellular shrinkage. Pyknotic nuclei were also observed, suggesting stimulation of apoptosis in cells (Kianinodeh et al. 2017).

Despite the large amount of in vitro data, so far only one animal study on *Bassia* extracts has been carried out. The anticancer properties of the methanolic extract of mature *B. scoparia* fruits were described in vivo, in C3H mice implanted with 3105AT-84 oral squamous cell carcinoma. The animals in the experimental groups received low (1 mg/kg body weight), medium (3 mg/kg body weight) or high (5 mg/kg body weight) doses of the extract, while the control animals were treated with a vehicle of 5% ethanol. The extract was introduced by intratumor injection once every two days (four times in total). The extract significantly reduced tumor volume in a dose-dependent manner, with the highest dose being the most effective. The authors also noted that the extract did not induce systemic toxicity and that no loss of body weight was also observed during treatment (Han et al. 2016).

Numerous reports indicate that momordin Ic, (Fig. 3B) a metabolite of saponin group, may be one of the active compounds of *Kochiae fructus* extracts as it has well-documented cytotoxic activity. Momordin Ic significantly reduced HaCaT cell viability, with IC_{50} of 168.70 and 76.40 µM/L for 24 and 48 h, respectively. The compound affected cell morphology, resulting in cell shrinkage, but also stimulated cell apoptosis and arrested the cells in S-phase. Furthermore, momordin Ic treatment significantly decreased β-catenin, c-Myc, and VEGF mRNA expression, compared to untreated cells, and modified Wnt/β-catenin pathway activation by affecting β-catenin nuclear distribution. The authors suggest that such activity of momordin Ic may be

of interest in antipsoriasis therapy in the future (Luo et al. 2021). In another study, the compound promoted the formation of autophagic vacuole and increased the expression of Beclin 1 and LC-3 in a dose- and time-dependent manner in HepG2 cells. The study results also revealed the crosstalk between autophagy and apoptosis stimulation by the compound, which simultaneously induced both processes by suppressing ROS-mediated PI3K/Akt and activating the ROS-related JNK and P38 pathways (Mi et al. 2016). Another study in the same HepG2 cellular model indicated that the compound induced apoptosis in cells, manifested as DNA fragmentation, caspase-3 activation, and PARP cleavage. In addition, momordin Ic stimulated reactive oxygen species (ROS) production and decreased mitochondrial membrane potential, cytochrome c release, down-regulation of Bcl-2 and up-regulation of Bax expression. Activation of p38 and JNK, inactivation of Erk1/2 and Akt, and alterations in the expression of iNOS and HO-1 were also observed after treatment with the compound. These results indicated that momordin Ic induced apoptosis through mitochondrial dysfunction regulated by oxidative stress involving the MAPK and PI3K-mediated iNOS and HO-1 pathways (Wang et al. 2013). In their further studies, the authors investigated the detailed mechanisms of momordin Ic apoptosis stimulation in HepG2 cells. The results demonstrated that momordin Ic activated PPARγ and inhibited COX-2. PGC-1α and FoxO4 expressions were increased by the PI3K or MAPK pathways, while inhibition of PPARγ decreased the expression of p-p38 and FoxO4, and restored COX-2 expression. ROS inhibition affected mainly PGC-1α expression, while PPARγ, COX-2 and FoxO4 expression was almost unaffected (Wang et al. 2014b).

In mouse fibroblast NIH 3T3 cells, momordin I suppressed the activator protein-1 (AP-1), an important protein in cellular signaling, responsible for the induction of several genes in response to physiological signals. Furthermore, momordin Ic also decreased the de novo synthesis of the AP-1 protein. The authors also suggest that the inhibitory site of momordin Ic might be in the Jun/Fos dimer and not in DNA, and the basic region of c-Jun is the most probable inhibitory action site (Park et al. 2000). Momordin Ic inhibited the proliferation of KB oral carcinoma cells with IC_{50} 10.4 μg/mL. Furthermore, the compound caused chromosomal DNA fragmentation and at a concentration of 20 μg/mL stimulated apoptosis in cells (approximately 20% apoptotic cells after 72 h) (Seo et al. 2007).

The small ubiquitin-like modifier (SUMO) protease, SENP1, plays an important role in cellular inflammation by regulating proteins in SUMOylation. Some studies suggest that momordin Ic might be a novel SENP1 inhibitor. In one of the studies momordin Ic reduced LPS-induced cellular inflammation in the RAW 264.7 macrophages model by depressing SENP1 expression. Furthermore, the effect of SENP1 on the LPS-induced inflammatory response was dependent on the interaction of SENP1-Sp3 and the promotion of Sp3 (transcription factor controlling the expression of genes involved in the cell cycle and inflammation response) expression by deSUMOylation of Sp3. Furthermore, momordin Ic-depressed Sp3 expression altered the Sp3-nuclear factor (NF)-κB interaction, which decreased cellular inflammation (Zheng et al. 2020). SUMO-specific protease 1 (SENP1), a member of the de-SUMOylation protease family, is elevated in prostate cancer cells and is involved in cancer pathogenesis. Momordin Ic inhibited SENP1 in vitro and altered the thermal stability of SENP1. Furthermore, the compound increased SUMOylated protein levels, namely hypoxia inducible factor-1α and nucleus accumbens associated protein 1 in PC3 prostate cancer cells, and also reduced SENP1 mRNA levels in cells. The authors suggest that momordin Ic may have therapeutic potential in prostate cancer (Wu et al. 2016). Another study focused on the effect of momordin Ic on a panel of colon cancer cells. The compound decreased the viability of colon cancer CT-116, HCT-8, SW480 and HT-29 cells, with IC_{50} values ranging from 6.40 to 12.79 μM. As HCT-116 and HCT-8 cells were most vulnerable (IC_{50} 6.40 and 6.83 μM, respectively) they were used in subsequent experiments. Momordin Ic stimulated apoptosis in cells, and arrested cells in the G0/1 phase of the cell cycle. Furthermore, the compound enhanced the SUMOylation of c-Myc, which led to the downregulation of the c-Myc protein. The authors conclude that momordin Ic revealed its cytotoxic effect through the SENP1/c-Myc signaling pathway (Xianjun et al. 2021).

In addition to in vitro studies, the antitumor activity of momordin Ic was investigated in an animal model. Momordin Ic was administered to

Balb/c nude mice implanted with PC3 prostate cancer cells, at a dose of 10 mg/kg daily for 20 days. On day 20, the xenograft tumors treated with the compound were less than those of the control group ($p < 0.05$). The authors observed the accumulation of SUMO1- and SUMO2/3-modified proteins in PC3 tumor xenografts treated with momordin Ic. However, a slight decrease in body weight was observed in the momordin Ic-treated group compared to the control group (Wu et al. 2016).

Although most of the research on cytotoxic activity has focused on momordin Ic, a single report on other compounds isolated from *Bassia* species has also been published recently. Three new steroidal glycosides, kochioside $1A_1$, kochioside $2A_1$ and kochioside $3A_1$, isolated from *Kochia prostrata,* were examined in a brine shrimp lethality assay, and their potential was comparable to the standard drug etoposide, with LD_{50} 8.3201, 8.8205, 8.2310, and 7.4625 μg/mL, respectively (Irfan et al. 2020).

Hypoglycemic activity and anti-obesity activity

The ethanol extract of *Kochiae fructus* demonstrated an anti-obesity effect in diet-induced obese mice. Oral administration of extracts together with the high-fat diet (1%, 3%) prevented weight gain. After 9 weeks, a reduction in fat storage was also observed (Han et al. 2006). A similar anti-obesity effect was found for the infusion of *B. scoparia* seeds prepared from 1.5 g of seeds/100 mL; 3 g of seeds/100 mL; 6 g of seeds/100 mL. Consumption of a high-fat diet with infusions (ad libitum) for 12 weeks by Wistar rats with diet-induced metabolic syndrome resulted in a reduction in retroperitoneal fat weight and the corresponding fat index. Furthermore, infusions dose-dependently inhibited the elevation in cholesterol level induced by diet (Gancheva et al. 2020). The alleviation of the increase in plasma triglyceride levels by *Kochiae fructus* ethanol extract (250 mg/g) and its total saponins (100 mg/g), after oral administration of the lipid emulsion, was also reported by Han et al. (2006). Further investigation (in vitro) revealed that the antiobesity effect of *Kochiae fructus* could be associated with saponins, such as momordin Ic, 2′-*O*-β-D-glucopyranosyl momordin Ic and 2′-*O*-β-D-glucopyranosyl momordin IIc which act as pancreatic lipase inhibitors (Han et al 2006). Furthermore, momordin can also induce an antiobesity effect via PPARδ (peroxisome-proliferator activated-receptor) mediated mechanism (Sasa et al. 2009).

PPARs play a role in the regulation of not only lipid but also glucose homeostasis (Gawrieh et al. 2021). The methanol extract (500 mg/kg) of *Kochiae fructus* and its butanol fraction (200 mg/kg) exhibited a significant hypoglycemic effect in glucose-loaded rats. Oral administration of extracts decreased serum glucose level by 53–58% compared to the control group (Yoshikawa et al. 1997b). Further research based on bioassay-guided fractionation showed that triterpene saponins were responsible for the hypoglycemic activity of the extracts (Yoshikawa et al. 1997b). Dai and Liu, (2002), observed that oral administration of the total saponin fraction of *Kochiae fructus* also inhibits the increase in serum glucose in alloxan-induced hyperglycemic mice. Structure activity-relationship (SAR) observations on isolated *Kochiae fructus* saponins revealed that the free carboxyl group at C-17 (28-COOH) in oleanane-type saponins, as well as the presence of the 3-*O*-glucuronide moiety in the sugar part, is essential for hypoglycemic activity in vivo. Monodesmosides of oleanolic acid that have a glucoside unit in the sugar chain attached to the C-3 of the aglycone were slightly less effective (Yoshikawa et al. 1997b; Matsuda et al. 1998b, 1999a). Furthermore, it was found that the mechanism of hypoglycemic action after oral administration of saponins is related to inhibition of gastric emptying and therefore the transfer of food to the small intestine (Matsuda et al. 1998a, 1999a, 1999b). It depends on serum glucose level and is mediated, inter alia, by capsaicin-sensitive sensory nerves (Matsuda et al. 1999b). In addition, an in vitro study revealed that momordin Ic and oleanolic acid 3-*O*-glucuronide also inhibited glucose uptake in the rat small intestine (Matsuda et al. 1998b).

Antioxidant activity in vitro

In recent years, phytochemical research has focused on the analysis of phenolic compounds in *Bassia* species. Phenolics are substances with a well-documented antioxidant effect, therefore, the antioxidant potential of different extracts of *Bassia* species were also studied. Most articles provide data on the different extracts prepared from aerial parts (leaves, shoots, fruits) of *Bassia* plants (Wang et al. 2014a;

Yusufoglu et al. 2015a; Mohammedi et al. 2019; Gancheva et al. 2020) and fractions obtained by partitioning extracts with solvents of increasing polarity (Chemsa et al. 2016; Khalil et al. 2017; Said et al. 2021). Among the studies, the assays based on the DPPH method predominated. The results of studies on the antioxidant potential of *Bassia* plants are presented in Table S1 (Supplementary information).

Khalil et al. (2017) evaluated the antioxidant potential of different plant parts (leaves, steams, roots) of *B. eriophora.* A significant DPPH radical scavenging effect (IC_{50}=19.2–46 µg/mL) of the ethyl acetate and butanol fraction of the 70% methanol extract was observed. A slightly lower antiradical potential was determined for the water fraction (IC_{50} 39.9 to 73.2 µg/mL). In turn, both the chloroform and the hexane fraction of the ethanol extract have the lowest ability to eliminate DPPH radicals (IC_{50} > 100 µg/mL). It is interesting that no significant differences in activity were found between extracts obtained from different parts of *B. eriophora*. In another study on *B. eriophora*, Said et al. (2021), revealed that 40% methanolic fraction obtained by elution of methanol (80%) extract from aerial parts of the plant on the C-18 short column has good antioxidant potential. The fraction had IC_{50} values of 177.8 µg/mL in the DPPH test and showed concentration-dependent total antioxidant capacity (TAC) and reducing power (RP). The authors underline the positive correlation between TAC and RP with total flavonoid content. It should be noted that the fraction analysed was defined by LC–MS/MS, which led to tentative detection of 28 flavonoids (acetylated and non-acetylated compounds). In the same study, further theoretical calculations on the O–H bond dissociation enthalpy (BDE) allowed the antioxidant activity to be linked to the location of hydroxyl groups in the flavonoid structure. The value of BDE decreased in structures with two adjacent hydroxyl groups. Therefore, such structures should have significant antioxidant potential (Said et al. 2021).

Antiradical activity was also investigated in hexane, ethyl acetate, and methanol extracts from aerial parts of *B. indica*. The results showed that the most potent effect was observed in methanol and water extracts with IC_{50} values of 1.30 µg/mL and 1.39 µg/mL as well as TEAC values of 1.44 mM and 3.60 mM in the DPPH and ABTS assays, respectively. The ABTS-free radical elimination effect of the water extract was higher than observed for the reference BHT (TEAC=1.80 mM) and slightly lower than the anti-DPPH potential (IC_{50}=0.91 µg/mL in DPPH). Compared to those extracts, the scavenging effect of hexane extract was much lower with IC_{50} values of 2.18 µg/mL in the DPPH test and 0.17 mM Trolox in the ABTS assay. It can be associated with a lower phenolic content in the hexane extract (5 mg PyE/100 g of extract) compared to the methanol and water extract (146 and 72 mg PyE/100 g of extract, respectively) (Bouaziz et al. 2009).

Several studies were also conducted to establish the antiradical activity of extracts of *B. muricata.* Mohammedi et al. (2019) revealed that methanol extracts from the aerial parts had stronger DPPH radical scavenging activity (EC_{50}=5–5.03 mg/L) than aqueous (EC_{50}=5.86–5.90 mg/L), ethanol (EC_{50}= 6.12–6.40 mg/L), acetone (EC_{50}=6.70–7.14 mg/L) and hexane extracts (EC_{50}=7.42–8.03 mg/L). However, water extracts were the most potent in the ferric reducing capacity assay (EC_{50}=1.39–2.60 mg/L) and β-carotene bleaching (EC_{50}=5.31-6.0 mg/L). The authors noted that the high antioxidant activity of methanol and water extracts is strictly associated with a high polyphenol content (TPC=122.15–144.82 mg of GAE / g of methanol extract and 98–100.12 mg of GAE / g of water extract). Furthermore, in the same study it was observed that the type of extraction technique used (MAE, Soxhlet, maceration) had no significant effect on the measured values of antioxidant activity (Mohammedi et al. 2019).

Recently, the essential oil of the *B. muricata* shoots, extracted by hydrodistillation by Abd-ElGawad et al. (2020), was tested for its DPPH and ABTS radical scavenging activity. To our knowledge, this was the only study on the antioxidant potential of essential oil of any *Bassia* species. The study revealed that the essential oil eliminated DPPH radicals with an IC_{50} value of 20.70 µL/mL and acted as anti-ABTS (IC_{50}=16.32 µL/mL). The authors suggested that considerable antioxidant potential may be associated with a large amount of oxygenated sesquiterpenes (53.18%), detected by the GC–MS method in the oil, including hexahydrofarnesyl acetone (47.34%) (Abd-ElGawad et al. 2020).

Unlike other *Bassia* species, the analysis of the antioxidant potential of *B. scoparia* focuses on the

study of dried fruits, which are a valued medicinal agent in traditional Chinese medicine. Wang et al. (2014a) revealed that the water and ethanol (50%) extract of *Kochiae fructus* possess the ability to reduce the ferricyanide complex (Fe^{3+}) to the ferrous form (Fe^{2+}) in the FRAP assay. Furthermore, extracts not only demonstrated the potential to eliminate DPPH (IC_{50}=0.24–0.31 mg/mL) and ATBS radicals (IC_{50}=0.35–0.43 mg/mL) but also showed superoxide anion (IC_{50}=5.42–6.64 mg/mL) and hydroxyl radical scavenger properties (IC_{50}=0.23 mg/mL and IC_{50}=2.25 mg/mL, ethanol extract and water extract, respectively) (Wang et al. 2014a). Reactive hydroxyl radicals, superoxide anion, and their by-products may cause oxidative damage to biomolecules. Wang et al. (2014a) confirmed that water and ethanol (50%) extracts of *Kochiae fructus* (0.1–7 mg/mL) were able to dose-dependently inhibit the free radical-induced destruction of biomolecules. Extracts (0.1–7 mg/mL) inhibited lipid peroxidation in the range of 3–80% (compared to the control group). The ethanol extract was found to almost completely suppress lipid peroxidation (at 7 mg/mL). Furthermore, at a much lower concentration, 50% ethanol extract (0.1 mg/mL) significantly suppressed protein oxidative damage by 73%, while water extract exerted similar activity with a dose of 10 mg/mL. It should be noted that both the ethanol and water extracts (at 0.1–7 mg/mL) effectively protected DNA from oxidative damage by 19–70% and 4–40%, respectively. The authors indicated that the observed effect, especially observed in the ethanol extract, may be related to the presence of momordin Ic. It is interesting that this triterpene saponin was able to protect free radical-induced protein oxidation in a dose-dependent manner (Wang et al. 2014a). Momordin Ic (at 1 µM= 0.76 µg/mL) showed significant activity in the model of AAPH- as well as Cu^{2+}/H_2O_2 -mediated oxidative damage ($>80\%$ intact proteins) (Wang et al. 2014a).

Published reports indicate that some of the extracts of *Bassia* plants, especially those rich in polyphenols, show significant antioxidant potential. As a result of the different methods of processing the plant material, it is very difficult to compare these results with each other. It should be noted that to date no analyses have been published that compare the antioxidant activity of several species of *Bassia* under the same conditions. To the best of our knowledge, only one analysis has been performed to date comparing the activity of two species: *B. indica* and *B. muricata* (Bouaziz et al. 2009). The study showed significant differences in the content of phenolic compounds and the antioxidant activity of the extracts depending on the type of extractant used (see Table S1, Supplementary information). The water extracts of aerial parts of *B. indica* showed the strongest antioxidant activity in the ABTS assay, even higher than the reference substance (BHT) (Bouaziz et al. 2009).

Although in vitro models may provide preliminary information on the activity of the extracts, they do not always reflect in vivo conditions. Recently, the antioxidant potential of *B. scoparia* and *B. eriophora* was investigated using animal models. The studies were related to the hepatoprotective and nephroprotective potential of the extracts (see next section).

Hepato-, nephro-, gastro- and neuroprotective activity

Kim et al. (2005a), revealed that *Kochiae fructus* had a hepatoprotective effect against CCl_4-induced liver damage in Wistar rats. Pre-treatment with methanol and the butanol fraction derived from the extract (200 mg/kg body weight; p.o.; once a day for 14 days) resulted in a significant reduction in serum levels of aspartate transaminase (AST), alanine transaminase (ALT), lactic dehydrogenase (LDH) and liver concentration of thiobarbituric acid reactive substances (TBARS) in the CCl_4 treated rats. Furthermore, both extracts significantly inhibited the reduction in glutathione, glutathione-S-transferase, and glutathione reductase activity produced by CCl_4. The study demonstrated that the hepatoprotective effect of *B. scoparia* was closely related to the antioxidant activity of the extracts and increased the hepatic antioxidant potential (Kim 2005a). Gancheva et al. (2020) came to similar conclusions by examining the protective potential of the infusion of *B. scoparia* seeds in Wistar rats with diet-induced metabolic syndrome. The animals received a high-calorie diet along with infusions (ad libitum) prepared with the use of 100 mL of boiling water and 1.5 g, 3 g and 6 g of seeds, respectively. After 12 weeks of treatment, all infusions demonstrated antioxidant activity in vivo in a dose-dependent manner. In the group of animals with metabolic syndrome, which were administered infusion made from 6 g of seeds, the most potent decrease in thiobarbituric acid

reactive substances (TBARS) in serum, comparable to healthy rats on a regular rat chow diet was observed. Furthermore, the histopathological study demonstrated that pre-treatment with infusion prevents the appearance of liver lesions (Gancheva et al. 2020). Although no bioassay-guided fractionations were performed in the investigation, the authors assumed that oleanolic acid and momordin Ic are the hepatoprotective substances in *Kochia fructus* as they are known to exert the effect (30 mg/g body weight; p.o.; once a day for 14 days) in the CCl_4-induced liver damage model in rats (Kim et al. 2005b). It is interesting that in the scientific literature there are also some reports on the gastroprotective potential of momordin Ic, oleanolic acid 3-*O*-glucuronide against ethanol- and indomethacin-induced gastric mucosal lesions in rats (Matsuda et al. 1998c, 1999c). However, to our knowledge, no reports on such activity of extracts of *Bassia* species have been published.

Among *Bassia* species, *B. eriophora also* revealed a preventive potential in vitro, not for liver but kidney damage. To assess plant activity, the CCl_4-induced lipid peroxidation model (Albino Wistar rats) and post-test measurement of the level of malondialdehyde in nephritic tissues, as well as histopathological investigation, were used. The study revealed that pre-treatment with 90% alcoholic extract from aerial parts of the plant (250 mg/kg body weight, p.o. and 500 mg/kg body weight p.o./six days) influenced kidney functions as a reduction in serum creatinine and urea levels was observed in animals intoxicated with CCl_4. Furthermore, the amount of total proteins, which represents the level of damage, was maintained as in normal rats. The extract of *B. eriophora* also significantly prevented the elevation of malondialdehyde, a marker of oxidative stress, in the kidney tissue of rats intoxicated with CCl_4. Finally, histopathological studies confirmed that pre-treatment of animals with *B. eriophora extract* significantly and dose-dependently reduced injuries such as vacuolization of the cytoplasm of the epithelial lining of renal tubules induced by CCl4 intoxication. The authors emphasize that kidney protective activity results from the antioxidant and free radical scavenging potential and may be related to polyphenol compounds in the extract of *B. eriophora* (Yusufoglu et al. 2015a).

Recently, Othman et al. (2022) demonstrated the neuroprotective effect of methanol extract of aerial parts or *B. indica*. To our knowledge, this was the only study on such activity of any *Bassia* species. The study revealed that the extract showed inhibitory activity against MAO-B (IC_{50}=8.7; selegiline: IC_{50}= 0.55 μg/mL), BACE-1 (IC_{50}=28.9 μg/mL; LY2811376: IC_{50}=0.8 μg/mL) and neurotoxic $A_{\beta 1\text{-}42}$ aggregation (IC_{50}=40.6 μg/mL; tecrine: IC_{50}= 1.93 μg/mL) in vitro. Furthermore, *B. indica* extract reduced the concentration of phosphorylated tau-protein to 6.62 pg/mL (control=10.8 pg/mL; LY2811376: IC_{50}=2.09 pg/mL). The search for active compounds revealed that phenylpropanoid amides, such as *N-trans*-feruloyl-3-methoxytyramine and *S*-(-)-*N-trans*-feruloyl octopamine, which occur in aerial parts of *B. indica,* are associated with the neuroprotective effect of the extract. *N-trans*-feruloyl-3-methoxytyramine (NTFT) exerted potent inhibitory activity against MAO-B, BACE-1 and $A_{\beta 1\text{-}42}$ aggregation with IC_{50}=0.71 μg/mL, IC_{50}= 5.39 μg/mL, IC_{50}=0.3 μg/mL, respectively. NTFT also demonstrated a significant effect in reducing the concentration of phosphorylated tau-protein (to 1.62 pg/mL; control=10.8 pg/mL; LY2811376: IC_{50}=2.09 pg/mL) (Othman et al. 2022). Furthermore, Khan et al. (2021) noted that NTFT exerts a stimulating effect on neurothrophins and the neurogenesis process through the TrkA/ERK /CREB pathway (Khan et al. 2021). Thangnipon et al. (2012) also indicated that the neuroprotective effect of NTFT against AAβ1–42-induced neuronal death may be associated with its antioxidant activity (Thangnipon et al. 2012). These studies on *B. indica* and isolated phenylpropanoid amides have provided promising results and thus should be the subject of further in-depth analyzes on neuroprotection and prevention of neurodegenerative diseases.

Antibacterial, antifungal, and antiparasitic activity

Antibacterial activity studies in representatives of the *Bassia* genus have been conducted mainly on extracts from aerial parts of plants, including fruits of *B. scoparia*, prepared with the use of different solvents. Most of the research has been carried out using agar diffusion methods, but studies on the determination of minimal inhibitory concentration (MIC) have also been performed. The list of antimicrobial studies is presented in Table S2 (Supplementary information).

In a preliminary study on the antimicrobial potential of *B. eriophora*, ethanol extract from aerial parts of the plant was found to inhibit *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae,* and *Proteus vulgaris* growth (Al-Mussawi et al. 2014). Activity toward *S. aureus* and *E. coli* was also observed for fractions obtained by partitioning 70% ethanol extract from different parts of *B. eriophora* plant (leaves, roots, stem) with hexane, ethyl acetate, and water. All extracts, but especially the water fraction from the roots and stems, exhibited high activity towards *S. aureus*, with inhibition zones between 27 and 40 mm (control: oxacillin 19 mm; erythromycin 22 mm). In turn, moderate activity towards *E. coli* was observed for the water extract of the roots and stems, as well as the ethyl acetate fraction of the stem (Khalil et al. 2017). In another study, the antibacterial activity of 95% ethanolic extract of aerial parts of *B. eriophora* against not only methicillin-sensitive *S. aureus* (MSSA) but also resistant (MRSA) strains were evaluated. The extract was found to inhibit the growth of both MSSA and MRSA strains, with MIC values of 25–75 μg/mL and 75 μg/mL, respectively. Interestingly, the authors also performed analyzes that evaluated the possibility of using *B. eriophora* extract to create an antibacterial layer on textiles against *S. aureus*. Furthermore, they indicate that anti-*S. aureus* fabrics do not lose their antibacterial properties, even after two washing cycles (prepared according to the test method 61(2A)-1996, the American Association of Textile Chemists and Colorists) (Alsaggaf et al. 2018). The potential of *B. scoparia* for MRSA was also investigated. The *n*-hexane fraction of the *Kochiae fructus* ethanol extract exhibited significant activity (MIC=7.8–31.25 μg/mL; ampicilin 31.25–1000 μg/mL; oxacilin 500–1000 μg/mL), whereas the butanol, ethyl acetate and water fraction did not inhibit the growth of bacteria. Furthermore, synergy in antibacterial activity was observed between the hexane fraction and antibiotics (oxacillin or ampicillin) (Joung et al. 2012). El-Shamy et al. (2012), investigated the antibacterial effect of essential oil from *B. scoparia* shoots. Although the oil significantly inhibited the growth of *E. coli*, *Bacillus subtilis,* and *S. aureus* (MIC= 12.5 μg/mL, 12.5 μg/mL and 25.0 μg/mL, respectively), the effect was lower compared to cefroperazone (MIC=0.8 μg/mL). The observed effect was probably related to α-thujaplicin, which is the major component of essential oil and has a well-documented antimicrobial activity (Yamaguchi et al. 1999; Morita et al. 2001; El-Shamy et al. 2012). Among *Bassia* species, also alcoholic extracts of *B. muricata* moderately suppressed the growth of *B. subtilis*, *S. aureus*, *P. aeruginosa*., *E. coli*, which was determined using the agar well diffusion method (Al-Barri et al. 2021). In another study, the ethanol extract from aerial parts of *B. muricata* (40 extract/disc) showed antimicrobial activity against *E. coli* and *P. aeruginosa*, which was comparable to amoxicilin (25/disc). Additionally, a moderate effect against *Vibrio cholerae*, *Salmonella enterica,* and *Enterococcus faecalis* was also observed (Chemsa et al. 2016). Some reports investigating the antibacterial potential of aerial parts of *B. indica* can also be found in the literature (Abdel-Hameed et al. 2008; Bouaziz et al. 2009; Bibi et al. 2021; Ahmed et al. 2022). However, they provide contradictory information that can be associated with, among others, different methods of processing plant material.

In addition to antibacterial activities, the antifungal potential of various extracts of *Bassia* plants was also tested. Unfortunately, some of the studies are not well documented, without a corresponding positive control (antifungal drug) and seem not to be too repetitive. Several reports provide preliminary data that alcoholic extracts from aerial parts of *B. muricata*, *B. prostrata,* and *B. indica* have moderate activity towards some pathogenic fungus. *B. muricata*, *B. indica,* and *B. scoparia* inhibited *Candida albicans* growth (Al-Barri et al. 2021; Ahmed et al. 2022) as well as *B. prostrata* was active toward *Candida glabrata*, *Microsporum canis*, *Aspergillus flavus,* and *Trichophyton longifusus* (Imran et al. 2017) (see Table S2). Most reports indicated inactivity of *Bassia* extracts toward *Aspergillus niger* or *A. fumigatus* (Abdel-Hameed et al. 2008; Al-Barri et al. 2021; Ahmed et al. 2022). Additionally, the essential oil obtained from the *B. scoparia shoots,* with α-thujaplicin as the main compound (22.91%), did not inhibit the growth of *A. niger*, while it showed moderate activity towards *C. albicans* (MIC= 12.5 μg/mL) (cefroperazone was used as a positive control, MIC=5.0 μg/mL) (El-Shamy et al. 2012). In another study, Liu et al. (2012) screened the antifungal activity of different extracts of *Kochiae fructus* (0.2 g fruits/mL) towards *Saccharomyces cerevisiae*

and *C. albicans*. The aqueous extract showed the best fungistatic activity and suppressed growth by 52% and 29%, respectively (control: miconazole (2 mg/mL) inhibited growth by 89–90%). In turn, the acetone extract exhibited a lower potential for both *S. cerevisiae* and *C. albicans* (24% and 15%), while the ethanol extract as well as the hexane extract showed a poor activity (5–10%) (Liu et al. 2012). On the other hand, ethanol extract of *B. scoparia* fruits (2 mg/mL) strongly inhibited the growth of the plant necrotrophic fungus–*Valsa mali* (by 96.16% after 96 h). Furthermore, the extract had a negative influence on the functional stability of the mycelium (Xiaoyan et al. 2019). Furthermore, Houlihan et al. (2019) demonstrated that water exudates from *B. scoparia* seeds suppress the formation of hyphae in *Colletotrichum graminicola* with a MIC value of 3.125 mg/L. However, it should be mentioned that the exudates were inactive in relation to the other fourteen fungus tested (Houlihan et al. 2019).

Significant inhibitory activity against *Macrophomina phaseolina* was also observed in the *n*-butanol fraction of the leaf methanolic extract of *Kochia indica*. At the concentrations tested (1.56–200 mg/mL), the extract caused a reduction in the biomass of this fungal plant pathogen in the range of 63–92% (Javed et al. 2018b).

Unlike antimicrobial studies, data on the antiparasitic activity of *Bassia* species are scarce. The methanol extract of the seeds of *B. scoparia* (100 μg/mL) showed moderate activity (47% inhibition) against the epimastigote stage of *Trypanosoma cruzi* in axenic cultures (allopurinol was used as a positive control, 67% inhibition) (Lirussi et al. 2004). In a study on the antitoxoplasmal potential of *B. eriophora*, a methanol extract of aerial parts of the plant (50 μg/mL) displayed very weak activity (5% of inhibition) against *Toxoplasma gondii* tachyzoites (Al Nasr 2020). In turn, 95% methanol extract of *B. indica* (100 and 200 μg/mL) was evaluated against *Schistosoma mansoni,* but no activity was detected (Abdel-Hameed et al. 2008). The reports published so far clearly indicate a low potential of extracts from *Bassia* species against analysed parasites, which cause disease in humans.

However, there are reports that show significant activity of *B. scoparia* extracts against animal and plant pathogens. Lu et al. (2012a) examined the antiparasitic potential of various extracts of fruits of *B. scoparia* against the fish pathogen *Dactylogyrus intermedius* using an in vivo anthelmintic efficacy model in goldfish (*Carassius auratus*). The methanolic extract of the fruits of the plant demonstrated potent activity with values of EC_{50} and EC_{90} of 31.28 mg/L and 52.52 mg/L (in bath), respectively. Furthermore, the acute toxicity assay revealed that the 48 h LC_{50} values (71.04 mg/L) are higher than therapeutic concentrations. The other extracts tested (petroleum ether, chloroform, ethyl acetate, acetone) exhibited a lower potential in the anthelmintic model and caused fish mortality in the concentration range 90–130 mg/L (Lu et al. 2012a). In turn, Shi et al. (2006) screened the acaricidal activity of extracts from aerial parts of *B. scoparia* against the spider mites *Tetranychus cinnabarinus, Tetranychus urticae, and Tetranychus viennensis,* which are parasites on many different plants and crops. All extracts showed systemic and contact toxicity to mites. Chloroform extract caused a strong mite mortality rate (73.3–89.12%) and the effect was stronger than observed for methanol extract (39.78–44.78%) and petroleum ether extract (41.92–54.21%) (Shi et al. 2006). These studies have provided promising results and thus should be the subject of further in-depth analyses.

Other activities

In addition to the biological activities mentioned above, some reports also demonstrated other effects observed for some *Bassia* species. The aqueous extract of *Kochiae fructus* (200 g/1500 mL) exerted a decrease in stroke volume and pulse pressure in beating rabbit atria. However, this inotropic activity was not mediated by atrial natriuretic peptide (ANP) secretion (Lee et al. 2016). In another study, *Kochiae fructus* water extract (20 mg/g, p.o.) demonstrated improvement in heart function parameters in the furazolidone-induced DCM model. Furthermore, the extract showed a regulatory effect on Th1/Th2 cell activity, which suppressed myocardial injury in dilated cardiomyopathy (DCM) (Zou et al. 2021).

Yusufoglu et al. (2015a) investigated the antipyretic potential of *B. eriophora* in the rat model of yeast-induced pyrexia. The 90% ethanol extract (250 mg/kg and 500 mg/kg) from the aerial part of the plant significantly reduced the elevated rectal temperature (39.35 °C). 120 min after oral administration, the temperature decreased to 36.68 °C and

35.83 °C, while indomethacin (4 mg/kg) reduced the temperature to 35.45 °C. However, the mechanism of action has not been evaluated. The ethanol extract of aerial parts of *B. eriophora* (250, 500 and 750 mg/kg; i.p.) was found to cause dose-independent skeletal muscle relaxant activity using the rota-rot test in male Swiss albino mice (Musa et al. 2016) as well. Recent studies in animal models with seizures induced by pentylentetrazol and electroshock indicate that essential oil from fresh leaves of *B. scoparia* (75, 150 and 300 mg/kg; p.o.) had anticonvulsant activity. Unfortunately, this study is only preliminary because no phytochemical investigation was conducted on the composition of essential oil. Therefore, it is not known which phytoconstituents may be responsible for activity (Imade et al. 2020). In turn, Othman et al. (2021b) screened seventeen constituents isolated from hydroalcoholic extract of aerial parts of *B. indica* as acetylcholinesterase inhibitors in vitro, including a new acylated flavonol tetraglycoside and a rare triglycoside. Among them, the most potent were 6,7-dihydroxycoumarin and quercetin with IC_{50} values of 3.6 μg/mL and 18 μg/mL, respectively (galantamine was used as a positive control, IC_{50}= 12.5 μg/mL). Flavonol glycosides: kaempferol-3-*O*-β-D-glucopyranosyl-(1→6)-*O*-[β-D-galactopyranosyl-(1→3)-2-*O*-*trans*-feruloyl-α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranoside (Fig. 2) and isorhamnetin-3-*O*-β-D-glucopyranosyl-(1→6)-*O*-[α-L-rhamnopyranosyl-(1→2)]-β-D-glucopyranoside (Fig. 3B) demonstrated weak activity (IC_{50}=250 μg/mL) (Othman et al. 2021b).

Yusufoglu (2015b) investigated the wound healing potency of gel preparations containing 1% and 2% ethanol extract of the aerial part of *B. indica*. Both formulations showed significant and dose-dependent wound contracting ability in the excision wound model in Albino Wistar rats. The reduction in wound size caused by topical application (once a day for 20 days) of 2% gel was more potent than that observed for 1% gel or Betadine (84.21%, 78.68% and 60.25%, respectively vs. base gel 56.70%).

Safety of Bassia species

The scientific literature provides only a few data on the toxicity of *Bassia* plant extracts. It is worth noting, however, that some species have been clinically used in traditional medicinal systems, which also provides information on their safety in humans. One of such plants is *B. scoparia*. Toxicological studies in mice indicated that *Kochiae fructus* water extract demonstrated very low oral acute toxicity with an LD_{50} value of 7.15 g/kg (Zou et al. 2021). Furthermore, in two investigations, it was confirmed that the ethanol extract from aerial parts of *B. eriophora* also exhibited low toxicity (Yusufoglu 2015b; Musa et al. 2016) and the LD_{50} after oral administration in mice was estimated at 33.4 g/kg (Musa et al. 2016). However, it should also be noted that the data available in the literature refer to acute toxicity, while there is no information on the chronic use of various *Bassia* plant extracts. There are only data on the consumption of hay from certain species as feed for livestock. Some species of the genus *Bassia* can accumulate oxalates and nitrates, which may be associated with signs of toxicosis in animals, but only after chronic consumption of large amounts of hay (Rankins et al. 1991a, b). However, it should be noted that the level of these components in the *Bassia* plants depended on many factors (maturity stage, environmental factors) (Finley and Sherrod 1971; López-Aguilar et al. 2013; Steppuhn et al. 1994; Yang et al. 2007; Ma et al. 2011, 2016). Furthermore, the observed presence of nitrates and oxalates did not exclude the medical or even food use of other plants from the *Amaranthacae* family, such as *Beta vulgaris*, *Amaranthus* sp., *Spinacia oleracea*, which also accumulate antinutritional compounds (Jaworska et al. 2005; Gadermaier et al. 2014; Liu et al. 2015; Corleto et al. 2018; Munekata et al. 2021; Avila-Nava et al. 2021). Thus, this indicates that more attention should be paid to the level of potentially toxic compounds before clinical application of *Bassia* plants.

Among the side effects that can appear in contact with plants of the genus *Bassia*, pollen allergy manifested as allergic rhinitis should also be mentioned. Most allergens found in pollen from the *Amaranthaceae* family belong to the profilin group (Gadermaier et al. 2014; Elvira-Rendueles et al. 2017). In a study by Zarinhadideh et al. (2015), the first pollen allergen of *Bassia scoparia* (named Koc s 2) was also characterized.

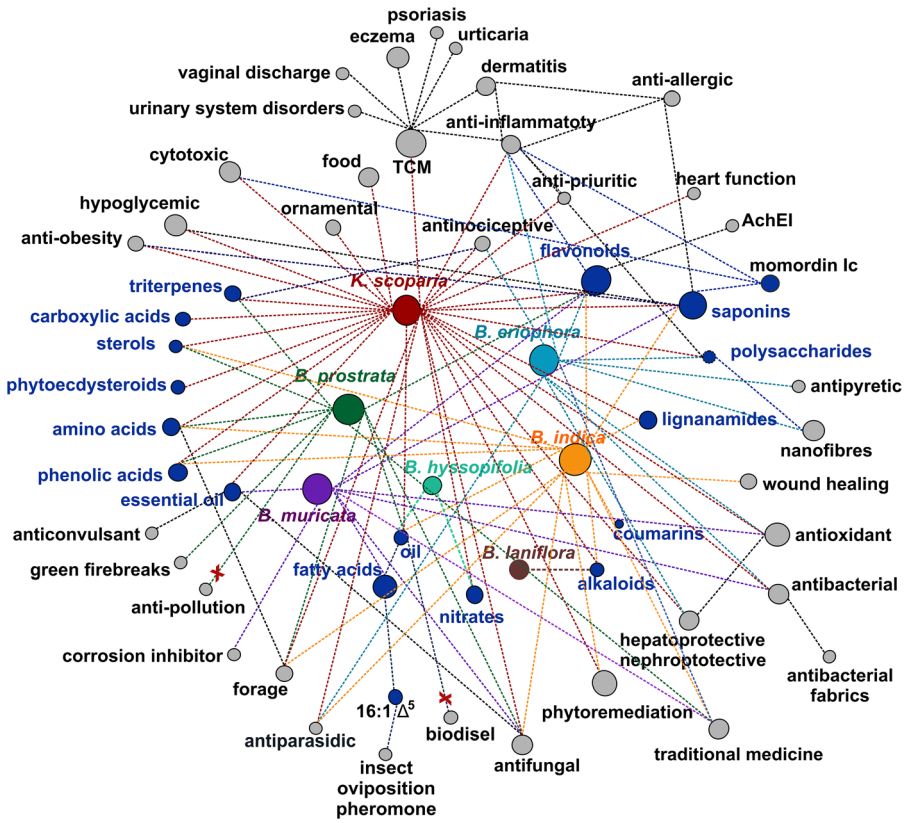

Fig. 6 Dependency network of between phytochemical studies and data on the biological activity of extracts and compounds from *Bassia* sp. (Abbreviations: "x"–not a promising direction of application)

Conclusions

The representatives of the genus *Bassia* have been used by humans in different parts of the world for medical as well as nonmedical purposes. This overview gathers and summarizes available scientific data on phytochemistry, biological activity, and significance of plants belonging to the genus, reorganized by Kaderit and Freitag (2011) and denoted *Bassia* All.

Based on the publications covered in the review, for many years the research on *Bassia* plants focused solely on one species (*B. scoparia*), and actually only one of its parts, *Kochiae fructus*, which is a valuable therapeutic agent in TCM. Only in recent years has there been growing interest in the phytochemistry and biological activity of the other species of the genus. Moreover, some investigations were also conducted on other parts of the *B. scoparia* plant. However, it should be noted that many species of the genus *Bassia* still remain poorly investigated or unexplored.

Phytochemical studies conducted on *Bassia* species indicate that these plants synthesize metabolites that belong to very different groups of compounds. The latest studies provided information on flavonoids in *B. eriophora* and *B. indica,* as well as lignanamides in the latter species. It is interesting that some of the substances found in *Bassia* plants are unique and rarely found in the plant kingdom. Such structural biodiversity may have a significant impact on the overall biological activity of specific extracts, but this issue requires in-depth research. So far, only some studies on the biological activity of extracts have attempted to answer the question of which compounds are responsible for the observed effect. Most of them focused on bioassay-guided fractionation of active compounds. This approach allows for the selection of a single active compound, but ignores the possibility of a synergistic effect between the phytoconstituents, which often occurs in plant extracts. For example, for many years, the anti-inflammatory activity of *Kochiae fructus* extracts was attributed

only to saponins. However, recent studies indicate that flavonoids and, in the case of aqueous extracts, polysaccharides may also be responsible for the effect. Therefore, determining the composition of the extract is extremely important to understand the resultant activity. Equally important are the quantitative analysis of the compounds in the extract and the selection of active markers responsible for the activity. Ensuring the standardization of extracts enables the maintenance of product quality, repeatability of test results, and potential therapy in the future. In the case of research on the activity of extracts from plants of the genus *Bassia*, although they undoubtedly indicate a multidirectional pharmacological effect of the extracts, including anti-inflammatory, cytotoxic, antioxidant, antimicrobial, glucose-lowering and several potential nontherapeutic effects, only some studies provide information on the chemical characterization and quantification of the main components in the extracts. Interestingly, this also applies to in vivo studies. As a result, there is a lack of data that would allow determining the relationship between the phytochemistry of a given species and the activity of its extracts. This is an issue that requires extensive analysis, especially considering some studies that indicate seasonal variability in the content of individual metabolites. However, it should be noted that many of the *Bassia* species have been used without standardization in traditional healing systems. In such a case, it would be extremely valuable to analyze the qualitative and quantitative profile of the form of the drug used in traditional medicine or at least to identify the main markers.

In this review, we try to present the current state of knowledge and research on species of the genus *Bassia*. After analyzing the published reports, we schematically summarized the network of relationships between phytochemical studies and data on the biological activity of extracts and compounds from individual *Bassia* species (see Fig. 6).

Based on published research on biological activity, one of the most promising directions of research on extracts from plants of the genus *Bassia* are analyses related to the therapy of inflammatory-related diseases. This aspect is in part in line with the current use of *Kochiae fructus* in TMC in the treatment of skin diseases. However, it should be mentioned that inflammatory processes are the basis or cause of the progression of many other diseases that are now increasingly common in the developing society, such as cancer, diabetes, and heart disease. Many investigations revealed that extracts (e.g. of *B. scoparia*, *B. eriophora, B. indica*) and some isolated compounds (e.g. momordin Ic, flavonoids, *N-trans*-feruloyl-3-methoxytyramine) show not only anti-inflammatory effects, but also significant cytotoxic, glucose lowering, anti-obesity, neuroprotective, and antioxidant effects in vivo. These results indicate a potential for in-depth research on activity against the metabolic syndrome and noncommunicable diseases.

The second direction related to potential further research on the biological activity of extracts from plants of the genus *Bassia* is the antimicrobial and antiparasitic activity. Unfortunately, some of the studies on this issue provide only preliminary information and others were conducted without comparison of results to the corresponding positive control. However, the studies that have been carried out so far indicated that extracts from plants of the genus did not have a broad and nonspecific range of antimicrobial activity, but some of them showed interesting activity against a specific pathogen, such as methicillin resistant *S. aureus* (MRSA), or against certain fungi or pests causing significant losses in plant crops. These studies should be significantly extended to determine which compounds present in the extracts are responsible for the effect.

In recent years, the possibilities of various non-medical and non-food uses of *Bassia* species have been explored. Some of them did not produce the expected good results. An example is the use of *B. prostrata* for the construction of green walls near highways, reducing air pollution (Hozhabralsadat et al. 2022) and the possibility of using *B. scoparia* oilseeds as a source for the production of biodiesel (Abideen et al. 2015). However, it should be noted that the latter potential application is possible, but not profitable, because of the possibility of using other plants that are much more abundant in the oil. In the literature, there are some single reports on the interesting potential of different nonmedical and medical applications of *Bassia* plants, such as the production of cellulose nanofibrils from *B. eriophora* biomass or the use of *B. muricata* extracts as an ecological corrosion inhibitor. These studies have provided promising results, but require confirmation, and thus should be subject to further in-depth

research. Another issue is the possible use of some species of *Bassia* (*B. scoparia*, *B. indica*) in soil phytoremediation. Research in this area is very promising from an industrial and ecological point of view. However, these studies indicate the likelihood of the accumulation of toxic substances in *Bassia* plants, which excludes the possibility of their use for medical purposes. Therefore, this indicates that more attention should be paid to the environmental conditions under which the plant grows or is cultivated in the case of plants of the genus *Bassia* used for medical purposes.

Species of the genus *Bassia* possess significant adaptation to unfavorable environmental conditions and the possibility of growth and cultivation even in arid areas. Therefore, one of the interesting potentials of *Bassia* plants may be their cultivation on wasteland and use as a source of bioactive substances. The research conducted indicates the possibility of obtaining (*Z*)-5-hexadecenoic acid from seeds of various species of *Bassia* (*B. prostrata*, *B. scoparia*, *B. hyssopifolia*) as an intermediate to produce insect ovioposition pheromone. It is also interesting to obtain momordin Ic, which is considered one of the main compounds of the *Bassia scoparia* fruit with multidirectional activity.

In summary, species of the genus *Bassia* are characterized by an interesting, complex phytochemical, and pharmacological profile. In addition, some of them, such as *B. scoparia,* exhibit several activities that justify its use in the traditional medical system. In turn, other species of *Bassia*, such as *B. muricata* or *B. indica*, which also have an established position in folk medicine, have not been subjected to research that justifies their traditional use. However, studies conducted in recent years have provided new data on the phytochemistry and activity of *Bassia* extracts that go beyond traditional applications. Additionally, considering the possibility of cultivation of some *Bassia* species, these plants are interesting targets for further research. However, it should be noted that, despite numerous reports, there are still many gaps in the current knowledge on species of the genus *Bassia* and there is a need to conduct in-depth research on the currently studied species as well as to start the analysis of plants that have not been investigated so far.

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Declarations

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

References

Abbas Z, Alam J, Muhammad S, Bussmann RW, Khan SM, Hussain M (2019) Phyto-cultural diversity of the Shigar valley (Central Karakorum) Baltistan, northern Pakistan. Ethnobot Res Appl 18:1–18. https://doi.org/10.32859/era.18.31.1-18

Abd-ElGawad A, El Gendy AE, El-Amier Y, Gaara A, Omer E, Al-Rowaily S, Assaeed A, Al-Rashed S, Elshamy A (2020) Essential oil of *Bassia muricata*: chemical characterization, antioxidant activity, and allelopathic effect on the weed *Chenopodium murale*. Saudi J Biol Sci 27:1900–1906. https://doi.org/10.1016/j.sjbs.2020.04.018

Abdel-Hameed ES, El-Nahas HA, Abo-Sedera SA (2008) Antischistosomal and antimicrobial activities of some Egyptian plant species. Pharm Biol 46:626–633. https://doi.org/10.1080/13880200802179543

Abdel-Hamid NM, Tabl GA, El-Bolkiny YE, Zeina WO (2017) *In vitro* antitumor efficacy of *Kochia indica* extract on human hepatocellular carcinoma cell line with or without 5-fluorouracil. Hepatoma Res 3:149–155. https://doi.org/10.20517/2394-5079.2016.50

Abeer H, Abdallah EF, Alqarawi AA, Al-Huqail AA, Alshalawi SRM, Wirth S, Dilfuza E (2015) Impact of plant growth promoting *Bacillus subtilis* on growth and physiological parameters of *Bassia indica* (Indian Bassia) grown under salt stress. Pak J Bot 47:1735–1741

Abideen Z, Qasim M, Rizvi RF, Gul B, Ansari R, Khan MA (2015) Oilseed halophytes: a potential source of biodiesel using saline degraded lands. Biofuels 6:241–248. https://doi.org/10.1080/17597269.2015.1090812

Abou Zeid AH, El-Khayat Z (2000) Volatile and lipophilic components of *Kochia indica* Weight and their analgesic and antipyretic activities. Pharm Pharmacol Lett 11:1–4

Aboul-Enein AM, El-Ela FA, Shalaby EA, El-Shemy HA (2012) Traditional medicinal plants research in Egypt: studies of antioxidant and anticancer activities. J Med Plants Res 6:689–703. https://doi.org/10.5897/JMPR11.968

Abouri M, El Mousadik A, Msanda F, Boubaker H, Saadi B, Cherifi K (2012) An ethnobotanical survey of medicinal plants used in the Tata Province, Morocco. Int J Med Plants Res 1:99–123

Abtulov MR, Zhelyazkova-Savova MD, Gancheva SM, Kuzmanov KA, Pavlov DV, Kuzmanova VK, Kuzmanov AK, Salbashian MT, Eftimov MT, Valcheva-Kuzmanova SV (2020) Effect of *Kochia scoparia* on carrageenan-induced paw edema in an experimental model of metabolic syndrome. Bulg Chem Commun 52:75–77

Abu Ziada ME, Al-Shami MA, Jalal MJ (2015) Biological aspects and phytochemistry of three desert plants growing in western desert, Egypt. J Plant Production 6:1385–1394. https://doi.org/10.21608/jpp.2015.51870

Acar R, Ozkose A, Isik S, Acar B (2016) Yield performance of forage kochia with different stem color under water shortage Konya province of Turkey. J Agric Econ Dev 4:21–26

Ahmad SS, Butt A, Erum S, Malik B, Jabeen A (2015) Exploring ethnomedico secrets of the herbs of Gatwala Forest Park, Faisalabad. Pakistan Pharm Chem J 2:41–51

Ahmed FA, Baraka DM, Donia AERM, Mostafa RM, Morsy ZM (2022) Phytochemical Investigation, HPLC Analysis and Antimicrobial Activity of Some Plants from *Chenopodiaceae* Family. Egypt Acad J Biolog Sci 13:13–24. https://doi.org/10.21608/eajbsh.2022.215451

Aihemaiti A, Jiang J, Li D, Liu N, Yang M, Meng Y, Zou Q (2018) The interactions of metal concentrations and soil properties on toxic metal accumulation of native plants in vanadium mining area. J Environ Manage 222:216–226. https://doi.org/10.1016/j.jenvman.2018.05.081

Ajaib M, Ali T, Siddiqui MF (2015) A survey of ethnobotanically important herbaceous plants of tehsil jatoi, district muzaffar garh, Punjab, Pakistan. Int J Biol Res 3:87–92

Akhani H, Khoshravesh R (2013) The relationship and different C4 Kranz anatomy of *Bassia eriantha* and *Bassia eriophora*, two often confused Irano-Turanian and Saharo-Sindian species. Phytotaxa 93:1–24. https://doi.org/10.11646/phytotaxa.93.1.1

Akhtar N, Siddique A, Anwar M (2018) Angiospermic plant resources and folk uses in district Karak, Khyber Pakhtunkhwa. Pakistan J Anim Plant Sci 28:1418–1425

Akopian JA, Ghukasyan AG, Shomurodov HF, Adilov BA (2020) On some medicinal plants of *Chenopodiaceae* family in the floras of Armenia and Uzbekistan. Electron J Nat Sci 34:12–17

Al Nasr I (2020) Evaluation of in vitro antitoxoplasmal activity of some medicinal plants collected from Al Qassim, Saudi Arabia. Indian J Tradit Know 19:744–750

Al-Ahmadi MJ, Kafi M (2007) Cardinal temperatures for germination of *Kochia scoparia* (L.). J Arid Environ 68:308–314. https://doi.org/10.1016/j.jaridenv.2006.05.006

Al-Barri SN, Al-Deeb TM, Al-Fawwaz AT, Al-Omari MM, Al-Qaoud KM (2021) Antimicrobial, antioxidant and cytotoxic activities of *Ephedra aphylla* AND *Bassia muricata* plants collected from northern Jordan. Plant Cell Biotechnol Mol Biol 22:47–64

Al-Harbi NA (2017) Diversity of medicinal plants used in the treatment of skin diseases in Tabuk region, Saudi Arabia. J Med Plants Res 11:549–555. https://doi.org/10.5897/JMPR2017.6438

Al-Mussawi AA (2014) Screening for antibacterial activity of twenty two Iraqi wild plants. Glo Adv Res J Microbiol 9:177–182

Alsaggaf MS (2018) Application of wild Saudi plant extracts to control antibiotic resistant Staphylococcus aureus. Egypt J Exp Biol (bot) 14:29–35. https://doi.org/10.5455/egyjebb.20180102120515

Al-Sanafi AE (2018) A review on pharmacological activities of *Kochia scoparia*-a review. Indo Am J P Sci 5:2213–2221. https://doi.org/10.5281/zenodo.1215000

Altundag E, Ozturk M (2011) Ethnomedicinal studies on the plant resources of east Anatolia, Turkey. Proc Soc Behavi Sci 19:756–777. https://doi.org/10.1016/j.sbspro.2011.05.195

Athinarayanan J, Periasamy VS, Alshatwi AA (2018) Fabrication and cytotoxicity assessment of cellulose nanofibrils using *Bassia eriophora* biomass. Int J Biol Macromol 117:911–918. https://doi.org/10.1016/j.ijbiomac.2018.05.144

Avila-Nava A, Medina-Vera I, Rodríguez-Hernández P, Guevara-Cruz M, Heredia-G Canton PK, Tovar AR, Torres N (2021) Oxalate content and antioxidant activity of different Ethnic foods. J Ren Nutr 31:73–79. https://doi.org/10.1053/j.jrn.2020.04.006

Badshah L, Hussain F, Sher Z (2012) An over view of people plant interaction in the rangeland of District Tank, Pakistan. J Med Plants Res 6:2820–2826. https://doi.org/10.5897/JMPR11.1262

Balsevich JJ, Bishop GG, Deibert LK (2009) Use of digitoxin and digoxin as internal standards in HPLC analysis of triterpene saponin-containing extracts. Phytochem Anal 20:38–49. https://doi.org/10.1002/pca.1095

Bibi H, Hussain M, Jan G (2021) Phytochemical analysis and antimicrobial activities of *Kochia indica* (Wight), plant growing in District Karak Khyber Puhktunkhuwa, Pakistan. Pure Appl Biol 10:789–796. https://doi.org/10.19045/bspab.2021.100081

Borkowski B, Drost K (1965) Presence of alkaloids in some species of genus *Kochia* L. Acta Pol Pharm 22:181–184

Bouaziz M, Dhouib A, Loukil S, Boukhris M, Sayadi S (2009) Polyphenols content, antioxidant and antimicrobial activities of extracts of some wild plants collected from the south of Tunisia. Afr J Biotechnol 8:7017–7027

Brignone NF, Denham SS (2021) Toward an updated taxonomy of the South American *Chenopodiaceae* I: Subfamilies Betoideae, Camphorosmoideae, and Salsoloideae1. Ann Mo Bot Gard 106:10–30. https://doi.org/10.3417/2020615

Chemsa AE, Derdouri S, Labbi Z, Acila S, Amara DG, Chouikh A, Kherraz K, Allali A, Zellagui A (2016) Total phenolic and total flavonoid contents of different solvent extracts of *Bassia muricata* (L.) Asch. and evaluation of antibacterial and antioxidant activities. J Chem Pharm Res 8:1317–1321

Chen HY, Lin YH, Hu S, Yang SH, Chen JL, Chen YC (2015) Identifying chinese herbal medicine network for eczema:

implications from a nationwide prescription database. Evid Based Complement Alternat Med 2015:347164. https://doi.org/10.1155/2015/347164

Chen YC, Lin YH, Hu S, Chen HY (2016) Characteristics of traditional Chinese medicine users and prescription analysis for pediatric atopic dermatitis: a population-based study. BMC Complement Altern Med 16:173. https://doi.org/10.1186/s12906-016-1158-1

Chen YL, Hwang TL, Fang JY, Lan YH, Chong KY, Hsieh PW (2017) Polysaccharides from *Kochia scoparia* fruits protect mice from lipopolysaccharide-mediated acute lung injury by inhibiting neutrophil elastase. J Funct Food 38:582–590. https://doi.org/10.1016/j.jff.2017.09.060

Chen J, Li S, Wu W, Xie J, Cheng X, Ye Z, Yin X, Liu Y, Huang Z (2021) Molecular identification and phylogenetic analysis of the traditional chinese medicinal Plant *Kochia scoparia* Using ITS2 Barcoding. Interdiscip Sci 13:128–139. https://doi.org/10.1007/s12539-021-00421-y

Chien PS, Tseng YF, Hsu YC, Lai YK, Weng SF (2013) Frequency and pattern of Chinese herbal medicine prescriptions for urticaria in Taiwan during 2009: analysis of the national health insurance database. BMC Complement Altern Med 13:209. https://doi.org/10.1186/1472-6882-13-209

Cho HD, Kim JH, Park JK, Hong SM, Kim DH, Seo KI (2019) *Kochia scoparia* seed extract suppresses VEGF-induced angiogenesis via modulating VEGF receptor 2 and PI3K/AKT/mTOR pathways. Pharm Biol 57:684–693. https://doi.org/10.1080/13880209.2019.1672753

Chodová D, Mikulka J (2000) Changes in free amino acids content in Kochia (*Kochia scoparia*) resistant to ALS-inhibitors. Plant Protect Sci 36:15–19. https://doi.org/10.17221/9615-PPS

Choi J, Lee KT, Jung H, Park HS, Park HJ (2002) Anti-rheumatoid arthritis effect of the *Kochia scoparia* fruits and activity comparison of momordin ic, its prosapogenin and sapogenin. Arch Pharm Res 25:336–342. https://doi.org/10.1007/BF02976636

Choi YY, Kim MH, Lee JY, Hong J, Kim SH, Yang WM (2014) Topical application of *Kochia scoparia* inhibits the development of contact dermatitis in mice. J Ethnopharmacol 154:380–385. https://doi.org/10.1016/j.jep.2014.04.009

Chung JM, Kim HJ, Park GW, Jeong HR, Choi K, Shin CH (2016) Ethnobotanical study on the traditional knowledge of vascular plant resources in South Korea. Korean J Plant Res 29:62–89. https://doi.org/10.7732/kjpr.2016.29.1.062

Cohen RDH, Iwaasa AD, Mann ME, Coxworth E, Kernan JA (1989) Studies on the feeding value of *Kochia scoparia* (L.) Schrad. Hay for beef cattle. Can J Animal Sci 69:735–743. https://doi.org/10.4141/cjas89-086

Cordeiro ML, Djerassi C (1990) Biosynthetic studies of marine lipids. 25. Biosynthesis of $\Delta^{9\ (11)}$-and Δ^{7}-sterols and saponins in sea cucumbers. J Org Chem 55:2806–2813

Corleto KA, Singh J, Jayaprakasha GK, Patil BS (2018) Storage stability of dietary nitrate and phenolic compounds in beetroot (*Beta vulgaris*) and arugula (*Eruca sativa*) juices. J Food Sci 83:1237–1248. https://doi.org/10.1111/1750-3841.14129

Dai Y, Liu X (2002) Hypoglycemic effect of the total saponins isolated from *Kochia scoparia* fruits. Chinese Wild Plant Resour 21:36–38

Das N, Mishra SK, Bishayee A, Ali ES, Bishayee A (2021) The phytochemical, biological, and medicinal attributes of phytoecdysteroids: an updated review. Acta Pharm Sin B 11:1740–1766. https://doi.org/10.1016/j.apsb.2020.10.012

Davis AM (1979) Forage quality of prostrate kochia compared with three browse species. J Agron 71:822–824. https://doi.org/10.2134/agronj1979.00021962007100050028x

Deuis JR, Dvorakova LS, Vetter I (2017) Methods used to evaluate pain behaviors in rodents. Front Mol Neurosci 10:284. https://doi.org/10.3389/fnmol.2017.00284

Dinan L (1994) Phytoecdysteroids in *Kochia scoparia* (burning bush). J Chromatogr A 658:69–76. https://doi.org/10.1016/0021-9673(94)85207-3

Dinan L, Whiting P, Scott AJ (1998) Taxonomic distribution of phytoecdysteroids in seeds of members of the *Chenopodiaceae*. Biochem Syst Ecol 26:553–576. https://doi.org/10.1016/S0305-1978(98)00005-2

Drost-Karbowska K (1978) Alkaloids of *Kochia scoparia* L. Acta Pol Pharm 35:497–502

Durrani MJ, Razaq A, Muhammad SG, Hussain F (2010) Floristic diversity, ecological, characteristics and ethnobotonical profile of plants of Aghberg Rangelands, Balochistan, Pakistan. Pak J Pl Sci 16:26–33

Dyer WE, Chee PW, Fay PK (1993) Rapid germination of sulfonylurea-resistant *Kochia scoparia* L. accessions is associated with elevated seed levels of branched chain amino acids. Weed Sci 41:18–22. https://doi.org/10.1017/S0043174500057519

El Shaer HM (2010) Halophytes and salt-tolerant plants as potential forage for ruminants in the Near East region. Small Ruminant Res 91:3–12. https://doi.org/10.1016/j.smallrumres.2010.01.010

El-Adawy MM, Aboelez ZR, Rashad AM, Elghandour MM, Adegbeye MJ, Ashtoy MR, Cipriano-Salazar M, Hernández SR, Salem AZ (2020) Effects of dietary inclusion of dried *Kochia indica* Wight tree foliages on growth performance and nutrient digestibility of growing rabbits. Agroforestry Syst 94:1219–1228. https://doi.org/10.1007/s10457-019-00352-0

El-Katori EE, Al-Mhyawi S (2019) Assessment of the *Bassia muricata* extract as a green corrosion inhibitor for aluminum in acidic solution. Green Chem Lett Rev 12:31–48. https://doi.org/10.1080/17518253.2019.1569728

El-Sayed M (1993) Molluscicidal saponins from *Bassia muricata* (L) Murr. Zag J Pharm Sci 2:92–102. https://doi.org/10.21608/zjps.1993.187355

El-Shamy ASI, El-Beih AA, Nassar MI (2012) Composition and antimicrobial activity of essential oil of *Kochia scoparia* (L.) Schrad. J Essent Oil Bear Pl 15:484–488. https://doi.org/10.1080/0972060X.2012.10644076

Elvira-Rendueles B, Zapata JJ, Miralles JC, Moreno JM, García-Sánchez A, Negral L, Moreno-Grau S (2017) Aerobiological importance and allergic sensitization to *Amaranthaceae* under arid climate conditions. Sci Total Environ 583:478–486. https://doi.org/10.1016/j.scitotenv.2017.01.119

Endo T, Kubo-Nakano Y, Lopez RA, Serrano RR, Larrinaga JA, Yamamoto S, Honna T (2014) Growth characteristics of kochia (*Kochia scoparia* L.) and alfalfa (*Medicago sativa* L.) in saline environments. Grassl Sci 60:225–232. https://doi.org/10.1111/grs.12061

Escudero NL, Fernández S, Albarracín G, de Lúquez GN, de Arellano LM, Mucciarelli S (1999) Estudio de la composición química, de dos especies vegetales silvestres en comparación con acelga [Chemical composition of 2 wild vegetable species compared with chard]. Arch Latinoam Nutr 49:40–43

Finley LG, Sherrod LB (1971) Nutritive value of *Kochia scoparia*. II. Intake and digestibility of forage harvested at different maturity stages. J Dairy Sci 54:231–234. https://doi.org/10.3168/jds.S0022-0302(71)85817-4

Gadermaier G, Hauser M, Ferreira F (2014) Allergens of weed pollen: an overview on recombinant and natural molecules. Methods 66:55–66. https://doi.org/10.1016/j.ymeth.2013.06.014

Gancheva S, Tzaneva M, Valcheva-Kuzmanova SV, Zhelyazkova-Savova MD (2020) Antiobesity, antioxidant and hepatoprotective properties of aqueous infusion of *Kochia scoparia* seeds in rats with diet-induced metabolic syndrome. Bulg Chem Commun 52:60–67

Gawrieh S, Noureddin M, Loo N, Mohseni R, Awasty V, Cusi K, Kowdley KV, Lai M, Schiff E, Parmar D, Patel P, Chalasani N (2021) Saroglitazar, a PPAR-α/γ Agonist, for treatment of NAFLD: a randomized controlled double-blind phase 2 Trial. Hepatology 74:1809–1824. https://doi.org/10.1002/hep.31843

GBIF The Global Biodiversity Information Facility (2022) https://www.gbif.org. Accessed 16 January 2022

Ghaffarian MR, Yadavi A, Movahhedi DM, Dabbagh Mohammadi Nassab A, Salehi M (2020) Improvement of physiological indices and biological yield by intercropping of Kochia (*Kochia scoparia*), Sesbania (*Sesbania aculeata*) and Guar (*Cyamopsis tetragonoliba*) under the salinity stress of irrigation water. Physiol Mol Biol Plants 26:1319–1330. https://doi.org/10.1007/s12298-020-00833-y

Gras A, Vallès J, Garnatje T (2020) Filling the gaps: Ethnobotanical study of the Garrigues district, an arid zone in Catalonia (NE Iberian Peninsula). J Ethnobiol Ethnomed 16:34. https://doi.org/10.1186/s13002-020-00386-0

Hammiche V, Maiza K (2006) Traditional medicine in Central Sahara: pharmacopoeia of Tassili N'ajjer. J Ethnopharmacol 105:358–367. https://doi.org/10.1016/j.jep.2005.11.028

Han LK, Nose R, Li W, Gong XJ, Zheng YN, Yoshikawa M, Koike K, Nikaido T, Okuda H, Kimura Y (2006) Reduction of fat storage in mice fed a high-fat diet long term by treatment with saponins prepared from *Kochia scoparia* fruit. Phytother Res 20:877–882. https://doi.org/10.1002/ptr.1981

Han HY, Kim H, Son YH, Lee G, Jeong SH, Ryu MH (2014) Anti-cancer effects of *Kochia scoparia* fruit in human breast cancer cells. Pharmacogn Mag 10(Suppl 3):S661–S667. https://doi.org/10.4103/0973-1296.139812

Han HY, Lee HE, Kim HJ, Jeong SH, Kim JH, Kim H, Ryu MH (2016) *Kochia scoparia* induces apoptosis of oral cancer cells in vitro and in heterotopic tumors. J Ethnopharmacol 192:431–441. https://doi.org/10.1016/j.jep.2016.09.019

Harrison RD, Waldron BL, Jensen KB, Page R, Monaco TA, Horton WH, Palazzo AJ (2002) Forage kochia helps fight range fires. Rangelands 24:3–7

Hashem A, Abd Allah EF, Alqarawi AA, Malik JA, Wirth S, Egamberdieva D (2019) Role of calcium in AMF-mediated alleviation of the adverse impacts of cadmium stress in *Bassia indica* [Wight] AJ Scott. Saudi J Biol Sci 26:828–838. https://doi.org/10.1016/j.sjbs.2016.11.003

Hegnauer R (1964) Chenopodiaceae. In Chemotaxonomie der Pflanzen, Lehrbücher und Monographien aus dem Gebiete der Exakten Wissenschaften, vol 18. Birkhäuser, Basel https://doi.org/10.1007/978-3-0348-9385-5_58

Hernández-Ledesma P, Berendsohn WG, Borsch T, Von Mering S, Akhani H, Arias S, Castañeda-Noa I, Eggli U, Eriksson R, Flores-Olvera H, Fuentes-Bazán S, Kadereit G, Klak C, Korotkova N, Nyffeler R, Ocampo G, Ochoterena H, Oxelman B, Rabeler RK, Sanchez A, Schlumpberger BO, Uotila P (2015) A taxonomic backbone for the global synthesis of species diversity in the angiosperm order Caryophyllales. Willdenowia 45:281–383. https://doi.org/10.3372/wi.45.45301

HKCMMS, Standards Hong Kong Chinese Materia Medica Standards (2012) The Government of the Hong Kong Special Administrative Region. Chinese Medicine Division, Department of Health Hong Kong Chinese Materia Medica Vol. 5 Hong Kong. http://www.cmd.gov.hk/hkcmms/vol5/main.html, Accessed 14 Jan 2021

Hong Y, Wei Z, Jiao XQ, Yan BJ, Zhou DW (2006) Analysis of organic acids accumulated in *Kochia scoparia* shoots and roots by reverse-phase high performance liquid chromatography under salt and alkali stress. Chem Res Chin Univ 22:315–318. https://doi.org/10.1016/S1005-9040(06)60106-2

Houlihan AJ, Conlin P, Chee-Sanford JC (2019) Water-soluble exudates from seeds of *Kochia scoparia* exhibit antifungal activity against *Colletotrichum graminicola*. PLoS ONE 14: e0218104. https://doi.org/10.1371/journal.pone.0218104

Hozhabralsadat MS, Heidari A, Karimian Z, Farzam M (2022) Assessment of plant species suitability in green walls based on API, heavy metal accumulation, and particulate matter capture capacity. https://doi.org/10.21203/rs.3.rs-1148370/v1, Accessed 14 May 2021

Im JH, Lee DE, Park KH, Kim SM, Kang DG (2016) Analysis of experimental articles of Korean medicinal prescriptions on the diuretic effect. Herb. Formula Sci 24:175–193. https://doi.org/10.14374/HFS.2016.24.3.175

Imade RO, Uchendu AP, Akhigbemen AM, Abah M (2020) Evaluation of anticonvulsant activity of *Kochia scoparia* L. Schrad (*Amaranthaceae*) volatile oil. Niger J Pharm Sci 16:85–90. https://doi.org/10.4314/njpr.v16i2.10S

Imran M, Ahmed E, Malik A (2007) Structural determination of kochiosides A-C, new steroidal glucosides from *Kochia prostrata*, by ID and 2D NMR spectroscopy. Magn Reson Chem 45:785–788. https://doi.org/10.1002/mrc.2042

Imran M, Khalid M, Qaiser MN, Iqbal M, Ali B, Sumrra SH, Hussain I, Ibrahim M (2017) Phytochemical studies on *Kochia prostrata*. Int J Agric Appl Sci 9:79–83

Irfan A, Imran M, Al-Sehemi AG, Assiri MA, Hussain A, Khalid N, Ullah S, Abbas G (2020) Quantum chemical,

experimental exploration of biological activity and inhibitory potential of new cytotoxic kochiosides from *Kochia prostrata* (L.) Schrad. J Theor Comput Chem 19:2050012. https://doi.org/10.1142/S0219633620500121

James LF, Williams MC, Bleak AT (1976) Toxicity of *Bassia hyssopifolia* to sheep. J Range Manag 29:284–285. https://doi.org/10.2307/3897082

Javed S, Javaid A, Al-Taie AH, Qureshi MZ (2018a) Identification of antimicrobial compounds from *n*-hexane stem extract of *Kochia indica* by GC-MS analysis. Mycopath 16:51–55

Javed S, Javaid A, Qureshi MZ (2018b) Antifungal phytocomponents in *n*-butanol fraction of leaf extract of *Kochia indica* Wight. Int J Biol Biotech 15:661–666

Jaworska G (2005) Content of nitrates, nitrites, and oxalates in New Zealand spinach. Food Chem 89:235–242. https://doi.org/10.1016/j.foodchem.2004.02.030

Jeon H, Kim DH, Nho YH, Park JE, Kim SN, Choi EH (2016) A mixture of extracts of *Kochia scoparia* and *Rosa multiflora* with PPAR α/γ dual agonistic effects prevents photoaging in hairless mice. Int J Mol Sci 17:1919. https://doi.org/10.3390/ijms17111919

Jo S, Ryu J, Han HY, Lee G, Ryu MH, Kim H (2016) Anti-inflammatory activity of *Kochia scoparia* fruit on contact dermatitis in mice. Mol Med Rep 13:1695–1700. https://doi.org/10.3892/mmr.2015.4698

Joung DK, Kim YH, Yang DW, So GW, Lee KH, Kwon DY, Choi JG, An BK, Ha DS, Shin DW (2012) Antibacterial and synergistic effects of *Kochia scoparia* extracts against methicillin-resistant Staphylococcus aureus. Afr J Microbiol Res 6:2455–2461. https://doi.org/10.5897/AJMR11.1513

Kadereit G, Freitag H (2011) Molecular phylogeny of Camphorosmeae (Camphorosmoideae, Chenopodiaceae): Implications for biogeography, evolution of C4-photosynthesis and taxonomy. Taxon 60:51–78. https://doi.org/10.1002/tax.601006

Kadereit G, Lauterbach M, Pirie MD, Arafeh R, Freitag H (2014) When do different C4 leaf anatomies indicate independent C4 origins? Parallel evolution of C4 leaf types in Camphorosmeae (Chenopodiaceae). J Exp Bot 65:3499–3511. https://doi.org/10.1093/jxb/eru169

Kamel MS, Mohamed KM, Hassanean HA, Ohtani K, Kasai R, Yamasaki K (2001) Acylated flavonoid glycosides from *Bassia muricata*. Phytochemistry 57:1259–1262. https://doi.org/10.1016/s0031-9422(01)00240-0

Kang Y, Luczaj L, Ye S, Zhang S, Kang J (2012) Wild food plants and wild edible fungi of Heihe valley (Qinling Mountains, Shaanxi, central China): herbophilia and indifference to fruits and mushrooms. Acta Soc Bot Pol 81:405–413. https://doi.org/10.5586/asbp.2012.044

Karimi G, Ghorbanli M, Heidari H, Khavari Nejad RA, Assareh MH (2005) The effects of NaCl on growth, water relations, osmolytes and ion content in *Kochia prostrata*. Biol Plant 49:301–304. https://doi.org/10.1007/s10535-005-1304-y

Kernan JA, Coxworth E, Fleming S (1973) Microdetermination of triterpene sapogenin content of *Kochia scoparia* seed using gas-liquid chromatography. J Agric Food Chem 21:232–234. https://doi.org/10.1021/jf60186a041

Khalil HE, Aljeshi YM, Saleh FA, Mohamed TS (2017) Assessment of chemical composition and the antimicrobial and antioxidant activities of *Bassia eriophora* growing in Eastern province of Saudi Arabia. J Chem Pharm Res 9:210–215

Khan MN, Badshah L (2019) Floristic diversity and utility of flora of district Charsadda, Khyber Pakhtunkhwa. Acta Ecol Sin 39:306–320. https://doi.org/10.1016/j.chnaes.2018.10.003

Khan SW, Khatoon S (2008) Ethnobotanical studies on some useful herbs of Haramosh and Bugrote valleys in Gilgit, northern areas of Pakistan. Pak J Bot 40:43–58

Khan MA, Qaiser M (2006) Halophytes of Pakistan: characteristics, distribution and potential economic usages. In: Khan MA, Böer B, Kust GS, Barth HJ (eds) Sabkha Ecosystems. Tasks for Vegetation Science. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5072-5_11

Khan M, Musharaf S, Shinwari ZK (2011) Ethnobotanical importance of halophytes of Noshpho salt mine, District Karak. Pakistan Res Pharm Biotech 3:46–52

Khan T, Khan IA, Rehman A, Ali H (2013) Ethnobotanical studies on non-medicinal plants of Shinaki Valley Hunza, Gilgit-Baltistan. Int J Biosci 3:63–70. https://doi.org/10.12692/ijb/3.11.63-70

Khan S, Jan G, Bibi H, Murad W, Ullah K (2018) An ethnomedicinal survey of plants used in traditional medicine in arid and semi-arid zone of Bahadur Khel, district Karak, Khyber Pakhtunkhwa, Pakistan. J Pharmacogn Phytochem 7:337–349

Khan Z, Hong SM, Lee JW, Moon EY, Huh J, Chang KA, Kim SY (2021) Potential of N-trans feruloyl tyramine from *Lycium barbarum* fruit extract on neurogenesis and neurotrophins; targeting TrkA/ERK/CREB signaling pathway. J Funct Food 80:104432. https://doi.org/10.1016/j.jff.2021.104432

Khare C (2007) *Kochia indica* Wt. In: Khare C (ed) Indian Medicinal Plants. Springer, New York, NY. https://doi.org/10.1007/978-0-387-70638-2_861

Kianinodeh F, Tabatabaei M, Alibakhshi A, Gohari M, Tari K (2017) Anti-tumor effects of essential oils of red clover and ragweed on MCF-7 breast cancer cell line. Multidiscip Cancer Investig 1:17–23. https://doi.org/10.21859/mci-01043

Kim NY, Lee JS, Kim SJ, Park MJ, Kim SH (2005a) Evaluation of the Efficacy of *Kochiae fructus* Extract in the Alleviation of Carbon Tetrachloride-induced Hepatotoxicity in Rats. Nutritional Sci 8:212–218

Kim NY, Lee MK, Park MJ, Kim SJ, Park HJ, Choi JW, Kim SH, Cho SY, Lee JS (2005b) Momordin Ic and oleanolic acid from *Kochiae Fructus* reduce carbon tetrachloride-induced hepatotoxicity in rats. J Med Food 8:177–183. https://doi.org/10.1089/jmf.2005.8.177

Kirtikar KR, Basu BD (1935) In: Indian medicinal plants, 2nd edn. Lalit Mohan Basu, Allahabad

Kleiman R, Rawls MH, Earle FR (1972) cis-5-Monoenoic fatty acids in some *Chenopodiaceae* seed oils. Lipids 7:494–496. https://doi.org/10.1007/BF02533169

Knipfel JE, Kernan JA, Coxworth EC, Cohen RDH (1989) The effect of stage of maturity on the nutritive value of *Kochia*. Can J Anim Sci 69:1111–1114. https://doi.org/10.4141/cjas89-130

Kubo M, Matsuda H, Dai Y, Ido Y, Yoshikawa M (1997) Studies on *Kochiae Fructus*. I. Antipruritogenic effect of 70% ethanol extract from *kochiae fructus* and its active component. Yakugaku Zasshi 117:193–201. https://doi.org/10.1248/yakushi1947.117.4_193

Kumar V, Jha P, Jugulam M, Yadav R, Stahlman PW (2019) Herbicide-resistant kochia (*Bassia scoparia*) in North America: a review. Weed Sci 67:4–15. https://doi.org/10.1017/wsc.2018.72

Lakhdari W, Dehliz A, Acheuk F, Mlik R, Hammi H, Doumandji-Mitiche B, Gheriani S, Berrekbia M, Guermit K, Chergui S (2016) Ethnobotanical study of some plants used in traditional medicine in the region of Oued Righ (Algerian Sahara). J Med Plants Stud 4:204–211

Lauriault L, Waldron BL (2020) Genotype and planting date influence on establishment and growth of Bassia prostrata (L) AJ Scott in a semiarid subtropical dry winter region. Agronomy 10:251. https://doi.org/10.3390/agronomy10020251

Lee MY, Shin IS, Lim HS, Seo CS, Ha H, Shin HK (2011) *Kochia scoparia* fruit attenuates allergic airway inflammation in ovalbumin (OVA)-induced murine asthma model. Inhal Toxicol 23:938–946. https://doi.org/10.3109/08958378.2011.627392

Lee YJ, Kwon OJ, Kim HY, Namgung S, Lee JY, Yu YC, Kang DG (2016) Screening of positive inotropic effect from herbal extracts in beating rabbit atria. J Physiol Pathol Korean Med 30:40–46. https://doi.org/10.15188/kjopp.2016.02.30.1.40

Lee HY, Lee JY, Kang SH, Chung KS (2017) The ethnobotanical investigation around national parks in the Northern Area of Province Gyeongsangbuk-do, Korea. Korean J Plant Res 30:623–639. https://doi.org/10.7732/kjpr.2017.30.6.623

Lin Y, Wang SP, Zhang JY, Zhuo ZY, Li XR, Zhai CJ, Li XX, Qi FH, Ding X, Chen CY, Zhou J, Li J, Liu Q, Qiu LL, Zhang YQ (2021) Ethnobotanical survey of medicinal plants in Gaomi, China. J Ethnopharmacol 265:113228. https://doi.org/10.1016/j.jep.2020.113228

Lirussi D, Li J, Prieto JM, Gennari M, Buschiazzo H, Ríos JL, Zaidenberg A (2004) Inhibition of *Trypanosoma cruzi* by plant extracts used in Chinese medicine. Fitoterapia 75:718–723. https://doi.org/10.1016/j.fitote.2004.09.017

Liu Q, Luyten W, Pellens K, Wang Y, Wang W, Thevissen K, Liang Q, Cammue BP, Schoofs L, Luo G (2012) Antifungal activity in plants from Chinese traditional and folk medicine. J Ethnopharmacol 143:772–778. https://doi.org/10.1016/j.jep.2012.06.019

Liu XX, Zhou K, Hu Y, Jin R, Lu LL, Jin CW, Lin XY (2015) Oxalate synthesis in leaves is associated with root uptake of nitrate and its assimilation in spinach (*Spinacia oleracea* L.) plants. J Sci Food Agric 95:2105–2116. https://doi.org/10.1002/jsfa.6926

Liubertas T, Kairaitis R, Stasiule L, Capkauskiene S, Stasiulis A, Viskelis P, Viškelis J, Urbonaviciene D (2020) The influence of amaranth (*Amaranthus hypochondriacus*) dietary nitrates on the aerobic capacity of physically active young persons. J Int Soc Sports Nutr 17:37. https://doi.org/10.1186/s12970-020-00366-5

Lodhi MAK (1979) Germination and decreased growth of *Kochia scoparia* in relation to its autoallelopathy. Can J Bot 57:1083–1088. https://doi.org/10.1139/b79-132

López-Aguilar R, Rodríguez-Quezada G, Lucero-Arce A, Naranjo-Murillo A (2013) Use of high-salinity waters to grow *Kochia scoparia* L. Schrad. As alternative fodder in saline environments in northwestern Mexico. Interciencia 38:325–331

Louhaichi M, Salkini AK, Estita HE, Belkhir S (2011) Initial assessment of medicinal plants across the Libyan Mediterranean coast. Adv Environ Biol 5:359–370

Lu C, Zhang HY, Ji J, Wang GX (2012a) *In vivo* anthelmintic activity of *Dryopteris crassirhizoma*, *Kochia scoparia*, and *Polygala tenuifolia* against *Dactylogyrus intermedius* (Monogenea) in goldfish (*Carassius auratus*). Parasitol Res 110:1085–1090. https://doi.org/10.1007/s00436-011-2592-0

Lu XH, Xu XD, Fu HW, Chen B, Tian JK, Zhang L (2012b) Study on chemical constituents of *Kochia scoparia*. Chin Pharm J 5:338–342

Luo M, Zeng B, Wang H, Yang Z, Peng Y, Zhang Y, Wang C (2021) *Kochia scoparia* saponin momordin Ic modulates HaCaT cell proliferation and apoptosis via the Wnt/β-catenin pathway. Evid Based Complement Alternat Med 2021:5522164. https://doi.org/10.1155/2021/5522164

Ma Y, Guo L, Wang H, Bai B, Shi D (2011) Accumulation, distribution, and physiological contribution of oxalic acid and other solutes in an alkali-resistant forage plant, *Kochia sieversiana*, during adaptation to saline and alkaline conditions. J Plant Nutr Soil Sc 174:655–663. https://doi.org/10.1002/jpln.201000337

Ma Y, Wang XP, Zhang SF, Shi DC, Sheng LX (2016) Effects of salt and alkali stress on growth, accumulation of oxalic acid, and activity of oxalic acid-metabolizing enzymes in *Kochia sieversiana*. Biol Plant 60:774–782. https://doi.org/10.1007/s10535-016-0650-2

Matsuda H, Dai Y, Ido Y, Ko S, Yoshikawa M, Kubo M (1997a) Studies on *Kochiae fructus* III. Antinociceptive and antiinflammatory Effects of 70% ethanol extract and its component, momordin Ic from dried fruits of *Kochia scoparia* L. Biol Pharm Bull 20:1086–1091. https://doi.org/10.1248/bpb.20.1086

Matsuda H, Dai Y, Ido Y, Yoshikawa M, Kubo M (1997b) Studies on *Kochiae fructus* IV. anti-allergic effects of 70% ethanol extract and its component, momordin Ic from dried fruits of *Kochia scoparia* L. Biol Pharm Bull 20:1165–1170. https://doi.org/10.1248/bpb.20.1165

Matsuda H, Dai Y, Ido Y, Murakami T, Matsuda H, Yoshikawa M, Kubo M (1998a) Studies on *Kochiae Fructus*. V. Antipruritic effects of oleanolic acid glycosides and the structure-requirement. Biol Pharm Bull 21:1231–1233. https://doi.org/10.1248/bpb.21.1231

Matsuda H, Li Y, Murakami T, Matsumura N, Yamahara J, Yoshikawa M (1998b) Antidiabetic principles of natural medicines. III. Structure-related inhibitory activity and action mode of oleanolic acid glycosides on hypoglycemic activity. Chem Pharm Bull 46:1399–1403. https://doi.org/10.1248/cpb.46.1399

Matsuda H, Li Y, Murakami T, Yamahara J, Yoshikawa M (1998c) Protective effects of oleanolic acid oligoglycosides on ethanol-or indomethacin-induced gastric mucosal lesions in rats. Life Sci 63:PL245–PL250. https://doi.org/10.1016/s0024-3205(98)00426-3

Matsuda H, Li Y, Murakami T, Yamahara J, Yoshikawa M (1999a) Structure-related inhibitory activity of oleanolic

acid glycosides on gastric emptying in mice. Bioorg Med Chem 7:323–327. https://doi.org/10.1016/s0968-0896(98)00207-7

Matsuda H, Li Y, Yamahara J, Yoshikawa M (1999b) Inhibition of gastric emptying by triterpene saponin, momordin Ic, in mice: roles of blood glucose, capsaicin-sensitive sensory nerves, and central nervous system. J Pharmacol Exp Ther 289:729–734

Matsuda H, Li Y, Yoshikawa M (1999c) Roles of capsaicin-sensitive sensory nerves, endogenous nitric oxide, sulfhydryls, and prostaglandins in gastroprotection by momordin Ic, an oleanolic acid oligoglycoside, on ethanol-induced gastric mucosal lesions in rats. Life Sci 65: PL27-32. https://doi.org/10.1016/s0024-3205(99)00241-6

Mazzio EA, Soliman KF (2009) *In vitro* screening for the tumoricidal properties of international medicinal herbs. Phytother Res 23:385–398. https://doi.org/10.1002/ptr.2636

Mi Y, Xiao C, Du Q, Wu W, Qi G, Liu X (2016) Momordin Ic couples apoptosis with autophagy in human hepatoblastoma cancer cells by reactive oxygen species (ROS)-mediated PI3K/Akt and MAPK signaling pathways. Free Radic Biol Med 90:230–242. https://doi.org/10.1016/j.freeradbiomed.2015.11.022

Moein M, Zarshenas MM, Khademian S, Razavi AD (2015) Ethnopharmacological review of plants traditionally used in Darab (south of Iran). Trends Pharm Sci 1:39–43

Mohamed KM, Hasanean HH, Ohtani K, Yamasaki K (1998) Triterpenoidal saponins from *Kochia indica* Wight. Bull Pharm Sci 21:27–36. https://doi.org/10.21608/bfsa.1998.67832

Mohammedi H, Idjeri-Mecherara S, Menaceur F, Hassani A (2019) The effect of solvents and extraction procedure on the recovery of phenolic compounds and the antioxidant capacity of Algerian *Bassia muricata* L. extracts. Chem J Mold 14:79–88. https://doi.org/10.19261/cjm.2019.637

Morita Y, Matsumura E, Tsujibo H, Yasuda M, Sakagami Y, Okabe T, Ishida N, Inamori Y (2001) Biological activity of α-thujaplicin, the minor component of *Thujopsis dolabrata* Sieb. et Zucc. var. hondai Makino. Biol Pharm Bull 24:607–611. https://doi.org/10.1248/bpb.24.607

Moubasher HA, Hegazy AK, Mohamed NH, Moustafa YM, Kabiel HF, Hamad AA (2015) Phytoremediation of soils polluted with crude petroleum oil using *Bassia scoparia* and its associated rhizosphere microorganisms. Int Biodeter Biodegr 98:113–120. https://doi.org/10.1016/j.ibiod.2014.11.019

Munekata PES, Pateiro M, Domínguez R, Pollonio MAR, Sepúlveda N, Andres SC, Reyes J, Santos EM, Lorenzo JM (2021) *Beta vulgaris* as a natural nitrate source for meat products: a review. Foods 10:2094. https://doi.org/10.3390/foods10092094

Musa A, Al-muaikel NS, Abdel-Bakky MS (2016) Phytochemical and pharmacological evaluations of ethanolic extract of *Bassia eriophora*. Der Pharma Chem 8:169–178

Musa A, Al-Sanea MM, Alotaibi NH, Alnusaire TS, Ahmed SR, Mostafa EM (2021) In silico study, protein kinase inhibition and antiproliferative potential of flavonoids isolated from *Bassia eriophora* (Schrad.) Growing in KSA. Indian J Pharm Educ 55:483–490. https://doi.org/10.5530/ijper.55.2.86

Na SH, Shin YC, Ko SG (2006) Effects of kochiae fructus extracts on the expression of angiogeneis and inflammation related proteins. J Physiol Pathol Korean Med 20:557–562

Nair J, Lima PM, Abdalla AL, Molnar LJ, Wang Y, McAllister TA, Geddes CM (2021) Kochia (*Bassia scoparia*) harvest date impacts nutrient composition, in vitro degradability, and feed value more than pre-harvest herbicide treatment or herbicide resistance traits. Anim Feed Sci Technol 280:115079. https://doi.org/10.1016/j.anifeedsci.2021.115079

Nam K, Lee SK (2000) Evaluation of cytotoxic potential of natural products in cultured human cancer cells. Nat Prod Sci 6:183–188

Narumi Y, Inoue M, Tanaka T, Takatsuto S (2001) Sterols in Kochia scoparia Fruit. J Oleo Sci 50:913–916. https://doi.org/10.5650/jos.50.913

Nedelcheva AM, Dogan Y, Guarrera PM (2007) Plants traditionally used to make brooms in several European countries. J Ethnobiol Ethnomed 3:20. https://doi.org/10.1186/1746-4269-3-20

Olagbemiro TO, Birkett MA (1999) Mordue (Luntz) AJ, Pickett JA (1999) Production of (5 R, 6 S)-6-acetoxy-5-hexadecanolide, the mosquito oviposition pheromone, from the seed oil of the summer cypress plant, *Kochia scoparia* (*Chenopodiaceae*). J Agric Food Chem 47:3411–3415. https://doi.org/10.1021/jf990294b

Orlovsky NS, Japakova UN, Shulgina I, Volis S (2011) Comparative study of seed germination and growth of *Kochia prostrata* and *Kochia scoparia* (*Chenopodiaceae*) under salinity. J Arid Environ 75:532–537. https://doi.org/10.1016/j.jaridenv.2011.01.014

Othman A, Amen Y, Matsumoto M, Nagata M, Shimizu K (2021a) Bassiamide A, a new alkaloid from xero-halophyte *Bassia indica* Wight. Nat Prod Res 18:1–9. https://doi.org/10.1080/14786419.2021.1872572

Othman A, Amen Y, Shimizu K (2021b) A novel acylated flavonol tetraglycoside and rare oleanane saponins with a unique acetal-linked dicarboxylic acid substituent from the xero-halophyte *Bassia indica*. Fitoterapia 152:104907. https://doi.org/10.1016/j.fitote.2021.104907

Othman A, Sayed AM, Amen Y, Shimizu K (2022) Possible neuroprotective effects of amide alkaloids from *Bassia indica* and *Agathophora alopecuroides*: *in vitro* and *in silico* investigations. RSC Adv 12:18746–18758. https://doi.org/10.1039/d2ra02275c

Panetta FD (2015) Weed eradication feasibility: lessons of the 21st century. Weed Res 55:226–238. https://doi.org/10.1111/wre.12136

Park S, Lee DK, Whang YH, Yang CH (2000) Momordin I, a compound of ampelopsis radix, inhibits AP-1 activation induced by phorbol ester. Cancer Lett 152:1–8. https://doi.org/10.1016/s0304-3835(99)00413-9

Petruk A, Pankova T, Osmonali B, Lomonosova M (2021) Phenolic compounds of *Bassia prostrata* (*Chenopodiaceae*). BIO Web Conf 38:00097. https://doi.org/10.1051/bioconf/20213800097

POWO. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:30025657-2 Accessed 28 September 2022

Rakhmankulova ZF, Shuyskaya EV, Shcherbakov AV, Fedyaev VV, Biktimerova GY, Khafisova RR, Usmanov IY (2015) Content of proline and flavonoids in the shoots of halophytes inhabiting the South Urals. Russ J Plant Physiol 62:71–79. https://doi.org/10.1134/S1021443715010112

Rankins DL Jr, Smith GS, Hallford DM (1991a) Altered metabolic hormones, impaired nitrogen retention, and hepatotoxicosis in lambs fed *Kochia scoparia* hay. J Anim Sci 69:2932–2940. https://doi.org/10.2527/1991.6972932x

Rankins DL Jr, Smith GS, Hallford DM (1991b) Serum constituents and metabolic hormones in sheep and cattle fed *Kochia scoparia* hay. J Anim Sci 69:2941–2946. https://doi.org/10.2527/1991.6972941x

Rashid A, Marwat SK (2006) Ethnobotanical study of important wild plants of Bahadur Khel tract (tehsil Banda Daud Shah) in Karak district. Gomal Univ J Res 2:165–172

Ravet K, Sparks CD, Dixon AL, Küpper A, Westra EP, Pettinga DJ, Tranel PJ, Felix J, Morishita DW, Jha P, Kniss A, Stahlman PW, Neve P, Patterson EL, Westra P, Gaines TA (2021) Genomic-based epidemiology reveals independent origins and gene flow of glyphosate resistance in *Bassia scoparia* populations across North America. Mol Ecol 30:5343–5359. https://doi.org/10.1111/mec.16215

Riasi A, Mesgaran MD, Stern MD, Moreno MR (2008) Chemical composition, in situ ruminal degradability and post-ruminal disappearance of dry matter and crude protein from the halophytic plants *Kochia scoparia*, *Atriplex dimorphostegia*, *Suaeda arcuata* and *Gamanthus gamacarpus*. Anim Feed Sci Technol 141:209–219. https://doi.org/10.1016/j.anifeedsci.2007.06.014

Ryabushkina N, Gemedjieva N, Kobaisy M, Cantrell CL (2008) Brief review of Kazakhstan flora and use of its wild species. Asian Australas J Plant Sci Biotechnol 2:64–71

Sachula G, Zhang YY, Hui Zhao K (2020) Wild edible plants collected and consumed by the locals in Daqinggou, Inner Mongolia. China J Ethnobiol Ethnomed 16:60. https://doi.org/10.1186/s13002-020-00411-2

Said RB, Rahali S, Aissa MAB, Abdel-Farid IB, Mohamed AA, Tangour B, Kowalczyk M, Oleszek W, Stochmal A, Hamed AI (2021) Fingerprinting profile of flavonol glycosides from *Bassia eriophora* using negative electrospray ionization, computational studies and their antioxidant activities. J Mol Struct 1241:130689. https://doi.org/10.1016/j.molstruc.2021.130689

Salehi B, Tumer TB, Ozleyen A, Peron G, Dallacqua S, Rajkovic J, Naz R, Nosheen A, Madau FN, Labanca F, Milella L, Tommasi N, Coutinho HD, Sharifi-Rad J, Verma DR, Martorell M, Martins N (2019) Plants of the genus *Spinacia*: from bioactive molecules to food and phytopharmacological applications. Trends Food Sci Technol 88:260–273. https://doi.org/10.1016/j.tifs.2019.03.028

Salt TA, Adler JH (1985) Diversity of sterol composition in the family *Chenopodiaceae*. Lipids 20:594–601. https://doi.org/10.1007/BF02534285

Sasa M, Inoue I, Shinoda Y, Takahashi S, Seo M, Komoda T, Awata T, Katayama S (2009) Activating effect of Momordin, extract of bitter melon (*Momordica charantia* L.), on the promoter of human PPARδ. J Atheroscler Thromb 16:888–892. https://doi.org/10.5551/jat.2790

Seitimova GA, Eskalieva BK, Burasheva GS, Choudhary MI (2018) Phenanthrenes from *Kochia prostrata*. Chem Nat Compd 54:749–750. https://doi.org/10.1007/s10600-018-2461-5

Seitimova GA, Alzhanbayeva AM, Burasheva GS, Yeskaliyeva BK, Choudhary M (2016) Phytochemical study of *Kochia prostrata*. Int J Biol Chem 9:51–54. https://doi.org/10.26577/2218-7979-2016-9-2-51-54

Seo KS, Kim JH, Kim YG (2007) Anti-proliferative and apoptosis inducing effect of momordin I on oral carcinoma (KB) cells. Int J Oral Sci 32:113–118

Shaker KH, Al Jubiri SM, Abd Elhady FK, AlSchemi AG (2013) New compounds from *Bassia muricata* and *Fagonia indica*. Int J Pharm Sci Rev Res 23:231–236

Shelef O, Gross A, Rachmilevitch S (2012) The use of *Bassia indica* for salt phytoremediation in constructed wetlands. Water Res 46:3967–3976. https://doi.org/10.1016/j.watres.2012.05.020

Sher H, Aldosari A (2013) Ethnobotanical survey on plants of veterinary importance around Al-Riyadh (Saudi Arabia). Afr J Pharm Pharmacol 7:1404–1410. https://doi.org/10.5897/AJPP2012.2177

Shi GL, Zhao LL, Liu SQ, Cao H, Clarke SR, Sun JH (2006) Acaricidal activities of extracts of *Kochia scoparia* against *Tetranychus urticae, Tetranychus cinnabarinus, and Tetranychus viennensis* (Acari: Tetranychidae). J Econ Entomol 99:858–863. https://doi.org/10.1603/0022-0493-99.3.858

Shi R, Liang L, Liu W, Zeb A (2022) *Kochia scoparia* L., a newfound candidate halophyte, for phytoremediation of cadmium-contaminated saline soils. Environ Sci Pollut R. https://doi.org/10.1007/s11356-022-18895-8

Shin KM, Kim YH, Park WS, Kang I, Ha J, Choi JW, Park HJ, Lee KT (2004) Inhibition of methanol extract from the fruits of *Kochia scoparia* on lipopolysaccharide-induced nitric oxide, prostagladin E2, and tumor necrosis factor-α production from murine macrophage RAW 264.7 cells. Biol Pharm Bull 27:538–543. https://doi.org/10.1248/bpb.27.538

Shin T, Fujikawa K, Moe AZ, Uchiyama H (2018) Traditional knowledge of wild edible plants with special emphasis on medicinal uses in Southern Shan State, Myanmar. J Ethnobiol Ethnomed 14:48. https://doi.org/10.1186/s13002-018-0248-1

Song L, Niu X, Tian Y, Xiao Y (2021) Assessment of PAH degradation potential of native species from a coking plant through identifying of the beneficial bacterial community within the rhizosphere soil. Chemosphere 264:128513. https://doi.org/10.1016/j.chemosphere.2020.128513

Steppuhn H, Green DG, Knipfel JE, Coxworth E, Kernan JA (1994) Response of *Kochia scoparia* to nitrogen fertilization on a saline soil. Can J Soil Sci 74:267–275. https://doi.org/10.4141/cjss94-038

Sukhorukov AP, Kushunina MA (2020) Morphology, nomenclature and distribution of *Bassia monticola* (*Chenopodiaceae-Amaranthaceae*), a poorly known species from Western Asia. Novit Syst Plant Vasc 51:13–17. https://doi.org/10.31111/novitates/2020.51.13

Tashiro A, Uchiyama Y, Kohsaka R (2019) Impact of geographical indication schemes on traditional knowledge in changing agricultural landscapes: an empirical analysis from Japan. J Rural Stud 68:46–53. https://doi.org/10.1016/j.jrurstud.2019.03.014

Thangnipon W, Suwanna N, Kitiyanant N, Soi-Ampornkul R, Tuchinda P, Munyoo B, Nobsathian S (2012) Protective role of *N*-trans-feruloyltyramine against β-amyloid peptide-induced neurotoxicity in rat cultured cortical neurons. Neurosci Lett 513:229–232. https://doi.org/10.1016/j.neulet.2012.02.047

Torbiak AT, Blackshaw RE, Brandt RN, Hamman B, Geddes CM (2021) Herbicide strategies for managing glyphosate-resistant and-susceptible kochia (*Bassia scoparia*) in spring wheat. Can J Plant Sci 101:607–620. https://doi.org/10.1139/cjps-2020-0303

Tripathi YC, Prabhu VV, Pal RS, Mishra RN (1996) Medicinal plants of Rajasthan in Indian system of medicine. Anc Sci Life 15(3):190–212

Tse WP, Che CT, Liu K, Lin ZX (2006) Evaluation of the anti-proliferative properties of selected psoriasis-treating Chinese medicines on cultured HaCaT cells. J Ethnopharmacol 108:133–141. https://doi.org/10.1016/j.jep.2006.04.023

Umair M, Altaf M, Abbasi AM (2017) An ethnobotanical survey of indigenous medicinal plants in Hafizabad district, Punjab-Pakistan. PLoS ONE 12:e0177912. https://doi.org/10.1371/journal.pone.0177912

Waldron BL, ZoBell DR, Olson KC, Jensen KB, Snyder DL (2006) Stockpiled forage kochia to maintain beef cows during winter. Rangel Ecol Manag 59:275–284. https://doi.org/10.2111/05-121R1.1

Waldron BL, Eun JS, ZoBell DR, Olson KC (2010) Forage kochia (*Kochia prostrata*) for fall and winter grazing. Small Ruminant Res 91:47–55. https://doi.org/10.1016/j.smallrumres.2010.01.011

Waldron BL, Sagers JK, Peel MD, Rigby CW, Bugbee B, Creech JE (2020) Salinity reduces the forage quality of forage kochia: A halophytic *Chenopodiaceae* shrub. Rangel Ecol Manag 73:384–393. https://doi.org/10.1016/j.rama.2019.12.005

Wang J, Yuan L, Xiao H, Xiao C, Wang Y, Liu X (2013) Momordin Ic induces HepG2 cell apoptosis through MAPK and PI3K/Akt-mediated mitochondrial pathways. Apoptosis 18:751–765. https://doi.org/10.1007/s10495-013-0820-z

Wang J, Yuan L, Cheng B, Li W, Xiao C, Wang Y, Liu X (2014a) Antioxidant capacity and antitumor activity of *Fructus Kochiae* extracts. Qual Assur Saf Crop 6:383–393. https://doi.org/10.3920/QAS2012.0218

Wang J, Yuan L, Xiao H, Wang C, Xiao C, Wang Y, Liu X (2014b) A novel mechanism for momordin Ic-induced HepG2 apoptosis: involvement of PI3K- and MAPK-dependent PPARγ activation. Food Funct 5:859–868. https://doi.org/10.1039/c3fo60558b

Wang H, Hu W, Zhou T, Liu H (2018) Capillary electrophoresis method for determining the content of rutin in *Fructus Kochiae*. Aer Adv Eng Res 169:103–106. https://doi.org/10.2991/mseee-18.2018.18

Weber DJ, Gul B, Khan A, Williams T, Williams N, Wayman P, Warner S (2001) Composition of vegetable oil from seeds of native halophytes In: McArthur E. Durant, Fairbanks DJ, comps. Shrubland ecosystem genetics and biodiversity. Ogden, UT, US Department of Agriculture, Forest Service, Rocky Mountain Research Station

Wen Y, Chen Y, Cui Z, Li J, Wang Z (1995) Triterpenoid glycosides from the fruits of *Kochia scoparia*. Planta Med 61:450–452. https://doi.org/10.1055/s-2006-958134

Weng SW, Chen BC, Wang YC, Liu CK, Sun MF, Chang CM, Lin JG, Yen HR (2016) Traditional Chinese medicine use among patients with psoriasis in Taiwan: a nationwide population-based study. Evid Based Complement Alternat Med 2016:3164105. https://doi.org/10.1155/2016/3164105

Whang WK, Hahn DR (1991) Saponins from the fructus of *Kochia scoparia*. Arch Pharm Res 14:176–180. https://doi.org/10.1007/BF02892025

Whitney HM, Sayanova O, Pickett JA (2004) Napier JA (2004) Isolation and expression pattern of two putative acyl-ACP desaturase cDNAs from *Bassia scoparia*. J Exp Bot 55 (397):787–789. https://doi.org/10.1093/jxb/erh072

Wu J, Lei H, Zhang J, Chen X, Tang C, Wang W, Xu H, Xiao W, Gu W, Wu Y (2016) Momordin Ic, a new natural SENP1 inhibitor, inhibits prostate cancer cell proliferation. Oncotarget 7:58995–59005. https://doi.org/10.18632/oncotarget.10636

Xia YF, Wang Q, Dai Y, Pei K (2002a) Determination of the content of saponin in *Kochia scoparia* fruits from different producing areas. Zhongguo Zhong Yao Za Zhi 27:890–893

Xia YF, Wang Q, Xu DR, Ye WC, Dai Y (2002b) Determination of the content of momordin Ic in *Kochia scoparia* by HPLC. J China Pharm Univ 33:216–218

Xianjun F, Xirui X, Jie T, Huiwen M, Shaojun Z, Qiaoyun L, Yunxin L, Xuqun S (2021) Momordin Ic induces G0/1 phase arrest and apoptosis in colon cancer cells by suppressing SENP1/c-MYC signaling pathway. J Pharmacol Sci 146:249–258. https://doi.org/10.1016/j.jphs.2021.04.007

Xiao X, Miller LL, Parchert KJ, Hayes D, Hochrein JM (2016) Atmospheric solids analysis probe mass spectrometry for the rapid identification of pollens and semi-quantification of flavonoid fingerprints. Rapid Commun Mass Spectrom 30:1639–1646. https://doi.org/10.1002/rcm.7601

Xiao Z, Xiao S, Zhang Y, Pan T, Ouyang B (2018) The anti-inflammatory effect of *fructus kochiae* on allergic contact dermatitis rats via pERK1/2/TLR4/NF-κB pathway activation. Evid Based Complement Alternat Med 2018:1096920. https://doi.org/10.1155/2018/1096920

Xiaoyan Z, Li R, Chun Y, Hui C (2019) Antifungal activity of the extracts from *fructus kochiae* against apple canker pathogen *Valsa mali* and their impacts on the cell structure and function. J Plant Prot 46:362–368

Xu Y, Huang H, Guo ZX, Zhang N, Kong DY, Hua ML (2012) Chemical constituents of antifungal extract from *Kochiae Fructus*. Chin Tradit Patent Med 34:1726–1729

Xu YH, Huang H, Zhang N, Kong DY, Hua ML (2014) Studies on the flavone glycosides from *Fructus Kochiae*. J Asian Nat Prod Res 16:141–147. https://doi.org/10.1080/10286020.2013.824427

Yamada S, Yamaguchi T, Lopez D, Aguilar R (2016) Characteristics of Na, K, Ca, Mg and P absorption in Kochia plant (*Kochia scoparia* (L.) Schrad.) under sainity stress. Sand Dune Res 63:1–8

Yamaguchi T, Fujita K, Sakai K (1999) Biological activity of extracts from *Cupressus lusitanica* cell culture. J Wood Sci 45:170–173. https://doi.org/10.1007/BF01192336

Yang C, Chong J, Li C, Kim C, Shi D, Wang D (2007) Osmotic adjustment and ion balance traits of an alkali resistant halophyte *Kochia sieversiana* during adaptation to salt and alkali conditions. Plant Soil 294:263–276. https://doi.org/10.1007/s11104-007-9251-3

Yoo SR, Jeong SJ, Lee NR, Shin HK, Seo CS (2017) Quantification analysis and *in vitro* anti-inflammatory effects of 20-hydroxyecdysone, momordin ic, and oleanolic acid from the fructus of *Kochia scoparia*. Pharmacogn Mag 13:339–344. https://doi.org/10.4103/0973-1296.211023

Yoshikawa M, Dai Y, Shimada H, Morikawa T, Matsumura N, Yoshizumi S, Matsuda H, Matsuda H, Kubo M (1997a) Studies on Kochiae fructus. II. On the saponin constituents from the fruit of Chinese *Kochia scoparia* (*Chenopodiaceae*): chemical structures of kochianosides I, II, III, and IV. Chem Pharm Bull 45:1052–1055. https://doi.org/10.1248/cpb.45.1052

Yoshikawa M, Shimada H, Morikawa T, Yoshizumi S, Matsumura N, Marakami T, Matsuda H, Hori K, Yamahara J (1997b) Medicinal foodstuffs. VII. On the saponin constituents with glucose and alcohol absorption-inhibitory activity from a food garnish Tonburi, the fruit of Japanese *Kochia scoparia* (L.) Schrad.: structures of scoparianosides A, B, and C. Chem Pharm Bull 45:1300–1305. https://doi.org/10.1248/cpb.45.1300

Youssef SA (2013) Medicinal and non-medicinal uses of some plants found in the middle region of Saudi Arabia. J Med Plant Res 7:2501–2517. https://doi.org/10.5897/JMPR12.798

Yusufoglu HS (2015a) Analgesic, antipyretic, nephritic and antioxidant effects of the aerial parts of *Bassia eriophora* (Family: *Chenopodiaceae*) plant on rats. Asian Pac J Trop Dis 5:559–563. https://doi.org/10.1016/S2222-1808(15)60836-2

Yusufoglu HS (2015b) Pharmacognostic and wound healing studies of the leaves of *Bassia eriophora* (Family: *Chenopodiaceae*) on albino rats. Annu Res Rev Biol 5:400–408. https://doi.org/10.9734/ARRB/2015/13069

Zahran MA, Wahid AAA (1982) Halophytes and human welfare. In: Sen DN, Rajpurohit KS (eds) Contributions to the ecology of halophytes. Tasks for vegetation science. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-8037-2_17

Zarinhadideh F, Amini A, Assarehzadegan MA, Borsi SH, Sepahi N, Ali-Sadeghi H (2015) Immunochemical and molecular characterization of allergenic profilin (Koc s 2) from *Kochia scoparia* pollen. J Korean Soc Appl Biol Chem 58:443–451. https://doi.org/10.1007/s13765-015-0063-5

Zhang W, Zhang XX, Liu CF, Song RL, Wang JJ (2013) Study on chemical constituents of *Kochia scoparia*. Zhong Yao Cai 36:921–924

Zheng C, Li D, Zhan W, He K, Yang H (2020) Downregulation of SENP1 suppresses LPS-induced macrophage inflammation by elevating Sp3 SUMOylation and disturbing Sp3-NF-κB interaction. Am J Transl Res 12:7439–7448

Zou W, Tang Z, Long Y, Xiao Z, Ouyang B, Liu M (2021) Kochiae fructus, the fruit of common potherb Kochia scoparia (L.) Schrad: a review on phytochemistry, pharmacology, toxicology, quality control, and pharmacokinetics. Evid Based Complement Alternat Med 2021:5382684. https://doi.org/10.1155/2021/5382684