REVIEW ARTICLE

The old world *salsola* as a source of valuable secondary metabolites endowed with diverse pharmacological activities: a review

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**ABSTRACT**

*Salsola* is an important genus in the plant kingdom with diverse traditional, industrial, and environmental applications. *Salsola* species are widely distributed in temperate regions and represent about 45% of desert plants. They are a rich source of diverse phytochemical classes, such as alkaloids, cardenolides, triterpenoids, coumarins, flavonoids, isoflavonoids, and phenolic acids. *Salsola* spp. were traditionally used as antihypertensive, anti-inflammatory, and immunostimulants. They attracted great interest from researchers as several pharmacological activities were reported, including analgesic, antipyretic, antioxidant, cytotoxic, hepatoprotective, contraceptive, antidiabetic, neuroprotective, and antimicrobial activities. Genus *Salsola* is one of the most notorious plant genera from the taxonomical point of view. Our study represents a comprehensive review of the previous phytochemical and biological research on the old world *Salsola* species. It is designed to be a guide for future research on different plant species that still belong to this genus or have been transferred to other genera.

**GRAPHICAL ABSTRACT**

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1. Introduction

Plants are considered as a latent treasure and a vital source for the discovery of medicines. They include a plethora of secondary metabolites that act as modulators for the enzymes involved in human diseases. Plant extracts and their derived natural products or analogues are extensively reported to exert promising effects on human devastating diseases including different types of cancer. They are also reported to protect humans against different types of microbes and recently evolved infectious diseases as COVID-19.

The genus *Salsola* (commonly known as saltwort) belongs to the family Amaranthaceae, previously Chenopodiaceae. The genus name is from the Latin words "salsus" or "sallere" meaning salty because they are halophytes capable of living in saline environments or due to their content of alkaline salts, such as potassium and sodium carbonates. The old genus *Salsola* comprised about 150 sp. growing in extreme climatic conditions as arid, semi-arid, and temperate regions worldwide. They represented about 45% of the desert plants and some of them are invasive species. Various plants of the genus *Salsola* are edible and some of them have been used in traditional medicine. Some of them are also reported to be rich in fibre content. They have important value as animal feed and they are beneficial in the reclamation and phytoremediation of soil contaminated with heavy metals. Plants belonging to this genus also represent a rich
source for endophytic microbes that could be used for potential biological applications\textsuperscript{17,18}. Furthermore, different plants of the genus \textit{Salsola} were reported to have industrial value as the use of \textit{S. soda} and \textit{S. kali} as a source of sodium carbonate, in linin, and cotton bleaching, and in glass and soap making\textsuperscript{14,19,20}.

Despite the importance of plants belonging to the genus \textit{Salsola}, they do not receive great research attention. Most of the research is done on the respiratory diseases and the hypersensitivity caused by the pollen grains of some \textit{Salsola} spp. and developing vaccines for it\textsuperscript{21–23}. Very limited reviews are made on the genus \textit{Salsola} such as the one made by Altay and Ozturk\textsuperscript{11} that discuss its fodder value. Hanif et al.\textsuperscript{14} discussed the environmental, industrial, and traditional uses of \textit{Salsola} spp. and they mentioned a small fraction of the biological studies made on them. This article addresses almost all the research articles concerning the phytochemistry and the biological activity of the plants belonging to the old genus \textit{Salsola} until 2021.

2. Morphological characters

Members of the genus \textit{Salsola} are shrubs, sub-shrubs, annual or perennial herbs. They are characterised by small, sessile, often succulent leaves that may be opposite or alternate. Most have bisexual axillary flowers that can be solitary or clustered to form loose or dense spikes (Figure 1). Each flower is subtended by two prominent bracteoles, with a frequently hard 5-segmented perianth (often winged in fruit), and a superior ovary. Seeds are horizontal, subglobose, with a spiral embryo\textsuperscript{17,24,25}.

3. Taxonomic classification

Genus \textit{Salsola} belongs to the flowering plant family Amaranthaceae descending from the order Caryophyllales\textsuperscript{26}. \textit{Salsola} has a long history of being considered as one of the largest genera within the family Chenopodiaceae containing 100 to 190 sp.\textsuperscript{27}. While it is classified now as one of the Amaranthaceae genera after merging family Chenopodiaceae with the family Amaranthaceae according to the angiosperm phylogeny group (AGP-IV)\textsuperscript{26,28–30}. Plants belonging to the genus \textit{Salsola} have the following taxonomic classification\textsuperscript{27,30–32}.

Kingdom: Plantae - Plants
Subkingdom: Tracheobionta - Vascular plants
Superdivision: Spermatophyta - Seed plants
Division: Magnoliophyta - Flowering plants
Class: Magnoliopsida - Dicotyledons
Subclass: Caryophyllidae
Order: Caryophyllales

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Photographs of selected Salsola spp.; a. \textit{S. kali} (adapted from kali https://gobotany.nativeplanttrust.org/sp./salsola/kali/), b. \textit{S. collina}, c. \textit{S. tragus}, d. \textit{S. imbricata} (adapted from https://www.floraofqatar.com/amaranthaceae.htm), e. \textit{S. komarovii}, f. \textit{S. oppositifolia} Desf. (adapted from adapted from https://powo.science.kew.org/), g. \textit{S. soda} (adapted from https://eunis.eea.europa.eu/sp./168053), h. \textit{S. laricifolia} (adapted from https://panama.inaturalist.org/taxa/985676-Salsola-laricifolia).}
\end{figure}
Family: Amaranthaceae (previously, Chenopodiaceae)
Subfamily: Salsoloideae
Tribe: Salsoleae
Genus: Salsola

The taxonomy of Salsola spp. is debateable and confusing due to their diversity and distribution in the Asian and the middle east deserts that lead to difficulties in their collection and investigation. The close relationship between Salsola spp. and the dependence on minor morphological differences in their old classification together with the recent use of molecular techniques in plant systematics led to major changes in the classification of the genus Salsola. The classification of the genus Salsola has been revised by Akhani et al. (2007) and it was split into 10 different genera. The transfer of different sp. from the old world Salsola to other genera, such as Caroxylon, resulted in decreasing the number of its sp. to 25.

The type of the genus Salsola was Salsola soda, which has been recently changed by the International Code of Nomenclature into Salsola kali as suggested by Mosyakin et al. This resulted in changing the name of many traditionally known Salsola spp. into Soda.

These taxonomical and nomenclatural changes together with the recent use of molecular techniques in plant systematics led to major changes in the classification of the genus Salsola spp. and their diversity and distribution in the Asian and the middle east. The close relationship between Salsola spp. and other genera, such as Caroxylon, resulted in decreasing the number of its sp. to 25.

4. Chemistry

4.1. Volatile constituents

Hexahydro-farnesyl acetone and benzoic acid esters were reported as the major constituents of S. cyclophylla volatile oil. However, GC analysis of the volatile fractions of different parts of S. vermiculata L. plant revealed that carvone and linalool were the major components in leaves (52.2% and 5.8%, respectively), while carvone and cuminaldehyde were the major components in roots (49.9% and 4.4%, respectively). Additionally, carvone, limonene, and linalool were detected as the major constituents of S. cyclophylla volatile oil.

4.1.1. Non-volatile constituents

Previous phytochemical investigations of plants belonging to the genus Salsola indicate the presence of diverse groups of secondary metabolites, such as alkaloids, cardenolides and sterols, coumarins and coumarolignans, fatty acids, flavonoids and iso-flavonoids, phenolics, and triterpene glycosides. The presence of optically active (-) pyrrolo[2,1-α]isouquinoline type alkaloids has been reported from S. collina Pall. Particularly, Zhao and Ding isolated and identified the first alkaloid of this group, salsoline (trolline), (S)-8,9-dihydroxy-1,2,5,6-tetrahydropyrrolo[2,1-α]isouquinolin-3(10H)-one followed by Xiang et al. who were able to isolate and identify another related positional isomer namely; salsoline B. Further, coumarins and coumarolignans, fatty acids, and triterpene glycosides have been reported from different Salsola spp. in both free and combined (glucoside) forms. They possess a skeleton of N-trans-furuloytaminone or N-trans-furuloyl dopamine structures. The structures of N-trans-furuloyl-3-O-methylidopamine and N-trans-furuloyl-3″-methoxydopamine were reported in S. collina whereas, N-trans-furuloyl dopamine and 7′-hydroxy N-trans-furuloyl tyramine were found in S. collina and S. tetrandra. Also, trans-N-furuloyl tyramine-4″-O-β-D-glucopyranoside was reported from S. inermis Forssk. The only reported mupiopinamide derivative with a "cis" double bond configuration of the cinnamoyl moiety was cis-N-furuloyl tyramine which was isolated from the aerial parts of S. baryosoma. It is worth noting that several tentatively (incompletely) defined structures were reported by UPLC/qTOF-MS analysis of the aerial parts and roots of S. verruculata and S. tetrandra. They included N-caffeoyl tyramine, N-(3′,4′-dimethoxy-cinnamoyl)-norepinephrine, N-(4′-methoxy-cinnamoyl)-norepinephrine, N-furuloyl-3″-methoxytyramine. However, further spectral analysis, such as 1D and 2D NMR are required to confirm their structures.

Another miscellaneous group of nitrogenous compounds was reported from different Salsola spp., including simple nitrogenous compounds, such as methyl carbamate, which was isolated from S. tetrandra, S. kali, S. longifolia and S. rigida. The amino acid derivative, N-acetyltprophan was isolated from S. collina Pall. and S. grandis Freitag, Vural & Adiguzel. Pericampyline-A, terrestic acid, uracil, and uridine were reported by Jin et al. from S. collina Pall. While salisomide was reported by Saleem et al. from S. imbricata Forssk. The alkylamine, tridecanamine was also reported from the aerial parts of S. tetranda Forssk.

4.1.2. Alkaloids and nitrogenous compounds

Different classes of alkaloids and other nitrogenous compounds have been reported from plants of the genus Salsola, Figure 2. A unique group of optically active l-methyl-tetrahydro-isoquinoline alkaloids have been early detected by Proskurnina and Orekhov from Salsola richteri Karel and the isolated alkaloids were identified as carnegine, salsonine, and N-norcarnegine (salsolidine). The southern Turkmenistan salsola, S. richteri Karel yielded 0.16% of salsonine. A fourth related derivative, N-methylisosalsonine, was detected by GC/MS in the aerial parts of S. oppositofolia, S. soda and S. tragus. In addition, 3,4-dihydro-6,7-dihydroxy-1(2H)-isoquinolinone; namely pericampyline-A (isuluxine), was also isolated from S. collina Pall. The presence of optically active (-) pyrrolo[2,1-α]isouquinoline type alkaloids has been reported from S. collina Pall. Particularly, Zhao and Ding isolated and identified the first alkaloid of this group, salsoline (trolline), (S)-8,9-dihydroxy-1,2,5,6-tetrahydropyrrolo[2,1-α]isouquinolin-3(10H)-one followed by Xiang et al. who were able to isolate and identify another related positional isomer namely; salsoline B. Further, coumarins and coumarolignans, fatty acids, and triterpene glycosides have been reported from different Salsola spp. in both free and combined (glucoside) forms. They possess a skeleton of N-trans-furuloytaminone or N-trans-furuloyl dopamine structures. The structures of N-trans-furuloyl-3-O-methylidopamine and N-trans-furuloyl-3″-methoxydopamine were reported in S. collina whereas, N-trans-furuloyl dopamine and 7′-hydroxy N-trans-furuloyl tyramine were found in S. collina and S. tetrandra. Also, trans-N-furuloyl tyramine-4″-O-β-D-glucopyranoside was reported from S. inermis Forssk. The only reported mupiopinamide derivative with a "cis" double bond configuration of the cinnamoyl moiety was cis-N-furuloyl tyramine which was isolated from the aerial parts of S. baryosoma. It is worth noting that several tentatively (incompletely) defined structures were reported by UPLC/qTOF-MS analysis of the aerial parts and roots of S. verruculata and S. tetrandra. They included N-caffeoyl tyramine, N-(3′,4′-dimethoxy-cinnamoyl)-norepinephrine, N-(4′-methoxy-cinnamoyl)-norepinephrine, N-furuloyl-3″-methoxytyramine. However, further spectral analysis, such as 1D and 2D NMR are required to confirm their structures.

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4.1.3. Cardenolides and sterols

Stereos is a group of natural products biosynthesized from the isopenoid pathway via the 2,3-oxidosqualene (C30) route. Cardenolides are cardioactive steroidal lactones with a 5-membered (furanone) or 6-membered (pyranone) ring at C-17. They are naturally present free or glycosylated with mono- or multi-sugar moieties. Several families are known for their high cardenolides content, such as Asclepiadaceae, Apocynaceae, and others. However, only one report on cardenolides from the Amaranthaceae family has been described. It addressed the isolation of five cardenolides, salsetetragrain 2.1, calactin 2.2, 12-dehydroxygalhalinokisine 2.3, desglucouzarin 2.4, and uazerginin 2.5 from the Algerian plant, Salsola tetragona Delile, Figure 3. Other reported steroids comprised several phytosteroids with diversity in the alkyl side chains at C-17, including campesterol, cholesterol, and desmosterol. Stigmastanol, stigmastanol, stigmastanol, stigmastanol, and stigmastanol have been further studied to be a combined phytosterol, stigmastanol-3-β-D-glucopyranoside from the aerial parts of S. inermis.
Table 1. Current taxonomic status and synonyms of *Salsola* plants mentioned in this review article.

| Plant           | Genus                     | Basionym and synonyms according to POWO34 and IPNI35 | Native Distribution range34 |
|-----------------|---------------------------|------------------------------------------------------|-----------------------------|
| *S. arbuscula*  | Xylosalsola Tzvelev       | Synonyms:                                           | European Russia to Mongolia and Pakistan |
|                 |                           | S. arborescens                                      |                             |
|                 |                           | S. exasperata                                       |                             |
|                 |                           | S. transhyrcanica                                   |                             |
| *S. collina*    | Salsola                   | Basionym of Kali collinum31 Synonyms:                | South European Russia to Korea |
|                 |                           | S. chinensis Gand.                                  |                             |
|                 |                           | S. erubescens Schrad.                               |                             |
|                 |                           | S. iriciana Gand.                                   |                             |
|                 |                           | S. kali subsp. collina (Pall.)                      |                             |
| *S. cyclophylla*| Transferred to Genus Caroxylon31 | Basionym of Caroxylon cyclophyllum (Baker)31         | Syria to Sudan and South Pakistan |
| *S. grandis*    | Salsola                   | Basionym for Soda grandis28                        | Turkey                      |
| *S. imbricata*  | Transferred to Genus Caroxylon31 | Basionym of Caroxylon imbricatum31 Synonyms:        | Sahara & Sahel to west India distributed throughout warm desert areas of northwest India, Pakistan, Iran, Afghanistan and tropical east Africa36 |
|                 |                           | S. baryosma Schult.                                 |                             |
|                 |                           | Caroxylon foetidum Moq.                             |                             |
|                 |                           | Nitrosalsola baryosma (Schult.) Theodorova          |                             |
|                 |                           | S. maroestum Moq.                                   |                             |
|                 |                           | S. moorcroftiana Wall.                              |                             |
|                 |                           | Chenopodium baryosman Schult.                       |                             |
| *S. inermis*    | Forssk                    | Basionym of Caroxylon inermis (Forssk.)31           | Egypt, Arabian Peninsula, and Iran Atlantic and Mediterranean coast countries |
| *S. kali*       | Salsola                   | It has different varieties and synonyms such as S.  |                             |
|                 |                           | scariosa, S. spinosa, S. turgida                    |                             |
| *S. komarovii*  | Salsola                   | Basionym of Kali komarovii (Iljin)31                | It grows in sand dunes and beaches in Japan, China, and Korea37 |
| *S. laricifolia*| Turcz                     | –                                                   | Central Asia to Mongolia and North Xinjiang |
| *S. longifolia* | Forssk                    | Basionym of Soda longifolia (Forssk.)28 Synonyms as | Sahara to Arabian Peninsula |
|                 |                           | S. fruticosa Cav.                                   |                             |
|                 |                           | S. longiflora J.F.Gmel.                             |                             |
|                 |                           | S. oppositifolia Sieber ex Moq.                     |                             |
| *S. micranthera*| Caroxylon                 | Basionym of Caroxylon micrantherum (Botsch.) Nitrosalsola micranthera (Botsch.) | Central Asia to Southern Xinjiang |
| *S. oppositifolia* Desf. | Salsola          | Basionym of Soda oppositifolia (Desf.)38 Synonyms:  | Mediterranean countries    |
|                 |                           | S. oppositifolia f. feminea Botsch.                 |                             |
|                 |                           | Sedlitzia oppositifolia (Desf.) Iljin Synonyms:     |                             |
| *S. richteri*   | Xylosalsola Tzvelev       | Xylosalsola richteri (Moq.) Salsola arborescens var. richteri Moq. | Central Asia and Pakistan |
| *S. rigida* Pall. | Caroxylon                 | Synonyms:                                           | Central Sinai to North Xinjiang and West Pakistan |
|                 |                           | Caroxylon orientale Salsola orientalis S.G.Gmel. Salsola syriaca Botsch Salsola heliaramiae Mouterde |                             |
| *S. soda* L.    | Salsola                   | Its name has been modified to Soda inermis28 Synonyms: | Growing on saline soils throughout Armenia, Iran, Turkey, and Turkmenistan, is cultivated and highly prized as a leaf vegetable (agretti) in the Mediterranean region |
|                 |                           | Salsola longifolia Lam.                             |                             |
| *S. somalensis* | Halothamnus Jaub. & Spach | Basionym of Halothamnus somalensis                  | Tropical Africa             |
| *S. tetrandra*  | Transferred to Genus Caroxylon31 | Basionym of Caroxylon tetrandrum (Forssk.)          | North Africa, Palestine, Saudi Arabia, Sinai |
| *S. tetragona*  | Caroxylon                 | Synonyms:                                           | North Africa to Palestine |
|                 |                           | Caroxylon tetragonum Salsola pachai Volkens & Asch. Salsola diplantha Botsch Haloteon tetragonus (Delilie) Moq |                             |
| *S. tragus*     | Salsola                   | Basionym of                                          | Europe to Siberia and Korea |
|                 |                           | S. kali var. tragus (L.) Moq.                       |                             |
|                 |                           | S. kali subsp. tragus (L.) Celak.                   |                             |
|                 |                           | S. rutherica var. tragus (L.) Morariu Synonyms as S.  |                             |
|                 |                           | rutherica                                           |                             |
|                 |                           | S. pestifer A.Nelson                                |                             |
| *S. tuberculatiformis* | Caroxylon             | Basionym of Caroxylon tuberculatiforme (Botsch.)39 Synonyms: S. tuberculata40 | Cape, South Africa |

(continued)
The existence of fatty acid esters or acylated sterols was reported by Mayakova et al. from the genus Salsola. They investigated the contents of the saponified acylsterols fraction of the pentane extract of *S. collina*. The neutral fraction indicated the presence of four sterols, including β-sitosterol, stigmasterol, cholesterol, and campesterol, whereas the acyl fraction of the hydrolysed esters composed of stearic, palmitic, and oleic acids.

### 4.1.4. Coumarins and coumarinolignans

Coumarins are bioactive secondary metabolites biosynthesized in plants from the phenylpropanoid (C6C3) pathway by cyclisation of cinnamic acid. They contribute to diverse biological activities, such as anticoagulant, antimicrobial, antiviral, and anticancer activities. Several studies reported the presence of simple coumarins in members of the genus Salsola. These reported coumarins are either free or glycosylated with mostly methoxylated C-6 and oxygenated C-7 positions. Two simple coumarins, namely umbelliferone 3.1 and scopoletin 3.2, were reported from the aerial parts of *S. inermis*. Whereas *S. kali* showed the presence of fraxidin 3.3. However, the highest record of coumarins from this genus was noted to *S. laricifolia* that included several simple coumarins (3.3–3.10) and two unusual coumarinolignans; cleomiscosin B 3.11, cleomiscosin D 3.12, formed by the association with another cinnamic acid moiety (C6C3). Calycantoside 3.10, a compound possessing the structure of 6,8-dimethoxy-coumarin-7-O-β-glucopyranoside was reported with the miss-spelled name, calicantoside from the epigeal (aerial) parts of *S. laricifolia*.

### 4.1.5. Fatty acids and their derivatives

Few saturated fatty acids compared to unsaturated ones were reported from Salsola plants, Table 2 and Figure 5. Ghorab et al. reported the isolation of the fatty acid ester, 2,3-dihydroxypropyl-palmitate 4.1 from the aerial parts of *S. tetragona*. Whereas free palmitic acid 4.10, in addition to three unsaturated fatty acids, including linoleic, linolenic, and oleic acids (4.5, 4.6, and 4.9, respectively) were detected by UPLC/qTOF-MS analysis of *S. vermiculata* and *S. tetrandra*. Also, oleic acid 4.9 was isolated from the aerial parts of *S. laricifolia*. A characteristic group of trihydroxylated mono-, di-, and tri-unsaturated fatty acids was reported from several plants of the genus Salsola, including 9,12,13-trihydroxy-Octadeca-10(E),15(Z)-dienoic acid 4.13 and 9,12,13-trihydroxy-10(E)-octadecenoic acid 4.14 from the aerial parts of *S. tetrandra*. The existence of fatty acid esters or acylated sterols was reported by Mayakova et al. from the genus Salsola. They investigated the contents of the saponified acylsterols fraction of the pentane extract of *S. collina*. The neutral fraction indicated the presence of four sterols, including β-sitosterol, stigmasterol, cholesterol, and campesterol, whereas the acyl fraction of the hydrolysed esters composed of stearic, palmitic, and oleic acids.

### Table 1. Continued.

| Plant          | Genus                  | Basionym and synonyms according to POWO and IPNI | Native Distribution range |
|----------------|------------------------|-------------------------------------------------|---------------------------|
| *S. villosa*   | Caroxylon              | Synonyms as *Salsola palaestinica* Botsch.       | Egypt, India, Lebanon-Syria, Libya, Palestine, Saudi Arabia, Sinai |
| *S. volkensii* | Caroxylon/Nitrosalsola | Basionym of *Caroxylon volkensii* (Schweinf. & Asch.) | Egypt, Iraq, and Arabian Peninsula |

![Figure 2. Structures of alkaloids and nitrogenous compounds (1.1–1.23) reported in the genus Salsola.](image-url)
tetrandra\textsuperscript{53} and 9,12,13-trihydroxydocosan-10,15,19-trienoic acid \textsuperscript{4.15} from the aerial parts of \textit{S. inermis}\textsuperscript{51}. Additionally, several fatty acids, including hydroxyoctadecenoic acid, dihydroxyoctadecenoic acid, hydroxyoctadecatienoic acid, hydroxyoctadecadienoic acid, and trihydroxyoctadecadienoic acid were also tentatively identified from the aerial parts and roots of \textit{S. vermiculata} and \textit{S. tetrandra} by UPLC/qTOF-MS analysis method\textsuperscript{68}.

4.1.6. Flavonoids and isoflavonoids

Flavonoids and isoflavonoids are predominant plant polyphenols having a C\textsubscript{6}-C\textsubscript{3}-C\textsubscript{6} skeleton and are considered as one of the frequently studied plant phytochemicals\textsuperscript{94}. Flavonoids are yellow-colored compounds possessing a highly distinctive biosynthetic pathway as they are synthesised from the mixed phenylpropanoid (4-coumaroyl-CoA) and polyketide (3 malonyl-CoA) pathway\textsuperscript{95}. The isoflavonoids subclass is characterised by the presence of a 2-phenyl instead of 3-phenyl substitution at the benzopyrone moiety\textsuperscript{94}. Concerning the biological activities, flavonoids are the main dietary antioxidants due to their action as scavengers of harmful free radicals. In addition, they act as signalling molecules by their modulatory effect on several protein kinases, such as MAP kinase (mitogen-activated protein kinase). The latter mechanism can explain their neuroprotection, cardioprotection, and anticancer activities\textsuperscript{96}. Isoflavonoids are much limited in their distribution in plant families (e.g. Leguminosae) compared to flavonoids and are characterised by their phytoestrogenic activity as in the case of genistein\textsuperscript{97}. In the genus \textit{Salsola}, the reported flavonoids (Figure 6) can be classified into flavones (such as apigenin \textsuperscript{5.1}, chrysin \textsuperscript{5.2}, luteolin-7-\textit{O}-\textit{\beta}-D-glucoside \textsuperscript{5.17}, and tricin \textsuperscript{5.28}, from \textit{S. imbricata} Forssk, \textit{S. kali} L., and \textit{S. collina} Pall., respectively\textsuperscript{60,66,75,84}, flavonols (such as isorhamnetin \textsuperscript{5.4}, quercetin \textsuperscript{5.18}, and kaempferol derivatives \textsuperscript{5.13–5.16}), flavanols (such as catechin \textsuperscript{5.33}), and flavanones (such as hesperidin \textsuperscript{5.34}, hesperitin \textsuperscript{5.35}, and naringenin \textsuperscript{5.36}). The free flavonal aglycone, kaempferol was incompletely identified by UPLC/qTOF-MS analysis of the aerial parts and roots of \textit{S. vermiculata} and \textit{S. Tetrandra} plants\textsuperscript{68}. The presence of OCH\textsubscript{3} groups (i.e. methoxylated flavonoids) was mainly observed at C-3 and C-4 in the B-ring of flavones (in tricin and its derivatives \textsuperscript{5.28–5.32}), and at C-3 of flavonols (in the isorhamnetin derivatives \textsuperscript{5.4–5.13}). However, diversity in methoxylation positions was recorded for the isoflavonoids group (\textsuperscript{5.37–5.52}), as both the A-ring (positions C-5, 6, 7, and 8) and the B-ring (positions C-2, 3, and 5) acquired OCH\textsubscript{3} groups. For detailed references and the plant source, see Table 2. Finally, a unique 8,2\textsubscript{0}-dimethoxylated isoflavon derivative, salisoflavan \textsuperscript{5.53} was reported from the aerial parts \textit{S. imbricata} Forssk\textsuperscript{57}.

4.1.7. Lignans

Lignans are natural secondary metabolites biosynthesized from the oxidative coupling of two p-hydroxyphenylpropene moieties (C\textsubscript{6}-C\textsubscript{3}) linked by a bond connecting the middle (\textit{\beta}-\textit{\beta}) carbons of their side chains\textsuperscript{98}. Regarding the genus \textit{Salsola}, six derivatives from two major subclasses, lignans and cylolignans, were identified. For the lignans subclass, three tetrahydrofuran derivatives, alangilignoside C \textsuperscript{6.2}, conicaoside \textsuperscript{6.3}, and lariicesinol-9-O-\textit{\beta}-D-glucopyranoside \textsuperscript{6.5} were isolated from the aerial parts of \textit{S. komarovi}\textsuperscript{89}. Regarding the cylolignans subclass, two tetrahydro-naphthalene derivatives, namely (8S,8R,7R)-9'-
Triterpenoids are structurally diverse, widely distributed natural phytochemicals possessing a C30-skeleton and are biosynthesized from the isoprenoid precursor, squalene. Pentacyclic triterpenoids (Table 2 and Figure 8). The triterpenoids group included mainly salsola derivatives, including two simple ethyl glucosides namely, ethyl biphenylsalsonoid B and salsonol B. Whereas the isoprenoid glycosides comprised the acyclic monoterpene, 9-hydroxylinolyl glycoside 9.11 from S. tetrandra, in addition to several ionone derivatives with different unsaturation and oxidation status, such as roseoside A 9.4 and blumenol B β-D-glycopyranosyl 9.5 from S. komarovii and the epoxy derivatives 9.12 from S. komarovii and S. tetrandra, respectively were reported, Table 2 and Figure 10.

4.1.10. Miscellaneous glycosides
Several miscellaneous glycosides with both phenolic and isoprenoid aglycones were reported from several plants of the genus Salsola. The glycone in most cases is either glucose or β-D-apiofuranosyl-(1→6)-β-D-glycopyranosyl group. The phenolic glycosides, benzyl 6-O-β-D-apiofuranosyl-β-D-glycopyranoside 9.1, biophenol B 9.2, cuneataside C 9.9, and 2-(3,4-dihydroxy)-phenyl-ethyl-β-D-glycopyranoside 9.10 were isolated from the aerial parts of S. komarovii. The cyanogenic glycosides, taxiphyllin 9.17 and 3,4,5-trimethoxymethyl-β-D-glycopyranoside 9.18 were reported in the aerial parts of S. tetrandra. Whereas the isoprenoid glycosides comprised the acyclic monoterpene, 9-hydroxylinolyl glycoside 9.11 from S. tetrandra, in addition to several ionone derivatives with different unsaturation and oxidation status, such as roseoside A 9.4 and blumenol B β-D-glycopyranosyl 9.5 from S. komarovii and the epoxy derivatives 9.12 from S. komarovii and S. tetrandra, respectively were reported, Table 2 and Figure 10.

4.1.11. Biphenylpropanoids
Biphenylpropanoids (Table 2 and Figure 11) were isolated from the aerial parts of S. villosa Delile. ex Schul. and the roots of S. imbricata. They are formed of dimeric C6C6 residues (linked head to head) with a characteristic oxirane ring formed by epoxidation of either one of the side chains’ double bond as in biphenylsalsolol 10.1 and biphenylsalsonoid A 10.2 or both as in case of biphenylsalsonoid B 10.3.

4.1.12. Polyhydric alcohols and carbohydrates
Syrrchana et al.93 described the presence of a few monosaccharide derivatives, including two simple ethyl glucosides namely, ethyl β-D-fructopyranosyl 11.1 and ethyl β-D-glycopyranoside 11.2 from S. collina Pall. In addition, they reported the presence of two polyhydric alcohols (D-mannit, 11.5 and myoinositol 11.6) from the same plant. Table 2 and Figure 12.
Table 2. Non-volatile constituents from the genus Salsola.

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 1.1 | N-Acetyltryptophan | The whole plant of S. collina Pall.; S. grandis Freitag, Vural & Adiguzel | 66,70,77 |
| 1.2 | Carnegine | S. richteri; GC/MS of the aerial parts of S. oppositifolia Desf. | 45,48 |
| 1.3 | N-[2-[(3,4-Dihydroxyphenyl)-2-hydroxyethyl]-3-(4-methoxyphenyl)prop-2-enamide] | The whole plant of S. foetida | 78 |
| 1.4 | N-[2-[(3,4-Dihydroxyphenyl)-2-hydroxyethyl]-3(3,4-dimethoxyphenyl)prop-2-enamide] | The whole plant of S. foetida | 78 |
| 1.5 | Cis-N-Feruloyltartramine | The aerial parts of S. baryosoma | 67 |
| 1.6 | N-Trans-feruloyl-3′-methoxydopamine 4′-O-β-D-glucopyranoside | The aerial parts of S. collina | 43 |
| 1.7 | Trans-N-Feruloyltartramine-4′′-O-β-D-glucopyranoside | The aerial parts of S. inermis Forssk | 51 |
| 1.8 | N-[2-(3-Hydroxy-4-methoxyphenyl)-2-hydroxyethyl][3-(4-methoxyphenyl)prop-2-enamide] | The whole plant of S. foetida | 78 |
| 1.9 | 7′-Hydroxy-3′-methylmoupinamide; N-trans-feruloyl-3-O-methyl dopamine | The whole plant of S. collina Pall.; HPLC of the aerial parts of S. komarovii | 43,66,79 |
| 1.10 | 7′-Hydroxymoupinamide (7′-Hydroxy N-trans-feruloyltartramine); trans-N-Feruloyloctopamine | The whole plant of S. collina Pall. and aerial parts of S. tetrandra; aerial parts of S. baryosoma | 53,66,67 |
| 1.11 | Methyl carbamate | S. tetrandra, S. kali, S. longifolia and S. rigida | 69 |
| 1.12 | N-Methylsosalsoline | By GC/MS of the aerial parts of S. tragus L., S. oppositifolia Desf., and S. soda L. | 48 |
| 1.13 | Moupinamide (N-trans-Feruloyltartramine) | The whole plant of S. collina Pall. and aerial parts of S. tetrandra; UPLC/qTOF-MS analysis of whole plants of S. vermiculata and S. Tetrandra; Forssk; aerial parts of S. baryosoma; HPLC of the aerial parts of S. komarovii | 43,53,66-68,80,79 |
| 1.14 | Pericampylinone-A (iseluxine) | The whole plant of S. collina Pall. | 66 |
| 1.15 | Salsisolidone | The aerial parts S. imbricata Forssk | 57 |
| 1.16 | Salsoline | Aerial parts and root of Salsolea kali L. and S. longifolia Forssk; GC/MS of the aerial parts of S. tragus L., S. oppositifolia Desf., and S. soda L. | 44,45,48,75,81 |
| 1.17 | Salsoline A (Trolline) | The whole plant of S. collina Pall.; UPLC/qTOF-MS analysis of whole plants of S. vermiculata and S. tetrandra | 47,49,66,68 |
| 1.18 | Salsoline B | S. collina Pall. | 43 |
| 1.19 | Salsolidone (N-Norcarnegine) | The aerial parts of S. kali L. and S. longifolia Forssk; GC/MS of the aerial parts of S. tragus L., S. oppositifolia Desf., and S. soda L. | 45,48,81 |
| 1.20 | Terrestrial acid; 4-Amino-1,2,5,6-tetrahydro-6-oxo-1,3,S-triazine-2-carboxylic acid | The whole plant of S. collina Pall. | 66 |
| 1.21 | Tridecanamine | By GC-MS analysis of the aerial parts of S. tetrandra | 71 |
| 1.22 | Uracil | The whole plant of S. collina Pall. | 66 |
| 1.23 | Uridine | The whole plant of S. collina Pall. | 66 |

II- Cardenolides and steroids

A. Cardenolides

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 2.1 | 3-O-[β-D-Allopyranosyl]corbigenin (salsotetragonin) | The aerial parts of S. tetragona | 50 |
| 2.2 | Calactin | The aerial parts of S. tetragona | 50 |
| 2.3 | 12-Dehydroxyghalakinoside | The aerial parts of S. tetragona | 50 |
| 2.4 | Desglucocuazarin | The aerial parts of S. tetragona | 50 |
| 2.5 | Uzarigenin | The aerial parts of S. tetragona | 50 |

B. Steroids

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 2.6 | Campesterol | S. collina | 73 |
| 2.7 | Cholesterol | S. collina | 73 |
| 2.8 | Desmosterol | S. collina | 73 |
| 2.9 | β-Sitosterol | The aerial parts of S. inermis; S. collina | 51,73 |
| 2.10 | Stigmastanol | The aerial parts of S. inermis; S. collina | 51 |
| 2.11 | Stigmasterol | The aerial parts of S. inermis; S. collina | 51,73 |
| 2.12 | Stigmastrol-3-O-β-D-glucopyranoside | The aerial parts of S. inermis | 51 |

III- Coumarins and coumarinolignans

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 3.1 | Umbelliferone | The aerial parts of S. inermis | 51 |
| 3.2 | Scopoletin | The aerial parts of S. inermis | 51 |
| 3.3 | Fraxidin | | 75,82 |
Table 2. Continued.

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 3.4 | Fraxidin-8-O-β-D-glucopyranoside | The epigeal part of *S. laricifolia*; Herb and root of *S. kali* L. | 82 |
| 3.5 | Isofraxidin | The epigeal part of *S. laricifolia* | 82 |
| 3.6 | Fraxetin | The epigeal part of *S. laricifolia* | 82 |
| 3.7 | Fraxin | The epigeal part of *S. laricifolia* | 82 |
| 3.8 | Scopolin | The epigeal part of *S. laricifolia* | 82 |
| 3.9 | 7-[O-β-D-Apiofuranosyl-(1→ 2)-6-D-glucopyranosyloxy]-6-methoxy-2H-1-benzopyran-2-one (lariside) | The epigeal part of *S. laricifolia* | 82,83 |
| 3.10 | Calycantoside; Calicantoside | The epigeal part of *S. laricifolia* | 76,82 |
| 3.11 | Cleomiscosin B | *S. laricifolia* | 52 |
| 3.12 | Cleomiscosin D | *S. laricifolia* | 52 |

IV- Fatty acids and their derivatives

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 4.1 | 2,3-Dihydroxypropylpalmitate | The aerial parts of *S. tetragona* | 50 |
| 4.2 | 2,7-Dimethyl-1-octanol | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.3 | 3,9-Diethyl-6-tridecanol | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.4 | 2,3-Dihydroxypropyl octadecanoate | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.5 | Linoleic acid | UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra* | 68 |
| 4.6 | Linolenic acid | UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra* | 68 |
| 4.7 | 9-Octadecenoic acid | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.8 | 9,12-Octadecadienoic (Z,Z) methyl ester | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.9 | Oleic acid | The aerial parts of *S. tetragona*; UPLC/qTOF-MS analysis of the aerial parts of *S. vermiculata* and *S. tetrandra* | 50,68 |
| 4.10 | Palmitic acid; Hexadecenoic acid | UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra* | 68 |
| 4.11 | Palmitic acid methyl ester; methyl palmitate | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.12 | Palmitic acid ethyl ester; Hexadecenoic acid ethyl ester | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.13 | 9,12,13-Trihydroxyoctadeca-10(Δ),15(Δ)-dienoic acid | The aerial parts of *S. tetrandra* | 53 |
| 4.14 | 9,12,13-Trihydroxyoctadecanoic acid | The aerial parts of *S. inermis* | 51 |
| 4.15 | 9,12,13-Trihydroxydocosan-10,15,19-trienoic acid | By GC-MS analysis of the aerial parts of *S. tetrandra* | 71 |
| 4.16 | Tetradecanoic acid methyl ester | By GC-MS analysis of the aerial parts of *S. tetrandra* | 68 |
| 4.17 | 9,12,13-Trihydroxy-7-octadecenoic acid | UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra* | 68 |

V- Flavonoids and flavonolignans:
A. Flavones and their derivatives

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 5.1 | Apigenin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |
| 5.2 | Chrysin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |
| 5.3 | Flavonol (Flavon-3-ol; 3-Hydroxyflavone) | *S. grandis* Freitag, Vural & Adiguzel | 70 |
| 5.4 | Isorhamnetin | The whole plant of *S. collina* Pall.; leaves of *S. imbricata*; HPLC of the aerial parts of *S. komarovii* | 66,79,80 |
| 5.5 | Isorhamnetin-3-O-rutinoside (Narcissoside) | *S. kali*; UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra*; *S. grandis* Freitag, Vural & Adiguzel; aerial parts of wild *S. soda*; aerial parts of *S. Oppositifolia*; HPLC of the aerial parts of *S. komarovii* | 70,77,85 |
| 5.6 | Isorhamnetin-3-O-α-L-arabinopyranosyl (1→6)-β-D-glucopyranoside | The whole plant of *S. collina* | 60 |
| 5.7 | Isorhamnetin-3-O-β-D-galactopyranoside | *S. grandis* Freitag, Vural & Adiguzel | 70,77,80 |
| 5.8 | Isorhamnetin-3-O-β-D-glucopyranoside | The whole plant of *S. collina*; aerial parts of *S. inermis*, and *S. kali*; UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra*; *S. grandis* Freitag, Vural & Adiguzel | 51,54,60,68,70,77,79,80,85 |
| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 5.9 | Isohamnetin-7-O-β-D-glucopyranoside | The whole plant of *S. imbricata* Forssk; aerial parts of *S. oppositifolia*; HPLC of the aerial parts of *S. komarovii* | 55 |
| 5.10 | Isohamnetin-3-O-β-D-glucuronate methyl ester (1""""→4")-β-D-glucuronate methyl ester | Leaves of *S. imbricata* Forssk | 70,77 |
| 5.11 | Isohamnetin-3-O-β-D-glucuronide | *S. grandis* Freitag, Vural & Adiguzel; aerial parts of wild *S. soda* | 70,77 |
| 5.12 | Isohamnetin-3-O-β-D-glucuronoyl-(1""""→4")-β-D-glucuronic acid | Leaves of *S. imbricata* Forssk | 80 |
| 5.13 | Kaempferol-3-O-methylether | The aerial parts of *S. inermis* | 51 |
| 5.14 | Kaempferol-3-O-β-D-(6'-O-(E)-p-coumaryl)glucopyranoside; trans-Tiliroside | *S. grandis* Freitag, Vural & Adiguzel | 70,77 |
| 5.15 | Kaempferol-3-O-β-D-glucopyranoside; Astragalin | The aerial parts of *S. tetragona*, and *S. inermis*; HPLC of the aerial parts of *S. komarovii* | 50,51,79 |
| 5.16 | Kaempferol-3-O-rutinoside | HPLC of the aerial parts of *S. komarovii* | 79 |
| 5.17 | Luteolin-7-O-β-D-glucoside | HPLC analysis of aerial parts and root of *S. kafi* L. | 75 |
| 5.18 | Quercetin | *S. collina* Pall., *S. kafi*; HPLC analysis of *S. imbricata* Forssk; UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra*; *S. grandis* Freitag, Vural & Adiguzel; LC-MS of *S. cyclophylla* | 15,66,68,70,77,84 |
| 5.19 | Quercetin-3-O-β-D-galactoside; Hyperin; Hyperoside | HPLC analysis of aerial parts and root of *S. kafi* L.; *S. grandis* Freitag, Vural & Adiguzel; LC-MS analysis of *S. cyclophylla* | 15,70,77,75 |
| 5.20 | Quercetin-3-O-glucopyranoside; Isoquercitrin | HPLC of the aerial parts of *S. komarovii* | 79 |
| 5.21 | Quercetin-3-O-β-D-glucopyranosyl-(1→6)-glucopyranoside | The aerial parts of *S. tetragona* | 50 |
| 5.22 | Quercetin-3-O-glucuronopyranoside | The aerial parts of wild *S. soda* | 10,79 |
| 5.23 | Quercetin-3-O-methylether | *S. grandis* Freitag, Vural & Adiguzel | 77 |
| 5.24 | Quercetin 3α-L-rhamnoside; Quercetrin | HPLC analysis of whole plant of *S. imbricata* Forssk; *S. grandis* Freitag, Vural & Adiguzel | 70,77,84 |
| 5.25 | Quercetin-3-O-rutinoside; Rutin | *S. collina* Pall.; HPLC analysis of *S. imbricata* Forssk; UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra*; *S. grandis* Freitag, Vural & Adiguzel; aerial parts of wild *S. soda*; HPLC of the aerial parts of *S. komarovii* | 10,66,68,70,77,79,84 |
| 5.26 | Quercetin 3-O-rutinoside-(1:2)-O-rhamnoside; Quercetin 3-O-(2′,6′-di-O-s-L-rhamnopyranosyl)-β-D-glucopyranoside (Manghaslin) | *S. grandis* Freitag, Vural & Adiguzel | 70,77 |
| 5.27 | Selagin; 3′-O-Methyltricetin | The whole plant of *S. collina* Pall. | 60 |
| 5.28 | Tricin | The whole plant of *S. collina* Pall. | 60,66 |
| 5.29 | Tricin-4′-O-(erythro-β-guaiaacylglyceryl) ether; Erythro-4′-O-(β-guaiaacylglyceryl)tricin (salcolin B) | The epigal part of *S. collina* | 56,86 |
| 5.30 | Tricin-4′-O-(threo-β-guaiaacylglyceryl) ether; Threo-4′-O-(β-guaiaacylglyceryl)tricin (salcolin A) | The epigal part of *S. collina* | 60,66 |
| 5.31 | Tricin-7-O-β-D-glucopyranoside | The whole plant of *S. collina* Pall | 60 |
| 5.32 | Tricin-4′-O-β-D-apioside | The whole plant of *S. collina* | 60 |

### B. Flavonols and flavanones

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 5.33 | Catechin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |
| 5.34 | Hesperidin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |
| 5.35 | Hesperitin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |
| 5.36 | Naringenin | HPLC analysis of whole plant of *S. imbricata* Forssk | 84 |

### C. Isoflavonoids

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 5.37 | 5,2′-Dihydroxy-3′-methoxy-6,7-methylenedioxy-isoflavone (Tetranin B) | *S. tetrandra* Folsk roots | 59 |
| 5.38 | 5,2′-Dihydroxy-6,7-methylenedioxyisoflavone (Irisone B) | The whole plant of *S. collina* Pall. | 66,87 |
| 5.39 | 5,3′-Dihydroxy-2′-methoxy-6,7-methylenedioxyisoflavone | The roots of *S. somalensis* | 55,88 |
| 5.40 | 5,3′-Dihydroxy-6,7,2′-trimethoxyisoflavone | The roots of *S. somalensis* | 55 |
| 5.41 | 5,3′-Dihydroxy-7,8,2′-trimethoxyisoflavone | The roots of *S. somalensis* | 55,88 |
| 5.42 | 6,3′-Dihydroxy-5,7,2′-trimethoxyisoflavone | The roots of *S. somalensis* | 55 |
### VII- Triterpenoids and their derivatives

#### A. Triterpenoids

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 7.1 | 3-O-β-D-Glucopyranosyl-6β,11β,23,24-tetrahydroxyolean-12-en-28-oic acid | The whole plant of *S. baryosma* | 64 |
| 7.2 | Guavenonic acid; 2x,3β,6β,23-Tetrahydroxyursa-12,20(30)-dien-28-oic acid | *S. baryosma* | 90 |
| 7.3 | Momordin Ilb; Silphioside G; Oleanolic acid 3-glucuronopyranosyl-28-glucoside | *S. imbricata* Forssk root; *S. grandis* Freitag, Vural & Adiguzel | 61,70,77 |
| 7.4 | Momordin Id; 3β-[[O-β-D-Xylopyranosyl-[1→2]-O-β-D-xylopyranosyl-[1→3]]-O-β-D-glucopyranuronosyl]-oxoolean-12-one-28-glucopyranoside | By HPLC-ESI-MS from aerial parts of wild *S. soda* | 10 |
| 7.5 | Olean-12-en-3β,28-diol | The aerial parts of *S. inermis* | 51 |
| 7.6 | Oleanolic acid; Olean-12-en-28-oic acid | The aerial parts of *S. inermis*; aerial parts of wild *S. soda* | 10,51 |
| 7.7 | Oleanolic acid-3-O-β-D-glucopyranosyl | The aerial parts of *S. inermis* | 51 |
| 7.8 | 1α,2α,3β,19α,23-Pentahydroxyursa-12,20(30)-dien-28-oic acid | *S. baryosma* | 90 |
| 7.9 | Pseudoginsenoside RT1 | *S. imbricata* Forssk root | 61 |
| 7.10 | Salsolins A; 3β,11β,24,30-Tetrahydroxyolean-12-en-28-oic acid | The whole plant of *S. baryosma* | 64 |
| 7.11 | Salsolins B; 2α,3β,23,24-Tetrahydroxyurs-12-en-28-oic acid | The whole plant of *S. baryosma* | 64 |
| 7.12 | Salsolic acid; 3β,6β,24-Trihydroxyolean-12-en-28-oic acid | *S. baryosma* | 90 |
| 7.13 | Salsoloside C; Momordin Ic; Oleanolic acid 28-O-β-D-glucopyranosyl-3-O-[[O-β-D-xylapyranosyl-[1→4]]-β-D-glucopyranoside] | The epigal part of *S. micranthera* Botsch; *S. grandis* Freitag, Vural & Adiguzel; By HPLC-ESI-MS aerial parts of wild *S. soda* | 10,62,70,77 |
| 7.14 | Salsoloside D; Hedergenin 28-O-β-D-glucopyranosyl 3-O-[[O-β-D-xylapyranosyl-[1→4]]-β-D-glucopyranoside] | The epigal part of *S. micranthera* Botsch | 62 |
| 7.15 | Salsoloside E; Oleanolic acid 28-O-β-D-glucopyranosyl 3-O-[[O-β-D-xylapyranosyl-[1→2]]-O-β-D-glucopyranosyl-[1→4]-β-D-glucopyranoside] | The epigal part of *S. micranthera* Botsch | 63 |
| 7.16 | 3-O-β-D-Xylapyranosyl-[1→2]-O-β-D-glucopyranuronosyl 29-hydroxyolean-28-O-β-D-glucopyranoside | *S. imbricata* Forsk root | 61 |
| 7.17 | 3-O-β-D-Glucuronopyranosyl-30-norolean-12,20-dien-28-O-β-D-glucopyranosyl 3-ester (boussingoside A2) | *S. imbricata* Forsk root | 61 |
| 7.18 | 3-O-β-D-Xylapyranosyl-[1→2]-O-β-D-glucuronopyranosyl-29-hydroxyolean-28-O-β-D-glucopyranoside | *S. imbricata* Forsk root | 61 |

#### B. Nortriterpenoids

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 7.17 | 3-O-β-D-Glucuronopyranosyl-30-norolean-12,20-dien-28-O-β-D-glucopyranosyl 3-ester (boussingoside A2) | *S. imbricata* Forsk root | 61 |
| 7.18 | 3-O-β-D-Xylapyranosyl-[1→2]-O-β-D-glucuronopyranosyl-28-O-β-D-glucopyranosyl | *S. imbricata* Forsk root | 61 |

#### VIII. Phenolic acids and simple phenols

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 8.1 | Acetyl ferulic acid | *S. collina* Pall. | 66 |
| 8.2 | Acetic acid | *S. collina* Pall. | 66 |
| 8.3 | Benzoic acid | *S. imbricata* Forsk | 84 |
| 8.4 | Caffeic acid | HPLC analysis of whole plant of *S. kari* and *S. imbricata* Forsk; UPLC/qTOF-MS analysis of whole plants of *S. vermiculata* and *S. tetrandra* | 12,68,84 |
| 8.5 | Caffeic acid phenethyl ester; β-Phenylethyl caffeate | LC-MS analysis of *S. cyclophylla* | 15 |
| 8.6 | Catechol | HPLC analysis of herb and root of *S. kari* | 15 |
| 8.7 | Chlorogenic acid | HPLC analysis of whole plant of *S. imbricata* Forsk; LC-MS analysis of *S. cyclophylla* | 15,84 |
| 8.8 | Cinnamic acid | HPLC analysis of whole plant of *S. imbricata* Forsk; LC-MS analysis of *S. cyclophylla* | 15,84 |
| 8.9 | p-Coumaric acid | | 12,15,60,66,84 |
Table 2. Continued.

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 8.10 | Ferulic acid | HPLC analysis of whole plants of S. kali and S. imbricata Forssk; S. collina Pall.; LC-MS analysis of S. cyclophylla | 12,15,60,68,80,84 |
| 8.11 | Gallic acid | HPLC analysis of whole plant of S. imbricata Forssk; LC-MS of S. cyclophylla | 15,84 |
| 8.12 | Gentisic acid | HPLC analysis of herb and root of S. kali | 12 |
| 8.13 | 4-Hydroxy-acetophenone; 1-(4-hydroxy-phenyl)-ethanone | S. tuberculatiformis Botsch. | 40 |
| 8.14 | 4-Hydroxy-3-methoxy-acetophenone; 1-(4-hydroxy-3-methoxy-phenyl)-ethanone | S. tuberculatiformis Botsch. | 40 |
| 8.15 | 4-Hydroxybenzaldehyde | S. collina Pall.; HPLC analysis of herb and root of S. kali; leaves of S. imbricata Forssk | 12,66,80 |
| 8.16 | p-Hydroxybenzoic acid | S. collina Pall.; HPLC analysis of herb and root of S. kali | 12,66,80 |
| 8.17 | p-Hydroxyphenylacetic acid | HPLC analysis of herb and root of S. kali | 12 |
| 8.18 | Isovanillic acid | Leaves of S. imbricata Forssk | 80 |
| 8.19 | Protocatechuc aldehyde | S. collina Pall. | 66 |
| 8.20 | Protocatechuc acid | HPLC analysis of whole plants of S. kali and S. imbricata Forssk | 12,84 |
| 8.21 | Resorcinol | HPLC analysis of aerial parts and root of S. kali | 75 |
| 8.22 | α-Resorcylic acid | HPLC analysis of herb and root of S. kali | 12 |
| 8.23 | β-Resorcylic acid | HPLC analysis of herb and root of S. kali | 12 |
| 8.24 | Rosmarinic acid | HPLC analysis of S. imbricata Forssk | 84 |
| 8.25 | Salicylic acid | S. collina Pall.; HPLC analysis of whole plants of S. imbricata Forssk | 60,66,84 |
| 8.26 | Syringic acid | HPLC analysis of herb and root of S. kali | 12 |
| 8.27 | Tetranin A | S. tetrandra Folsk roots | 59 |
| 8.28 | Vanillic acid | HPLC analysis of whole plants of S. kali and S. imbricata Forssk; from the aerial parts of S. tetragona | 12,50,84 |
| 8.29 | Vanillin | S. collina Pall. | 66 |

IX- Miscellaneous glycosides

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 9.1 | Benzyl 6-O-β-D-apiosyl-β-D-glucopyranoside | The aerial parts of S. komarovii | 89 |
| 9.2 | Biophenol 2 | The aerial parts of S. komarovii | 89 |
| 9.3 | Blumenol B 9-O-β-D-apiosyl-(1,3,4,6)-β-D-glucopyranoside | The aerial parts of S. komarovii | 89 |
| 9.4 | Blumenyl A β-D-glucopyranoside; Roseoside A | The aerial parts of S. komarovii | 89 |
| 9.5 | Blumenyl B β-D-glucopyranoside | The aerial parts of S. komarovii | 89 |
| 9.6 | Canthoside C | The aerial parts of S. tetragona and S. komarovii | 50,89 |
| 9.7 | Canthoside D | The aerial parts of S. tetragona | 50 |
| 9.8 | Corchoinoside C | The whole plant of S. collina Pall. | 66 |
| 9.9 | Cuneatasis C | The aerial parts of S. komarovii | 89 |
| 9.10 | 2-(3,4-Dihydroxy)-phenyl-ethyl-β-D-glucopyranoside | The aerial parts of S. komarovii | 89 |
| 9.11 | 9-Hydroxylinoloyl glucoside | The aerial parts of S. tetragona | 53 |
| 9.12 | Icariside B2 | The aerial parts of S. komarovii | 89 |
| 9.13 | Isotachioside | The aerial parts of S. komarovii | 89 |
| 9.14 | Lyohebecarpin A (3β-Hydroxy-5R,6R-epoxy-β-D-ionone-2R-0-β-D-glucopyranoside) | The aerial parts of S. tetragona | 53 |
| 9.15 | Staphylionoside D | The aerial parts of S. komarovii | 89 |
| 9.16 | Tachioside | The aerial parts of S. komarovii | 89 |
| 9.17 | Taxiphyllin | The aerial parts of S. tetragona | 53 |
| 9.18 | 3,4,5-Trimethoxyphenyl-β-D-glucopyranoside | The aerial parts of S. tetragona | 89 |
| 9.19 | 3-Oxo-α-ionol 9-O-β-D-apiosyl-(1,3,4,6)-β-D-glucopyranoside | The aerial parts of S. komarovii | 89 |

X- Phenylpropanoids

| No. | Class/Name | Plant/ part | Reference |
|-----|------------|-------------|-----------|
| 10.1 | Biphenylsalinosol; 4’-[3-(hydroxymethyl)oxiran-2-yl]-3-[(E)-3-hydroxyprop-1-en-1-yl]-6, 2’-dimethoxy [1, 1’-biphenyl]-2-ol | The aerial parts of S. villosa Delile. ex Schul. | 91 |

(continued)
4.1.13. Miscellaneous group

Only two compounds are included in this group; the first one is a dimeric methylcyclopentenyl alcohol namely, salsolanol 12.1 isolated from the aerial parts of *S. villosa* Dellile. ex Schul. 91. While, the second compound is an isohexyl 2-pentyl ester of sulphurous acid 12.2 detected by GC-MS analysis of the aerial parts of *S. tetrandra*71, Table 2 and Figure 13.

5. Pharmacological activities

Plants of the genus *Salsola* are widely used in the folk medicine of different countries for the treatment of several diseases, such as hypertension, broken bones as well as for boosting the immun-

Research studies showed that extracts of different *Salsola* spp. and compounds isolated from them exert a wide range of variable pharmacological activities. These activities will be discussed in detail in this section. They are also summarised in Table 4 and Figure 14.

5.1. Effect on the cardiac system and blood pressure

One of the early reported pharmacological activities of *Salsola* spp. is their antihypertensive action. Different *Salsola* spp. are used as ingredients in different Chinese patents obtained from Faming Zhuanli Shenqing for treating hypertension. Of these, *S. collina* was the most extensively used sp. as indicated by the number of patents addressed this particular plant. Also, *S. ruthenica* and *S. arbuscula* were used in some Chinese patents. Likewise, *S. rutherica*, a synonym for *S. fruticosa* was reported as a potential treatment for essential hypertension77. The ethanolic extract obtained from the aerial parts of *S. triflora* Forsk to sal-

The anti-inflammatory and antinociceptive activities of *S. grandis* were tested using the carrageenan-induced paw edema in rats. The same research group also tested the analgesic activity of *S. imbricata* extract using NaCl-induced withing and formalin-induced paw licking models in rats. Their obtained results indicated that *S. imbricata* exhibited a dose-dependant analgesic activity by reducing the number of abdominal withing mediated by 4% NaCl intraperitoneal injection at all tested doses (100, 300, and 500 mg/kg)106. Nevertheless, it decreased the time of paw licking by rats only at the dose of 500 mg/kg. Also, *S. imbricata* showed significant antipyretic activity in the brewer’s yeast-induced pyrexia model in rats106. The aqueous methanolic extract of *S. imbricata* leaves and the phenolic compounds isolated from it decreased the NO production levels in RAW 264.7 macrophage cells and were found to be non-toxic at the concentration of 100 μg/mL10. Regarding the tested phenolic compounds, isorhamnetin-3-O-glucopyranoside 5.8 displayed higher activity than its corresponding galactopyra-

The flavonoidal compounds, tiliroside 5.14 and quercetin-3-O-beta-D-glucopyranoside 5.10 displayed higher activity than its corresponding galactopyra-

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To assess its traditional use in inflammatory conditions. They confirmed the anti-inflammatory activity of *S. imbricata* as it significantly inhibited carrageenan-induced paw edoema in rats. The same research group also tested the analgesic activity of *S. imbricata* extract using NaCl-induced withing and formalin-induced paw licking models in rats. Their obtained results indicated that *S. imbricata* exhibited a dose-dependant analgesic activity by reducing the number of abdominal withing mediated by 4% NaCl intraperitoneal injection at all tested doses (100, 300, and 500 mg/kg). Nevertheless, it decreased the time of paw licking by rats only at the dose of 500 mg/kg. Also, *S. imbricata* showed significant antipyretic activity in the brewer’s yeast-induced pyrexia model in rats. The aqueous methanolic extract of *S. imbricata* leaves and the phenolic compounds isolated from it decreased the NO production levels in RAW 264.7 macrophage cells and were found to be non-toxic at the concentration of 100 μg/mL. Regarding the tested phenolic compounds, isorhamnetin-3-O-glucopyranoside 5.8 displayed higher activity than its corresponding galactopyra-

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The anti-inflammatory and antinociceptive activities of *S. cyclophylla* was evaluated by Mohammed et al.15 using the carrageenan-induced paw edema method. The aqueous-ethanolic extract showed the highest anti-inflammatory activity among the tested extracts and its activity was close to the well-known anti-inflammatory drug, diclofenac. Mohammed et al. attributed cardio toxicity in male Swiss albino mice. This effect was attributed to lowering the oxidative stress in the heart and inhibiting lipid peroxidation107.

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this anti-inflammatory activity to the antioxidant potential of the phenolic and flavonoid components present in the aqueous-ethanolic extract. The same research group also investigated the analgesic activity of *S. cyclophylla* using the hot-plate and acetic-acid writhing models in mice. The aqueous ethanolic extract showed the highest activity with 87.50–99.66% pain reduction rates after different time intervals, which was comparable to the diclofenac activity.15

Seo et al.37 reported that the ethanol extract of *S. komarovii* showed effective anti-inflammatory activity as hydrocortisone by reducing the production of LPS-induced IL-6. It also exerted glucocorticoid receptor binding activity and interfered with NF-κB nuclear translocation.17

The synthetic analogue of the active principle of *S. tuberculata*, 2–(4-acetoxyphenyl)2-chloro-N-methylethlammonium-chloride, was reported to inhibit UVB induced intracellular interleukin-1
alpha (icIL-1α) in the UVB in-vitro model for inflammation. Contrarily, the methanol extract of *S. tuberculata* exerted a pro-inflammatory activity by boosting the UVB induced-icIL-1α production and enhanced cytotoxicity. While the dichloromethane extract showed no significant effect on skin cells inflammation. The investigated synthetic analogue was also suggested to exert its anti-inflammatory and contraceptive activities by competitive inhibition of glucocorticoid binding to corticosteroid-binding globulin (CBG) leading to increased levels of the *in vivo* free corticosterone.
Figure 7. Structures of lignans (6.1–6.6) reported in the genus *Salsola*.

Figure 8. Structures of triterpenoids and nortriterpenoids (7.1–7.18) reported in the genus *Salsola*. 
5.3. Antioxidant and iron chelation activities

The antioxidant potential is one of the most extensively studied activities of *Salsola* species. It could be concluded from the reported results that the used plant parts and the extraction solvent could greatly affect the antioxidant activity. Flavonoids and their glucosidal derivatives are mostly the responsible compounds for antioxidant activities. While other compounds, such as essential oil components, alkaloids, and biphenylpropanoids showed only moderate activities.

The antioxidant activity of *S. cyclophylla* extracts was tested using 2,2-diphenyl-1-picrylhydrazyl (DPPH) colorimetric assay. The best DPPH-free radicals scavenging potential was observed for the aqueous-ethanolic extract that showed comparable activity to the used standard, quercetin. While, the ethyl acetate extract showed the highest ferrous ions (Fe$^{2+}$) chelating activity using ferrozine-based assay. The same group reported the antioxidant activity of the essential oil obtained by water distillation of *S. cyclophylla* that showed only one-half of the quercetin activity. They attributed this activity to the benzoic acid esters and the hexahydropfarnesyl acetone components that occur in the essential oil in high concentrations.

Antioxidant and iron chelation activities of the methanolic extract of different plant parts of *S. kali* were also investigated by Boulabaa et al. using the same methods used for *S. cyclophylla* extracts. Leaf and stem extracts showed the highest antioxidant activity while leaf and root extracts showed the highest iron chelation activity.

The alkaloidal extracts of *S. oppositofolia*, *S. soda*, and *S. tragus* were prepared by extraction of their aerial parts with methanol, alkalinization with NH$_4$OH then extraction with ethyl acetate. The three alkaloidal extracts showed significant antioxidant activity when tested using the DPPH method. Remarkably, *S. oppositifolia* showed the highest activity with an IC$_{50}$ value of 16.30 $\mu$g/mL.

Oueslati et al. investigated the antioxidant activity of biphenylsalsonoids A (10.2) and B (10.3) isolated from the ethyl acetate fraction of the roots of *S. imbricata* using DPPH and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS$^+$) assay methods. The two compounds showed moderate antioxidant activity.
Figure 10. Structures of miscellaneous glycosides (9.1–9.20) reported in the genus *Salsola*.

Figure 11. Structures of biphenylpropanoids (10.1–10.3) reported in the genus *Salsola*.

Figure 12. Structures of polyhydric alcohols and carbohydrates (11.1–11.6) reported from the genus *Salsola*. 
**Trans-N-feruloyltyramine derivatives isolated from *S. foetida*** (1.3, 1.4, and 1.8) exhibited moderate antioxidant activity with IC$_{50}$ ranging from 378 to 427 $\mu$M using DPPH radical scavenging assay$^{76}$. The ethyl acetate extract of *S. komarovi* aerial parts was subjected to HPLC separation and the obtained elutes were tested for antioxidant activity using ABTS$^+$ radical scavenging method. The components responsible for the antioxidant activity were identified by HPLC-MS as the flavonoids, isorhamnetin 5.4, astragalin 5.15, isouqueretin 5.20, and rutin 5.25$^{79}$. 

The ethyl acetate fraction of *S. baryosma* showed 77% DPPH radicals scavenging activity while other tested fractions showed lower activities below 57%$^{109}$. This result is contradictory with that obtained by Khacheba et al.$^{125}$ who reported weak antioxidant activity of *S. baryosma* ethyl acetate extract using DPPH assay.

The antioxidant activity of 80% (v/v) aqueous-methanol extracts of *S. vermiculata* and *S. baryosma* in addition to other Algerian herbs was tested using the hydroxyl (OH$^-$), nitroxide (NO$^-$) and (ABTS$^+$) radicals scavenging assays, and Fe$^{3+}$-TPTZ complex reductive power assay. The results showed that *S. baryosma* exhibited the highest antioxidant activity in OH$^-$ radical assay with an EC$_{50}$ of 0.26 ppm despite its low phenolic content$^{22}$.

Beyaoui et al.$^{59}$ investigated the antioxidant activity of two compounds, tetranins A and B, isolated from the ethyl acetate extract of *S. tetrandra* roots using DPPH and ABTS assays. The dihydrostilbene, tetranin A 8.27 exerted higher antioxidant activity than the isoflavonoid, tetranin B 8.37. However, both compounds showed lower activity than the standard antioxidant, Trolox$^{59}$.

The ethanol extract of *S. collina* Pall demonstrated anti-oxidative activity through DPPH radical scavenging capacity (Oh et al., 2014).

**5.4. Cytotoxic activity**

Only a few studies were made for investigating the cytotoxic activity of a small number of *Salsola* spp., including *S. cyclophylla*, *S. oppositifolia*, *S. collina*, *S. baryosma*, *S. richteri* and *S. cyclophylla*. The cytotoxic activity of 95% aqueous-ethanolic extract of the aerial parts of *S. cyclophylla* was investigated using MTT assay against M14 melanoma derived epithelial breast cancer (MDA cells), human pancreatic cancer (PANC-1), Michigan Cancer Foundation-7 (MCF-7) breast cancer cells, and the normal human fibroblast cells. The aqueous-ethanolic extract of *S. cyclophylla* showed low to moderate cytotoxic activity only at high concentrations (50–400 $\mu$g/mL) against the tested cell lines and no significant cytotoxic effect was observed at low concentration (< 50 $\mu$g/mL)$^{15}$.

Different fractions obtained from the extract of the aerial parts of *S. oppositifolia* were screened for cytotoxic activity against a panel of cancer cell lines$^{85}$. The n-hexane fraction showed the highest cytotoxic activity on lung carcinoma (COR-L23) and amelamonic melanoma (C32) cell lines with IC$_{50}$ values of 19.1 $\mu$g/mL and 24.4 $\mu$g/mL, respectively. The dichloromethane fraction also demonstrated cytotoxic activity against these two cell lines with IC$_{50}$ values of 30.4 $\mu$g/mL and 33.2 $\mu$g/mL for COR-L23 and C32 cell lines, respectively. The ethyl acetate fraction exhibited a selective moderate cytotoxic activity against breast cancer, MCF-7 cells (IC$_{50}$ 67.9 $\mu$g/mL). The major constituents isolated from the ethyl acetate fraction, isorhamnetin-3-O-glucopyranoside 5.8 and isorhamnetin-3-O-rutinoside 5.5 also demonstrated a potential activity against MCF-7 with IC$_{50}$ values of 18.2 and 25.2 $\mu$g/mL, respectively. Additionally, isorhamnetin-3-O-rutinoside 5.5 showed high activity against the hormone-dependent prostate carcinoma cell line (LNCaP) with an IC$_{50}$ value of 20.5 $\mu$g/mL$^{85}$.

The ethanol extract of *S. collina* Pall showed cytotoxic activity against human colon carcinoma cells (HT29). It resulted in a reduction in the number and size of the cells through cell cycle regulation and caused cell arrest in the G2/M phase$^{110}$.

The ethanol extract of *S. baryosma* whole plant showed no significant cytotoxic activity when tested with other plant extracts using the brine shrimp method$^{126}$. The same result was reported by Ahmed et al.$^{109}$, while 80% ethanol extract of *S. baryosma* did not exhibit cytotoxic activity against brine shrimp larvae and only the ethyl acetate fraction showed 50% cytotoxic activity. However, all tested fractions of *S. baryosma* showed phytotoxicity against *Leuca minor* plant growth$^{109}$.

**Figure 13.** Miscellaneous compounds (12.1–12.2) reported in the genus *Salsola*.

**Table 3.** Traditional medical uses of *Salsola* species.

| Country                        | S. sp.                          | Traditional use                                                                 | Reference |
|--------------------------------|---------------------------------|---------------------------------------------------------------------------------|-----------|
| China                          | *S. collina* Pall.              | Treatment of hypertension, headache, vertigo                                    | 43, 106   |
| Sahara-arabic and Soudano-deccanian | *S. baryosma*                  | Vascular hypertension                                                          | 101       |
| Middle East                    | *S. baryosma*                   | Against inflammation and as a diuretic agent                                   | 14, 102   |
| Chhindwara, India              | The whole plant of *S. kali* L. | Treatment of cough                                                             | 14, 103   |
| Ethiopia                       | *S. somalensis*                 | Anthelmintic                                                                   | 55, 86    |
| Mongolia                       | Aerial parts of *S. lanicola*   | Used by the nomads of the Gobi Desert as winter tonic tea, for wound healing,  | 15, 41    |
|                                |                                 | treatment of broken bones and swollen joints                                   |           |
| Saudi Arabia                   | Leaves of *S. cyclophylla*      | Used by local Bedouin as diuretic, laxative, anthelmintic, and anti-inflammatory| 15, 41    |
| Turkmenistan, Tajikistan, and Kyrgyzstan | *S. richteri* | Used to treat skin conditions and hypertension in Tajik folk medicine          | 76        |
| Southern Africa                | Aqueous extract of *S. tuberculatiformis* | Used by Bushmen women as oral contraceptive                                       | 40, 104   |
Table 4. Reported pharmacological activities of *Salsola* species.

| Pharmacological action/medicinal use | Salsola spp./part used | Extract /or product used | Collection place | Reference |
|-------------------------------------|------------------------|---------------------------|------------------|-----------|
| **Effect on the cardiac system and blood pressure** | | | | |
| Antihypertensive                      | *S. kali*, *S. longifolia*, and *S. ruthenic* | – | – | 81,105 |
| Angiotensin-converting enzyme inhibiting activity | Aerial parts of *S. oppositofolia*, and *S. soda* | Ethyl acetate extracts | Italy | 106 |
| Cardioprotective effect              | Whole shrub of *S. kali* | Aqueous extract | New Damietta City, Egypt | 107 |
| **Anti-inflammatory, analgesic, and antipyretic activities** | | | | |
| Anti-inflammatory and antinociceptive activities | Aerial parts of *S. grandis* | Ethanol extract | Nallihan bird sanctuary, Ankara, Turkey | 77 |
| Anti-inflammatory and analgesic activity | Aerial parts of *S. Cyclophylla* | Aqueous-ethanol extract | Al-Fuwayiq City in the Qassim region, Saudi Arabia | 15 |
| Anti-inflammatory                     | *S. komarovi*             | Ethanol extract | Yongin, Korea | 37 |
| Anti-inflammatory                     | Leaves of *S. imbricata* Forssk | Aqueous methanolic extract | Baharia, Oasis, Egypt | 80 |
| Anti-inflammatory, analgesic, and antipyretic activity | Aerial parts of *S. imbricata* | Aqueous ethanol (30:70 v/v) extract | Cholistan desert, Punjab, Pakistan | 108 |
| **Antioxidant and Iron chelation activity** | | | | |
| Antioxidant and Iron chelation activity | *S. cyclophylla* | Aqueous ethanol extract | Al-Fuwayiq City in the Qassim region, Saudi Arabia | 15 |
| Antioxidant                           | *S. Cyclophylla*          | Essential oil | Qassim region, Saudi Arabia | 41 |
| Antioxidant                           | Leaves and stems of *S. kali* L. | Methanol extract | Borg-Cédria coastal, Region, Tunis | 75 |
| Antioxidant activity                  | Aerial parts of *S. oppositofolia*, *S. soda*, and *S. tragus* | Alkaloid extract | Central and Southern Italy | 48 |
| Antioxidant activity                  | Aerial parts of *S. komarovi* | Ethyl acetate extract | Gangneung, Korea | 79 |
| Antioxidant                           | *S. baryosma*             | Ethyl acetate fraction | Cholistan desert, Pakistan | 109 |
| Antioxidant                           | *S. baryosma*             | 80% (v/v) Aqueous methanolic extract | Algeria | 22 |
| **Cytotoxic activity**                | | | | |
| Cytotoxic activity                    | Aerial parts of *S. oppositofolia Desf.* | Different extracts were tested | Sicily, Italy | 85 |
| Cytotoxic activity                    | *S. collina*              | Ethanol extract | Cholistan desert, Pakistan | 110 |
| Phytotoxic activity                   | *S. baryosma*             | Ethyl acetate fraction | Cholistan desert, Pakistan | 109 |
| **Effect on the liver and the gallbladder** | | | | |
| Hepatoprotective effect               | Aerial parts of *S. collina Pall* | 25% Ethanol extract | Russia | 111 |
| Anti-cholelithiasis                   | *S. collina Pall*         | Aqueous extract | Russia | 112 |
| Hepatoprotective effect               | Aerial parts of *S. tetrandra* | 70% Hydroalcoholic extract | Saudi Arabia | 113 |
| Hepatoprotective and antioxidant effect | *S. imbricata*       | Ethanolic and methanolic extracts | Muhaisnah desert, Dubai, UAE | 84 |
| Hepatoprotective effect               | Aerial parts of *S. tetrandra and S. baryosma* | 70% Ethanol-water | Saudi Arabia | 113 |
| Hepatoprotective effect               | *S. villosa* and *S. volkensii* | Aqueous-alcoholic extract | Egypt | 114 |
| **Effects on the gastrointestinal system** | | | | |
| Gastroprotective                      | *S. komarovi*             | 50% Alcohol extract | Korea | 115 |
| Gastroprotective                      | *S. tetrandra*            | 70% Alcoholic extract | El Doubleia at ElRiyadh- El Dallamroad, Saudi Arabia | 71 |
| Anthelmintic Activity                 | Bark of *S. imbricata*    | Chloroform extract | Bahawalpur District, Pakistan | 116 |
| Antispasmodic                         | *S. baryosma*             | Ethyl acetate fraction | Cholistan desert, Pakistan | 109 |
| Antispasmodic and bronchorelaxant activities | Aerial parts of *S. imbricata* | Aqueous-ethanolic extract | Cholistan desert, district Bahawalpur, Pakistan | 117 |
| Improving gastric emptying            | *S. collina*              | Ethyl acetate extract | – | 118 |
| **Antidiabetic activity**             | | | | |
| γ-amylase inhibitory activity         | *S. kali*                 | Ethyl acetate fraction | Calabria, Italy | 65 |
| Moderate γ-amylase inhibitory activity | Whole plant of *S. collina Pall* | N-Acetyltryptophan isolated from 80% EtOH extract | Shandong province, China | 66 |
| γ-Glucosidase and α-Amylase enzyme inhibitory activity | *S. vermiculata and S. baryosma* | Phenolic extract | Algeria | 22 |
| Aldose reductase inhibition           | Aerial parts and cultivated buds of wild *S. soda* | The n-BuOH extracts | Pisa, Italy | 10 |
| **Effect on neurodegenerative diseases** | | | | |
| Nerve growth factor induction         | Aerial parts of *S. komarovi* | 80% Methanol extract | Jejudo, Korea | 89 |
| Anti-Alzheimer’s, and antioxidant activity | Aerial parts of *S. oppositofolia*, *S. soda*, and *S. tragus* | Alkaloid extract | Central and Southern Italy | 48 |
| Acetylcholinesterase inhibitory activity | Root of *S. vermiculata* | Methanol extract | Marsa Matrouh, Egypt | 68 |
| Acetylcholinesterase inhibitory activity | Aerial parts of *S. grandis* | 96% EtOH extract | Ankara, Turkey | 70 |
| Butyrylcholinesterase inhibitory activity | *S. baryosma* | Chloroform extract | Pakistan | 90 |

(continued)
5.5. Effect on the immune system

Interestingly, *S. laricifolia* Turcz is reported to be one of the immune system-boosting drugs, and a pharmaceutical product derived from it “Salimon” represents one of the best-selling immunostimulant drugs in the Mongolian drug market76.

5.6. Effect on the liver and the gallbladder

Lochein, a liquid extract of the Russian thistle *S. collina* Pall, was reported to show a significant hepatoprotective effect on patients with chronic hepatitis127. It also has been approved as an active food supplement by the Ministry of Health of the Russian
Federation. Ethanol extract (25%) of the aerial parts of S. collina Pall. was reported to decrease the signs of paracetamol-induced liver damage in rats and to exert a better hepatoprotective activity than the reference drug, silymarin. It was also reported to decrease the levels of the liver enzymes and lipid peroxidation products and to enhance the detoxification of bilirubin, and ammonia. Moreover, S. collina aqueous extract was reported to protect against choledolithiasis in rabbits through enhancing cholesterol and water absorption and decreasing inflammation and formation of biliary slough.

Oral administration of S. imbricata methanol extract was reported to prevent liver toxicity in CCl₄-induced hepatotoxicity in mice. This hepatoprotective activity was attributed to the ability of the phenolic content of S. imbricata to enhance the antioxidant capacity of the liver.

Ethanol extracts (70%) of S. tetrandra and S. baryosma showed a prophylactic and therapeutic hepatoprotective activity against paracetamol-induced hepatorenal toxicity in rats. The results showed that S. tetrandra was more active and showed a higher ability to decrease the levels of inflammatory markers, such as interleukin-1β (IL-1β) and tumour necrosis factor alpha (TNF-α).

The alcoholic extracts of S. volkensii and S. villosa showed hepatoprotective effects with a broad safety margin against CCl₄-induced hepatotoxicity in Sprague Dawely rats indicating their potential use for the treatment of liver damage.

5.7. Effects on the gastrointestinal system

Different plants of the Salsola genus were reported to exert several effects on the gastrointestinal tract, including gastroprotective activity against ulcer, anthropimic, and antispasmodic activities.

Alcoholic extract (50%) of S. komarovi in 500 mg/kg concentration was found to significantly protect against gastric ulcer and to be more potent than Ranitidine (300 mg/kg) in 60% HCl-ethanol induced gastritis model. While 70% alcoholic extract of S. tetrandra showed a similar gastroprotective effect to that of Ranitidine against aspirin-induced gastric ulceration in rats.

Chloroform extract of S. imbricata bark demonstrated antihelminthic activity against Haemonchus contortus worms. Ethanol extract (80%) of S. baryosma (synonym for S. imbricata) demonstrated antispasmodic activity as it inhibited the rabbit jejunal contraction at a concentration of 0.3–3 mg/mL. It was suggested to act as a calcium channel blocker because it resulted in 70% inhibition of K⁺-induced contractions in rabbit jejunal at the concentration of 1–5 mg/mL. The ethyl acetate fraction of the aerial parts extract of the same sp. showed the highest spasmylic and broncho-relaxant activities on isolated rabbit jejunal and tracheal preparations which were suggested to be due to its agonist action on β-adrenergic receptors and Ca²⁺-antagonising activity.

On the other hand, the ethyl acetate extract of S. collina was reported to increase the gastric motility and gastric emptying rate through activating M-cholinergic receptor, increasing ghrelin and gastrin plasma levels and increasing the expression of the vasoactive intestinal peptide receptors in rats.

5.8. Antidiabetic activity

Decreasing post-prandial hyperglycaemia by inhibiting digestive enzymes involved in carbohydrate hydrolysis, such as α-amylase and α-glucosidase enzymes is a commonly used therapeutic approach for the management of diabetes. Therefore extensive studies were made on the α-amylase and α-glucosidase inhibitory activity of different Salsola spp.

The α-amylase inhibitory activity of different fractions of the aerial parts of S. kali, S. soda, and S. oppositifolia was investigated by Tundis et al. The ethyl acetate fraction of S. kali showed the highest α-amylase inhibitory activity with an IC₅₀ value of 0.022 mg/mL. The bioassay-guided chromatographic separation of this most active fraction resulted in the isolation of two flavonol glycosides, of which isorhamnetin-3-O-rutinoside displayed significant α-amylase inhibitory activity with an IC₅₀ value of 0.129 mM.

Djeridane et al. investigated the antidiabetic potential of the aqueous-methanol extracts of S. vermiculata and S. baryosma by testing their ability to inhibit α-amylase and α-glucosidase enzymes activities. The results indicated that S. baryosma exhibited the highest competitive inhibitory activity with inhibition constant (K) values of 7 and 16 μM against α-amylase and α-glucosidase, respectively suggesting its potential for type 2 diabetes management. Similarly, N-acetyltyroptphan showed 44% inhibition of α-amylase enzyme activity.

Iannuzzi et al. studied the chemical profile of the cultivated buds of S. soda and compared it to that of the wild plant. They also screened the inhibitory activity of the compounds isolated from their n-BuOH fraction against three enzymes of the aldol keto reductase superfamily, namely aldose reductase (hAKR1B1), aldose-reductase-like protein (hAKR1B10), and carbonyl reductase (hCBR1). They found that quercetin-3-O-glucuronopyranoside was the only flavonoid identified in both plant types was the most effective inhibitor for the tested enzymes and suggested its use as a functional nutraceutical to counteract diabetic complications.

5.9. Effect on neurodegenerative diseases

The effect of the isolated compounds from the methanol extract of S. komarovi aerial parts on the production of the endogenous Nerve Growth Factor (NGF) in C6 glioma cells was investigated by Cho et al. The lignan derivative, conicoside 6.3 showed the highest NGF-production stimulating activity and the lowest toxicity among the tested compounds indicating its potential for the regulation of neurodegenerative diseases, such as Alzheimer’s and Parkinson’s diseases. Alzheimer’s disease (AD) is one of the most common neurodegenerative diseases that is combined with acetylcholine deficiency. Therefore, it can be improved by inhibiting the enzymes affecting the cleavage of acetylcholine, such as acetylcholinesterase (AChE) and butyrylcholinesterase (BChE).

The ethanolic extract of the aerial parts of S. grandis and the different compounds isolated from its n-BuOH sub-extract were investigated for AChE inhibitory activity by Orhan et al. Only N-acetyltyroptphan showed AChE inhibitory activity suggesting its neuroprotective potential against Alzheimer’s disease.

The methanolic extract of S. vermiculata root demonstrated strong anti-acetylcholinesterase inhibitory activity which was higher than that of S. vermiculata aerial parts and S. tetrandra roots and aerial parts. It showed an IC₅₀ of 0.45±0.17 mg/mL. While the standard drug, ezerine showed IC₅₀ of 0.27±0.1 mg/mL. This activity could be attributed to the rich catecholamines content in S. vermiculata root.

The alkaloidal extracts of S. tragus, S. soda, and S. oppositifolia Desf. were screened for AChE and BChE inhibitory activities. S. tragus showed the highest inhibitory activity with IC₅₀ of 30.2 and 26.5 μg/mL against AChE and BChE, respectively. While S. soda...
and S. oppositifolia Desf. showed selective inhibition of BChE with IC\textsubscript{50} values of 34.3 and 32.7 \mu g/mL, respectively\textsuperscript{46}. Salsolic acid 7.12 and other two triterpenes 7.2 \& 7.8 isolated by Ahmad et al.\textsuperscript{90} from the chloroform extract of S. baryosma were reported to inhibit the BChE enzyme\textsuperscript{90}.

5.10. Effect on fertility

The contraceptive activity of Salsola plants was firstly described by Ploss in 1960. He reported the use of the aqueous extract of an undefined Salsola sp. as an oral contraceptive in Algeria\textsuperscript{40}. The aqueous extract of S. tuberculatiformis (previously known as S. tuberculate and commonly known as Gannabos) was reported to be used by Bushmen women as an oral contraceptive and to cause prolonged gestation and foetal post-maturity in Karakul sheep in Namibia region, South Africa\textsuperscript{40,119,129}. Swart et al.\textsuperscript{40} investigated the phytochemicals responsible for this activity in S. tuberculatiformis. The compound responsible for this activity was reported to be a labile synephrine analogue with a reactive aziridine group. Therefore, they synthesised the compound, 2-[(4-ace-toxyphenyl)-2-chloro-N-methylethylammonium-chloride, as a stable analogue for the active principle of S. tuberculatiformis. This compound was found to disturb the mammalian steroid hormones homeostasis and to inhibit adrenal steroidogenesis\textsuperscript{40}.

The ethanolic extract of S. imbricata was reported to cause a slight decrease in the testis weight and to cause a significant decline in the sperm count when administered orally to male albino rats suggesting its potential use as a reversible male contraceptive\textsuperscript{104}. They attributed this contraceptive activity to the phenolic content of the plant, especially quercitrin\textsuperscript{104}.

5.11. Effect on melanin biosynthesis

Trans-N-feruloyltyramine derivatives (1.3, 1.4, and 1.8) isolated from S. foetida were reported to exhibit significant tyrosinase enzyme inhibitory activity with IC\textsubscript{50} ranging from 0.40–2.61 \mu M which was lower than that of the standard tyrosinase inhibitors, kojic acid and L-mimosine, with IC\textsubscript{50} of 16.67 and 3.68 \mu M, respectively. Therefore, these derivatives could have promising activities on melanocytes and skin pigmentation abnormalities\textsuperscript{78}.

5.12. Antimicrobial activity

The chloroform extract of the aerial parts of S. villosa and the compounds isolated from it were tested against different bacterial strains using the paper disc diffusion method\textsuperscript{91}. The isolated compound biphenylsalsinol 10.1 showed the highest antimicrobial activity against Staphylococcus epidermidis, Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa bacterial strains with an inhibitory zone diameter (IZD) ranging from 12.33 to 28.66 mm. While salsonanol 12.1 showed slight activity against S. aureus, E. coli, S. epidermidis with IZD ranging from 9.33 to 12.66 mm\textsuperscript{91}. Oueslati et al.\textsuperscript{120} also investigated the antibacterial activity of the roots of S. imbricata and the bioactive compounds, biphenylsalsinoid A 10.2 and B 10.3, isolated from its ethyl acetate fraction. The two isolated compounds showed similar antibacterial activity against S. aureus, S. epidermidis and E. coli with MIC values ranging from 16–32 \mu g/mL\textsuperscript{92}. While biphenylsalsinoid A 10.2 was two times more active than biphenylsalsinoid B 10.3 against Micrococcus luteus. It is worth noting that both compounds showed lower activity than the standard drug, Kanamycin which showed MIC values ranging from 2–8 \mu g/mL\textsuperscript{92}.

The antimicrobial activities of the methanol extract of S. kali leaves and stems were investigated by Boulaaba et al.\textsuperscript{75}. The stem extract showed higher activity than the leaf extract. It showed antibacterial activity against P. aeruginosa and M. luteus with an inhibition zone diameter (IZD) of 10 mm. It showed weak or slight activity against other bacterial pathogens and Candida sp.\textsuperscript{75}.

Mohammed et al.\textsuperscript{41} investigated the antimicrobial activity of S. cyclophyllla essential oil against different microorganisms using the agar well-diffusion method. It showed good antibacterial activity against the Gram +ve, S. aureus and Streptococcus pyogenes, and the Gram -ve, P. aeruginosa, and E. coli. However, it had no activity against S. epidermidis. It also demonstrated powerful antifungal activity against C. albicans\textsuperscript{41}.

Gannoun et al.\textsuperscript{42} investigated the antimicrobial activities of S. vermiculata leaf, root, and stem extracts and their volatile fractions towards different pathogens. They reported that the ethanolic roots extract showed the highest activity against S. aureus with a MIC value of 0.28 mg/mL\textsuperscript{42}. The used extracts showed low antifungal activity against the tested fungal sp. with IZD ranging from 6–9.5 mm\textsuperscript{42}. On the other hand, S. vermiculata aqueous extract was reported to be an effective antifungal agent that can be used as a preservative during grain storage. This activity was examined by the decrease of fungal growth on wheat samples that were coated with S. vermiculata aqueous extract, dried, and stored for one year\textsuperscript{120}.

Terrestrial acid 1.20 isolated from S. collina Pall by Jin et al.\textsuperscript{66} showed antifungal activity against Candida albicans with a minimum 80% inhibitory concentration (MIC\textsubscript{90}) of 8 \mu g/mL\textsuperscript{66}. The alkaloid salsonine A (trolline) 1.17, present in S. collina Pall. and the flowers of Trollius chinensis, was reported to exhibit significant antibacterial activity against S. aureus, Streptococcus pneumoniae, and Klebsiella pneumoniae. It also exhibited moderate antiviral activity against influenza viruses A and B\textsuperscript{46}.

5.13. Insectical activity

The ethanol extract of S. baryosma was reported to cause moderate insecticidal activity (22.08% mortality) against Trogoderma granarium insects (Everts) which was lower than the standard insecticidal compound, cypermethrin (37.64% mortality)\textsuperscript{121}.

6. Conclusion

The impressive diversity of the pool of phytochemicals of Salsola spp. is comprehensively studied in this review. Furthermore, up-to-date taxonomic classification and description of the important morphological characteristics of the plants of this genus were discussed herein. The phytochemical profile of Salsola spp. is composed of alkaloids, nitrogenous compounds, flavonoids and isoflavonoids, triterpenoids, cardenolides and steroids, coumarins, coumarolignans, lignans and diphenylpropanoids, and simple phenolic acids. These secondary metabolites represent a great interest for the chemotaxonomy of the genus. Furthermore, they would support the diverse traditional medicinal uses and pharmacological activities of Salsola species demonstrated by many reports as antihypertensive, immunostimulant, anti-inflammatory, hepatoprotective, anthelmintic, antispasmodic, and antidiabetic. The current study represents a guiding light for researchers studying such widely distributed wild medicinal plants.
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