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JUNCACEAE PLANTS OF ISRAEL AND PALESTINE – UNIQUE PHYTOCHEMISTRY BUT INTENSE RESEARCH IS NEEDED

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ABSTRACT

The Juncaceae family is represented in the reviewed region by ten species, where they distributed in all landscapes. Some of these species were and still being used by traditional societies, and part of these uses is well documented. Modern research of these plants is strangely very limited, and some species were not published for any medicinal activity. This lack applies also for the knowledge of these plants chemical compositions. Despite this, the limited knowledge of their chemistry reveals very interesting phenanthrenes and few other compounds. Interestingly, these plants are reported for phytoremediation activity, and this will be presented in the discussion section of this minireview article. So, in addition to presenting the very limited medicinal knowledge of these plants, the main objective of this article is to draw the attention of scholars to future research opportunities. Finally, it is important to mention that some of these plants are endangered in the reviewed region between the Mediterranean sea and the Jordan river.

KEYWORDS: Juncaceae, *Juncus*, basket weaving, *Juncus acutus*, *Juncus maritimus*, chemical composition, ethnobotany, antimicrobial activity, phenanthrenes, phytoremediation.

Abbreviations: ABTS 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid), ahc and her/his colleagues, AChE acetylcholine esterase, BuChE butyrylcholine esterase, CTC condensed tannins content, DPPH 2,2-Diphenyl-1-picrylhydrazyl, DCM dichloromethane, EO essential oil, FRAP ferric reducing activity power, TAC total antioxidant capacity, TEAC Trolox equivalent antioxidant capacity, TFC total flavonoid content, TPC total phenolic content.

1. INTRODUCTION

Juncaceae or the Rush family by English common name, is named أسليات in Arabic and סמריים in Hebrew. Globally, this family is comprised of eight genera and 474 species.[1] Among these species, 332 belong to the *Juncus* genus.[2] In the reviewed region, the Juncaceae family is monogeneric and it is represented only by *Juncus* genus and ten species: *Juncus acutus*, *Juncus arabicus*, *Juncus articulatus*, *Juncus bufonius*, *Juncus capitatus*, *Juncus fontanesii*, *Juncus inflexus*, *Juncus maritimus*, *Juncus sphaerocarpus* and *Juncus subulatus*.

The *Juncus* plants played important role in human early history but only the ten species of the reviewed region will be presented here. Archeological studies have shown that ancient Egyptians used *J. maritimus* in papyrus production for writing and *J. acutus* and *J. arabicus* for baskets weaving.[3,4] Other studies found that *Juncus* plants (species is not indicated) were probably used for reed matting that covered the wrapped mummified bodies.[5] In Europe, *J. articulatus* was used for several purposes but mainly for making hay, throughout Roman period to post medieval times.[6] A recent study revealed that as in ancient Egypt, *Juncus* plants (species is not indicated) were used in burial materials of the dead.[7]

To conclude this introduction, it is important to mention that contrary to what was mentioned in the abstract of this article that medicinal and compositions of the ten *Juncus* plants of the reviewed region were very limitedly published; some other species of this genus were studied and published in relatively extended manner. For example, *Juncus effusus* which is not native to the reviewed region, was published and reviewed in many article, and its medicinal activities and chemical composition are well recorded.[8]

2. Ethnobotany and Ethnomedicine

Human societies all over the globe have used *Juncus* plants and these uses are mostly documented, but this article will present ethnobotanical and ethnomedicinal uses of the ten species in the reviewed region between the Mediterranean sea and the Jordan river. These uses are summarized in **Table 1**.

Table 1: Ethnobotanical and Ethnomedicinal Uses of *Juncus* Plants of Israel and Palestine.

Species	Region*	Plant part, use objectives, reference
J. acutus	Morocco	Seeds, diuretic, fever treatment.[9] Flowers, mixed with honey, treats stomach disorders.[11,13] Roots, treatment of cold, pests fumigation.[12] Whole plant, infusion, orally, kidney disorders.[14] Latex applied as poultice to treat skin burns and diseases.[15,17] Aerial parts, snack.[16]. Leaves, decoction, renal stones, skin infections, abdominal pains.[20]
	Italy	Stems, weaving baskets.[10] Aerial parts, ornamental, artisan, paper production, human food.[18] Stems, fish traps, boat building.[19]
J. arabicus	Israel	Stems and leaves, tent ropes, mats, baskets.[21]
	Egypt	Stems and leaves, tent ropes, mats, baskets.[21]
J. articulatus	Italy	Aerial parts, artisan.[18] Crushed leaves to treat acne.[25]
	Turkey	Shoots, hats weaving.[22]
	Pakistan	Aerial parts, animal food.[23] Leaves, crushed to treat anemia and bleeding.[24] Plant part not indicated, medicine, no other details.[26]
	Latvia	Plant indicates presence of underground water.[27]
	Nepal	Plant part not indicated, medicine, no other details.[28]
	Britain	Aerial parts, animal food.[29]
	Ireland	Aerial parts, animal food.[29]
J. bufonius	Morocco	Roots, treatment of cold, pests fumigation.[12]
	India	Plant parts not mentioned, back pains, joint pains, rheumatic, headaches.[30] Aerial parts, animal food.[32]
	China	Whole plants, soup, coolant and promotes dampness.[31]
	Pakistan	Aerial parts, roof cover.[33]
J. capitatus	No published reports.	
J. fontanesii	Iran	Roots, decoction, orally, infections treatment.[34]
J. inflexus	Pakistan	Aerial parts, roof cover.[33]
	Turkey	Stems, baskets for linseed press.[35]
	Iran	Aerial parts, weaving ropes and baskets.[36]
J. maritimus	Morocco	Roots, treatment of cold, pests fumigation[12] Leaves, decoction or infusion, cold, influenza, anxiety.[20] Seeds, decoction, orally, cold treatment.[38]
	Italy	Aerial parts, ornamental, phytodepuration, artisanal, digestive disorders, diabetes, insomnia, reproductive tract infections, wounds, skin disorders.[18] Stems, fish traps.[19]
	Israel	Flowers, decoction, orally, abortion induction.[21]
	Egypt	Flowers, decoction, orally, abortion induction.[21]
	Algeria	Leaves, urinary tract, gallbladder, analgesic, antiseptic, anti-inflammatory, skin diseases.[37]
J. sphaerocarpus	No published reports.	
J. subulatus	No published reports.	

* We preferred using “region” instead of “country” in order to avoid political controversies.

3. Published Medicinal-Biological Activities

The published medicinal-biological activities of the ten species of the *Juncus* genus, which are the species of the Juncaceae family in the reviewed region, reveal a situation similar to the publications of ethnomedicine and ethnobotany. This means a notable general lack in these publication for the entire genus, and clear gaps between the different species. These publications are summarized in **Table 2**.

Table 2: Selected Published Activities of Juncaceae Plants of Israel and Palestine.

Testing Method, Results and Reference/s
Juncus acutus
Roots methanolic extract had moderate antiviral activity against herpes simplex, sindbis and poliovirus.[9]
Whole plant was sequentially extracted with petroleum ether, ethyl acetate and methanol. Extracts were analyzed and thirty-one compounds were isolated and characterized, where 26 were dihydrophenanthrene derivatives, four phenanthrene derivatives and one pyrene derivative. Nine of these compounds were novel (**Figure 1**). All 31 compounds were tested against *Selenastrum capricornutum* (microalgae) showing moderate to strong activity.[39]
Aerial parts with fruits were extracted with ethanol/ethyl-acetate/water, 1:1:1, v/v/v, and the obtained extract was tested against HaCaT, A549, T24, KATO III and MeWo cell lines, showing weak to moderate activity.[40]
Aerial parts 90% aqueous ethanolic extract was analyzed for anti-eczema active compounds resulted isolation and characterization of five known phenolics. Two of these compounds that had highest activity are shown in **Figure 1**.[41]
Rhizomes methanolic extract was analyzed resulting four compounds that had anti-inflammatory activity, tested with inhibitory effect of inducible nitric oxide synthase in lipopolysaccharide-stimulated RAW264.7 macrophage cells. Three compounds were previously described (ref. 39) and one was novel (**Figure 1**).[42]
Leaves and roots were separately extracted with 99% aqueous ethanol, and both extracts were tested for antimicrobial (three bacteria and two fungi species) and antioxidant (DPPH, TAC methods) activities. Extracts were analyzed for chemical compositions resulting cinnamic acid as major component in both extracts (24.1% leaves, 44.71% roots).[43]
Rhizomes ethanolic extract, aqueous infusion and aqueous decoction were tested for antioxidant activity (ABTS, DPPH, FRAP methods). They were analyzed for CTC, TFC and TPC.[44], see note in **References**]
Seeds were successively extracted with ethyl acetate and methanol using conventional method and ultrasound-assisted extractions, resulting four extracts. These extracts were analyzed for TFC, TPC and tested for antioxidant (DPPH, FRAP, TAC methods) and antilithiatic activity (kidney stones dissolution method).[45]
Rhizomes, stems and flowers from two locations were extracted with methanol and fractionated with several solvents. The extracts and solvents were analyzed for active components, and extracts and pure compounds were tested against HCoV-229E, SARS-CoV-2 and MERS-CoV viruses. Activity was found against the first virus but not the other two, mainly by luteolin (**Figure 1**), a major component of the extracts. A mechanism of action is proposed.[46]
Mineral composition is presented.[47]
Cellulosic fiber was obtained from treating stem material with NaOH aqueous solution (3 h, 100 °C) followed by H_2O_2 aqueous solution (45 min, 95 °C).[48]

Seeds and stems were separately prepared for animal food and the general nutritional compositions were determined. TFC, TPC and antioxidant activity (DPPH method) was tested for the aqueous extracts.[49] Aerial parts were prepared for animal food and analyzed for nutritional composition: average crude protein ratio, insoluble fiber in acid solvents, insoluble fiber in neutral solvents, total digestible nutrients, dry matter intake, digestible dry matter, Metabolic energy and relative feed value.[50] Leaves and roots were separately extracted with 20% methanol/DCM and the antioxidant activity of the extracts was tested with ABTS, DPPH, FRAP, metal chelating (Fe^{+2} , Cu^{+2}) and NO scavenging methods. The neuroprotective activity of extracts, juncunol and galanthamine (compounds contained in the extracts, **Figure 1**), was tested by AChE and BuChE inhibition, and molecular docking was performed juncunol.[51] Whole plant methanolic extract was prepared and fractionized with *n*-hexane, DCM and *n*-butanol. Crude extract and fractions were tested against ten bacteria strains, and were analyzed for active phenanthrene derivatives: juncuenin D, juncusol, dehydrojuncuenin B and jinflexin B (**Figure 1**).[52]
Juncus arabicus Roots aqueous extract had growth inhibition (wheat roots), cytotoxic (against two melanoma cell lines) and antimalarial (against *Plasmodium falciparum* strain) activities.[53]
Juncus articulatus Crushed leaves ethanolic extract had no to weak activity against acne.[25] Whole plant methanolic extract was prepared and fractionized with *n*-hexane, DCM and *n*-butanol. Crude extract and fractions were tested against ten bacteria strains, and were analyzed for active phenanthrene derivatives: juncuenin D, juncusol, dehydrojuncuenin B and jinflexin B (**Figure 1**).[52] Leaves and fruits were separately extracted with ethanol and extracts were tested against *S. aureus* resulting negligible activity.[54]
Juncus bufonius Aerial parts methanolic extract was analyzed for general chemical composition and its antioxidant activity was tested with DPPH method. It had allelopathic activity against *Bidens pilosa*.[55] Aerial parts were extracted with 25, 75% aqueous ethanol and ethanol. The three extracts were active against *Escherichia coli*, but the activity of 25% aqueous ethanolic extract was not significant.[56] Seeds oil was extracted with *iso*-propanol/*n*-hexane (3:2, v/v) and analyzed for fatty acids composition. Its antioxidant activity was determined with TEAC method.[57]
Juncus capitatus **No published activities**
Juncus fontanesii **No published activities**
Juncus inflexus Rhizomes and stems were separately extracted with methanol and fractionated with several solvents. The extracts and fractions were tested against HCoV-229E, SARS-CoV-2 and MERS-CoV viruses. Activity was found against the first virus but not the other two.[46] Leaves and roots were separately extracted with 20% methanol in DCM and the antioxidant activity of the extracts was determined with ABTS, DPPH, FRAP, metal chelating (Fe^{+2} , Cu^{+2}) and NO scavenging methods. The neuroprotective activity was tested by AChE and BuChE inhibition.[51] Whole plant methanolic extract was prepared and fractionized with *n*-hexane, DCM and *n*-butanol. Crude extract and fractions were tested against ten bacteria strains, and were analyzed for active phenanthrene derivatives: juncuenin D, juncusol, dehydrojuncuenin B and jinflexin B.[52] Roots methanolic extract was prepared and fractionated with *n*-hexane, DCM and ethyl acetate. Extract and fractions were analyzed for active components against *S. aureus* resulting eleven compounds. Four compounds were new, jinflexins A-D (**Figure 2**, the structure of jinflexin B is shown in Figure 1).[58] Roots ethanolic extract had ameliorative effect against thioacetamide-induced hepatotoxicity in rats.

Effect was measured with concentrations of five biomarkers. The major components of the extract were (%): 10-methoxy-(N)b-alpha-methylcorynantheol 32.56, ergosterol 15.71 and 1,2,4-Trimethylanthraquinone 9.66 (**Figure 2**).[59]

Juncus maritimus

Rhizomes and stems were separately extracted with methanol and fractionized with several solvents. The extracts and fractions were tested against HCoV-229E, SARS-CoV-2 and MERS-CoV viruses. Activity was found against the first virus but not the other two.[46]

Leaves and roots were separately extracted with 20% methanol in DCM and the antioxidant activity of the extracts was determined with ABTS, DPPH, FRAP, metal chelating (Fe^{+2} , Cu^{+2}) and NO scavenging methods. The neuroprotective activity was tested by AChE and BuChE inhibition.[51]

Whole plant methanolic extract was prepared and fractionized with *n*-hexane, DCM and *n*-butanol. Crude extract and fractions were tested against ten bacteria strains, and were analyzed for active phenanthrene derivatives: juncuenin D, juncusol, dehydrojuncuenin B and jinflexin B.[52]

Aerial parts 50% aqueous methanolic extract was prepared and fractionated with *n*-hexane, chloroform and ethyl acetate. Crude extract and fractions were analyzed for active components and eleven compounds were isolated and characterized. Four compounds were new, maritins A-D (**Figure 3**). All compounds were tested for anticancer activity (against seven cancer cell lines, and one normal cell line as control). Maritins A-C showed weak to moderate activity but maritin D and another known dimeric phenanthrene (**Figure 3**), showed strong activity against some cancer cell lines.[60]

Leaves were defatted with petroleum oil and extracted with 70% aqueous ethanol and extract was analyzed for general chemical composition. Extract alone or in combination with other plant extracts (8) or standard antibiotics (7), was tested against seven bacteria species. In most combinations a synergistic effect was recorded.[61]

Leaves and stems methanolic extract was active against four fungal dermatophytes. Extract was analyzed for chemical composition and the major components were (%): *n*-propyl-11-octadecenoate 8.96, *n*-hexadecanoic acid 10.55 and *n*-pentacosane 13.78.[62]

Flowers, rhizomes and stems were separately extracted with methanol, and extracts had antifungal activity against *Zymoseptoria tritici*. The active component in these extracts was effusol (**Figure 3**).[63]

Whole plant was extracted with 96% aqueous ethanol, and extract was active against *Agrobacterium tumefaciens* but had no cytotoxic effect against *Artemia salina* or *Daphnia magna*.[64]

Leaves were macerated in wine resulting improvement of its antioxidant activity (TEAC method). For control, leaves 50% aqueous ethanolic extract was prepared and tested with the same method. Qualitative chemical composition of both extracts was determined.[65]

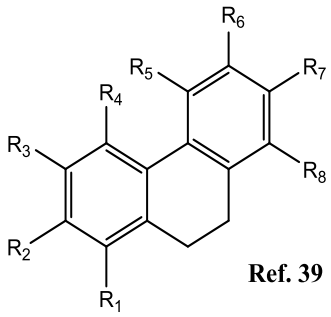
Rhizomes methanolic extract was prepared and fractionized with DCM. Extract and fraction were analyzed to isolate an active antiviral compound, dehydrojuncusol, which was active against some viruses and inactive against some others (**Figure 3**).[66]

Juncus sphaerocarpus

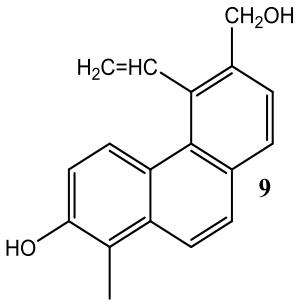
No published activities

Juncus subulatus

Tubers were successively extracted with 70% aqueous ethanol, chloroform, ethyl acetate and *n*-butanol, and EO was prepared by hydrodistillation. Extracts and EO had ameliorative effect against ethanol-induced hepatotoxicity in rats: EO was most active followed by ethyl acetate extract. Aqueous methanolic extract and EO were analyzed for chemical compositions resulting known compounds in both cases, most of them (phenanthrenes) were presented in **Figures 1-3**, in addition to bergamal, 59.23% of EO (**Figure 4**).[67]



Ref. 39



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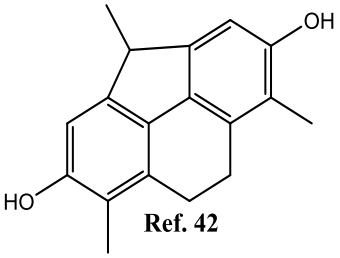
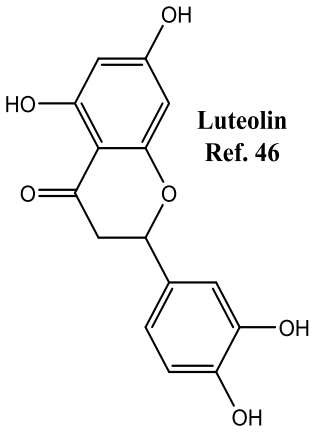
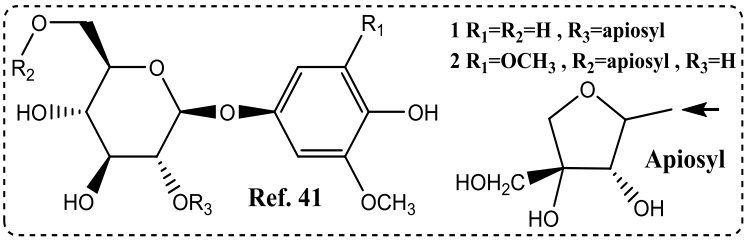


Ref. 42

1 R_1=CH_3 , R_2=OCH_3 , R_3=R_4=H , R_5=$CH=CH_2$, R_6=H , R_7=OH , R_8=H
2 R_1=CH_3 , R_2=OCH_3 , R_3=R_4=H , R_5=$CH=CH_2$, R_6=H , R_7=CH_3 , R_8=H
3 R_1=CH_3 , R_2=OH , R_3= R_4=H , R_5=$CH=CH_2$, R_6=CH_3 , R_7=R_8=H
4 R_1=CH_3 , R_2=OH , R_3=R_4=H , R_5=$CH=CH_2$, R_6=CH_2OH , R_7=OH , R_8=H
5 R_1=CH_3 , R_2=OH , R_3=R_4=H , R_5=$CH=CH_2$, R_6=CO_2H , R_7=R_8=H
6 R_1=CH_3 , R_2=R_3=OH , R_4=H , R_5=$CH=CH_2$, R_6=CH_3 , R_7=OH , R_8=OH
7 R_1=CH_3 , R_2=OH , R_3=R_4=H , R_5=CH_2OH , R_6=H , R_7=OH , R_8=H
8 R_1=CH_3 , R_2=OH , R_3=R_4=H , R_5=CH_2OH , R_6=H , R_7=OH , R_8=CH_3



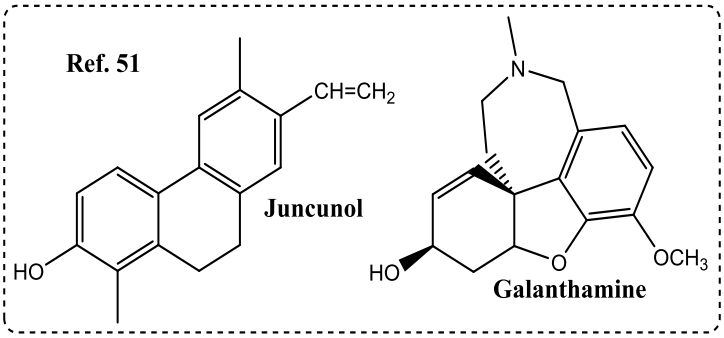
Luteolin
Ref. 46

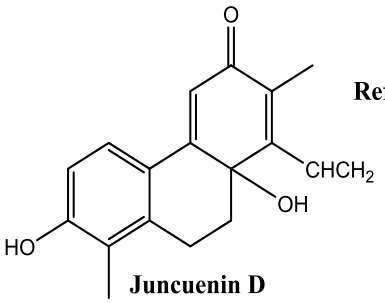


Ref. 41

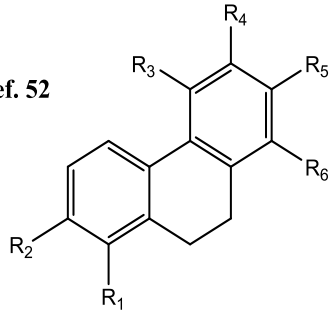
1 R_1=R_2=H , R_3=apiosyl
2 R_1=OCH_3 , R_2=apiosyl , R_3=H

Apiosyl





Ref. 52



Juncusol R_1=CH_3 , R_2=OH , R_3=$CHCH_2$, R_4=CH_3 , R_5=OH , R_6=H
Dehydrojuncuenin B R_1=CH_3 , R_2=OH , R_3=H , R_4=OH , R_5=CH_3 , R_6=$CHCH_2$
Jinflexin B R_1=CH_2OH , R_2=OCH_3 , R_3=$CHCH_2$, R_4=CH_3 , R_5=OH , R_6=H

Figure 1: Natural products isolated from *Juncus acutus*.

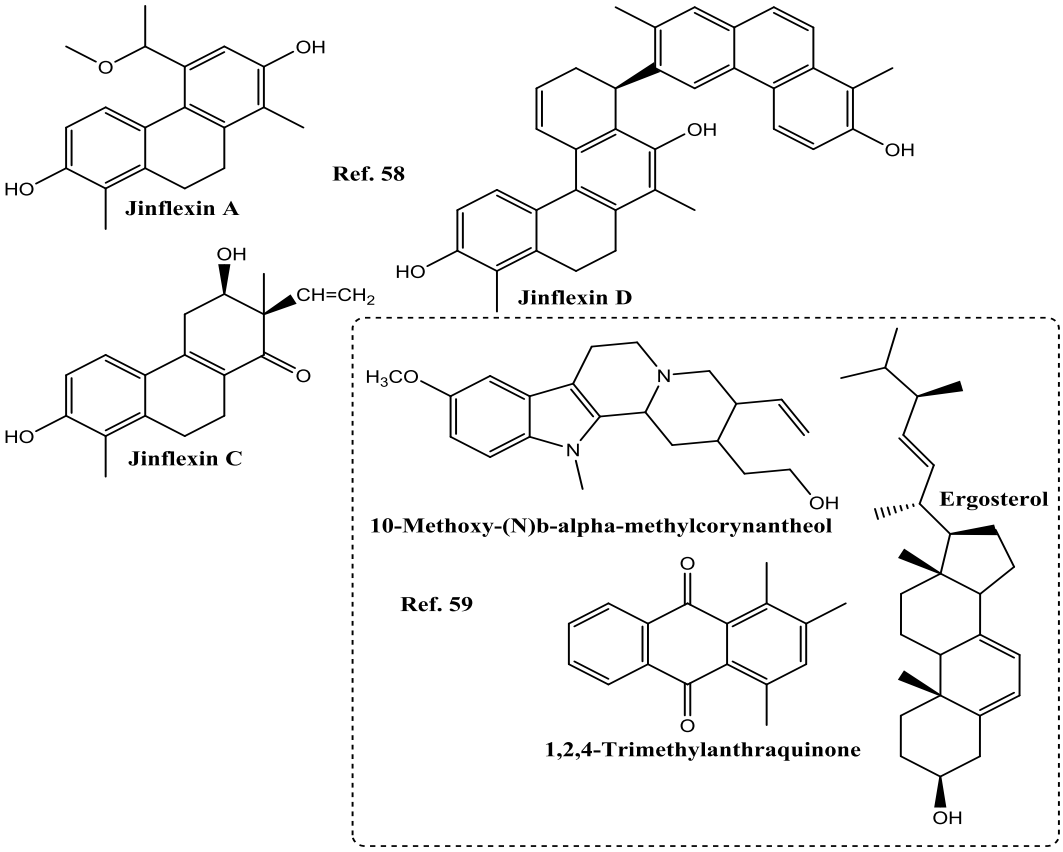


Figure 2: Natural products isolated from *Juncus inflexus.*

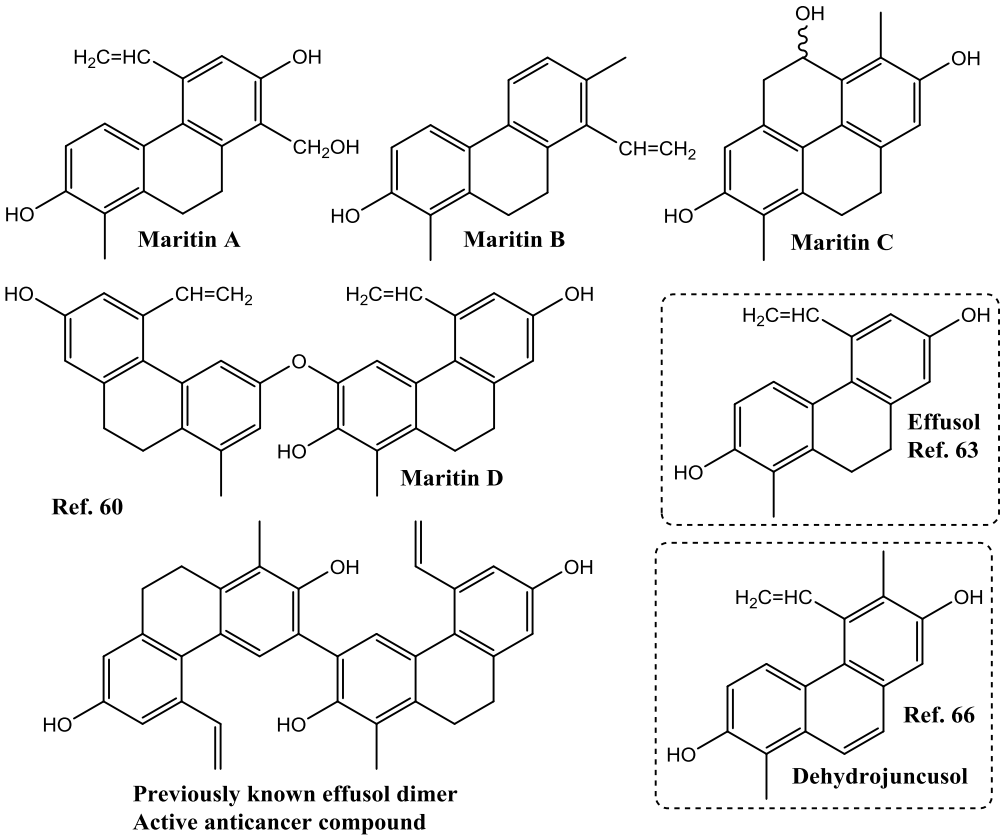
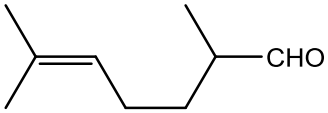


Figure 3: Natural products isolated from *Juncus maritimus.*



Bergamal
Ref. 67

Figure 4: Bergamal isolated from *Juncus subulatus.*

4. DISCUSSION

Reviewing the *Juncus* species as the genus of the Juncaceae plant family in Israel and Palestine results two contradicting impressions. On the one hand, the richness and uniqueness of the natural products that were isolated from these plants, but, and on the other hand, the great gaps in their published studies, all shown in **Table 2**. While *Juncus acutus* and *Juncus maritimus* were reasonably published, all other species were limitedly, very limitedly or not published at all.

In addition to what was presented in **Table 2**, *J. acutus* was published for other uses and propertis. F. Erdem and N. Cetinkaya tested the digestibility of *J. acutus* and its effects on ruminal cellulolytic bacteria and discovered that it is higher qualities than many other grazing plants, and second only to (low quality) alfalfa.[68] E.S. El-Sayed from Egypt published a method of paper preparation from *J. acutus*, following one of the ancient and traditional uses of this plant.[69] Obviously, he used two modern methods that involved chemical processes and he reported good yields and high qualities.

Some of the *Juncus* plants are marsh inhabitants and some grow mainly in arid landscapes. This can explain the high tolerance of these plants towards salinity, as was found by M. Boscaiu ahc for *J. acutus* and *J. maritimus*[70], and by J.L. Espinar ahc for *J. subulatus*[71] *J. inflexus* is a typical wetlands plant, that grows next to salty and freshwater. S. Mishra ahc used shoots aqueous extract to reduce F^{+3} ions ($FeCl_3$) to obtain FeO nanoparticles (FeONPs), which they used for adsorption of methylene blue from aqueous solution.[72]

But the most notable property of *Juncus* plants which was not presented in **Table 2**, is the ability of these species to accumulate pollutants and consequently, have phytoremediation capacity of polluted soils or aquatic environments. Numerous articles were published about this topic but we will present here only those of the reviewed region plants. A summary of these publications is presented in **Table 3**.

Table 3: Phytoremediation Activities of *Juncus* Plants of Israel and Palestine.

***Juncus* Species**	**Pollutant/s; Notes**	**Ref.**
J. acutus	Lab. Cd^{+2}, Cu^{+2}, Pb^{+2}; efficiency $Cd^{+2} > Cu^{+2} > Pb^{+2}$	[73]
	Fie. As, Al, B, Cr, Cu, Fe, Mn, Zn, Hg	[74]
	Lab. sodium dodecyl sulfate; H_2O_2 pretreated	[75]
	Fie. As, Se, Cu, Zn, Cd, Pb; focused on As	[76]
	Lab. Diesel, with and without NaC*l*	[77]
	Lab. (greenhouse) Zn	[78]
	Lab. and Fie. Zn, Pb; not efficient for Pb	[79]
J. arabicus	No published studies	
J. articulatus	Fie. As, Al, B, Cr, Cu, Fe, Mn, Zn, Hg	[74]
	Lab. (greenhouse) Zn	[80]
	Lab. (greenhouse) Cu	[81]
J. bufonius	No published studies	
J. capitatus	No published studies	
J. fontanesii	Lab. Cu^{+2}, Pb^{+2}; more efficient for Cu^{+2}	[82]
	Fie. Phenol	[83]
J. inflexus	Lab. Device & Fie. wastewater, Zn, Cd, Pb	[84]
	Lab. Device & Fie. wastewater, NO_3^-	[85]
J. maritimus	Fie. As, Al, B, Cr, Cu, Fe, Mn, Zn, Hg	[74]
	Fie. Hg	[86-89]
	Fie. NaC*l* (de-icing water)	[90]
	Fie. total suspended solids, phosphorus, nitrogen	[91]
J. sphaerocarpus	No published studies	
J. subulatus	Fie. total suspended solids	[92]

Lab. Laboratory, Fie. Field, Ref. Reference/s

5. CONCLUSIONS

a- *Juncus* plants of Israel and Palestine are ecofriendly.

b- The phenanthrene derivatives contained in these plants have great medicinal potential.

c- Some of these species were not published at all. Serious research is needed.

d- More research is needed to prepare extracts and essential oils of these plants.

e- Testing the products in item d for medicinal activities will provide new opportunities.

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