

## Review article

A review on bioactive phytochemicals and ethnopharmacological potential of purslane (*Portulaca oleracea* L.)Ajay Kumar<sup>a,\*</sup>, Sajana Sreedharan<sup>a,1</sup>, Arun Kumar Kashyap<sup>b</sup>, Pardeep Singh<sup>c</sup>, Nirala Ramchiary<sup>d</sup><sup>a</sup> Department of Plant Science, School of Biological Sciences, Central University of Kerala, Kasaragod, 671316, Kerala, India<sup>b</sup> Department of Biotechnology, Government E. Raghavendra Rao Postgraduate Science College, Bilaspur, Chhattisgarh, India<sup>c</sup> Department of Environmental Science, PGDAV College, University of Delhi, New Delhi, 110065, India<sup>d</sup> School of Life Sciences, Jawaharlal Nehru University, New Delhi, 110067, India

## HIGHLIGHTS

- Purslane is one of the richest terrestrial sources of omega-3-fatty acids essential for healthy human growth and development.
- It is an important traditional food and ethnomedicinal plant with potential to mitigate hunger and improve public wellbeing.
- Purslane easily grows in wide climate and edaphic zones making it a wonderful home garden nutritious food at doorsteps.
- Its rich phytochemical composition makes it an important pharmacological and nutraceutical food for future readiness.

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## ABSTRACT

The *Portulaca oleracea* L. commonly known as purslane is distributed all over the world and easily grows in diverse soil and climatic conditions. It has been traditionally used as a nutritious and ethnomedicinal food across the globe. Various studies have shown that the plant is a rich source of various important phytochemicals such as flavonoids, alkaloids, terpenoids, proteins, carbohydrates, and vitamins such as A, C, E, and B, carotenoids and minerals such as phosphorus, calcium, magnesium and zinc. It is particularly very important because of the presence of a very high concentration of omega-3- fatty acids especially  $\alpha$ -linolenic acid, gamma-linolenic acid and linoleic acid, which are not generally synthesized in terrestrial plants. Various parts of purslane are known for ethnomedicinal and pharmacological uses because of its anti-inflammatory, antidiabetic, skeletal muscle relaxant, antitumor, hepatoprotective, anticancer, antioxidant, anti-insomnia, analgesic, gastro-protective, neuroprotective, wound healing and antiseptic activities. Due to multiple benefits of purslane, it has become an important wonder crop and various scientists across the globe have shown much interest in it as a healthy food for the future. In this review, we provide an update on the phytochemical and nutritional composition of purslane, its usage as nutritional and an ethnomedicinal plant across the world. We further provide a detailed account on ethnopharmacological studies that have proved the ethnomedicinal properties of purslane.

## 1. Introduction

The *Portulaca oleracea* L. commonly known as purslane is an important member of the family Portulacaceae Juss [1]. It has a worldwide distribution and grows mainly in the tropics and subtropics and it has its

centres of origin in South America and Africa [1, 2]. The term "Portulaca" is derived from two Latin words ('Porto' means 'to carry' and lac means 'milk') which means the presence of milky juice in the plant [3, 4]. Several studies show that purslane is very important because of its nutritional [5, 6, 7], medicinal [3, 8, 9, 10, 11], phytoremediation

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properties [12, 13] and aesthetic value [12]. Purslane has been used in various parts of the world as folk medicine and traditional food since ancient times [3, 14]. Several ethnobotanical studies suggest that it is used by indigenous communities as an important medicine against several ailments such as diabetes, urinary infections, kidney and cardiovascular diseases, diarrhoea, headache and ulcers to name a few and against snake and insect bites [15, 16, 17, 18, 19, 20]. Its use as an ethno medicinal plant is reported from almost all the continents suggesting its huge importance in the healthcare of the indigenous communities. Recent advancements in the quantitative tools for the analysis of phytochemicals has led to the identification of several hundred metabolites from various parts of the purslane [5, 7, 10, 18, 21, 22]. Using ethnobotanical leads, scientists have tested the efficacy of purslane as a medicinal plant using *in vitro* as well as *in vivo* studies and have found impressive results on its pharmacological potential [23, 24, 25, 26, 27, 28, 29, 30]. The confirmation of the medicinal uses against the diseases using modern scientific studies provide evidence in support of the ethno medicinal properties of the purslane. Phytochemical studies have shown that purslane is one of the richest terrestrial sources of  $\omega$ -3 and  $\omega$ -6 fatty acids, ascorbic acid, tocopherols, glutathione and  $\beta$ -carotene [31, 32, 33, 34] suggesting its nutraceutical potential. It is found that it contains nearly 300–400 mg of alpha-linolenic acid, 12.2 mg of  $\alpha$ -tocopherol, 26.6 mg of ascorbic acid, 1.9 mg of  $\beta$ -carotene, and 14.8 mg of glutathione per 100 g of fresh weight in its leaves [33, 35]. Purslane is also an important source of specialised metabolites such as alkaloids, catecholamines, phenolic acids, anthocyanins, flavonoids, lignans, terpenoids and betalains [20, 36, 37, 38, 39, 40, 41]. Some of these metabolites have been proved to possess health promoting benefits to humans. In this review, we provide comprehensive details of the importance of purslane with an emphasis on its ethnomedicinal use, phytochemical, nutritional richness, and pharmacological potential. This article discusses the ethnomedicinal importance, phytochemical composition and pharmacological potential of purslane. Research articles from various databases such as scopus, pubmed, sciencedirect and google scholar have been used to consolidate the ethnobotanical importance of purslane, its phytochemical constitution, nutritional composition and its pharmacological potential. Figure 1 shows purslane in its natural habitat growing profusely.

## 2. Ethnomedicinal importance of purslane

People from many countries have been traditionally using purslane for medicinal and nutritional purposes. Various parts of the plant are used against a number of diseases such as diarrhoea and throat infections, diabetes, obesity, toothache, asthma, ulcers, snake bites, jaundice and dysentery [15, 16, 17, 19, 20, 42, 43]. Its use for various ailments is mentioned in the ancient texts such as *Materia Medica* by Dioscorides, *Canon of Medicine* by Avicenna and *Charaka Samhita*, a Sanskrit text on Indian traditional medicine [44, 45, 46]. It is also used in the Chinese and Persian Traditional Systems of Medicines [44]. The Chinese Traditional Medicine has strong prescriptions of purslane for various ailments [44, 47]. It is known by various names such as *Khorfeh* in Persian, *Loni* or *Lonna* in Ayurvedic system of medicine, *Kulfaa* and *Khurfaa*, *Tukhme khurfa* in the Unani system of medicine, *Paruppu Keerai* and *Pulli Keerai* in Siddha system of medicine and *Ma Chi Xian* or *Chang Shou Cai* in Chinese traditional medicine [44, 48, 49, 50]. Its use as traditional medicine is well documented recently by many researchers from various countries. Various ethnomedicinal uses of purslane across globe along with the part(s) used are shown in Table 1. Figure 2 depicts the ethnobotanical usage reports of purslane across 44 countries.

## 3. Phytochemical richness of purslane

Considering the ethnobotanical relevance of purslane, dissection of its phytochemical composition is important. Various studies have attempted phytochemical analysis of *P. oleracea* [18, 21, 50, 98]. Qualitative and quantitative tools have been employed to study the phytoconstituents present in various parts of *P. oleracea* [21, 99, 100, 101, 102]. Studies show that it contains many important metabolites that provide health benefits [3, 27, 99]. The chemical composition of purslane varies during its growth stages [5]. It has been revealed that purslane contains abundant quantities of proteins, starch and essential amino acids [5, 50]. Considerably higher level of fat is found in leaf and stem and fiber content was found in leaves but not in stem [103]. Apart from being a source of primary metabolites, it contains varying quantities of specialised metabolites (earlier known as secondary metabolites) such as



Figure 1. Purslane plant in its natural habitat.

**Table 1.** Ethno-medicinal uses of purslane in treating various diseases across the globe.

Country	Ethnomedicinal use	Reference(s)
<b>Asia</b>		
Afghanistan	Seeds are used against diarrhea and throat infections.	[19]
Armenia	Leaves and stem are used against liver, gastric, kidney, and bladder diseases and as a hypoglycemic agent.	[51]
Azerbaijan	Infusion of leaves is used against diabetes.	[52]
Bangladesh	Dried seeds are used for toothache and asthma.	[17]
China	Used against dysentery, swellings, abnormal uterine bleeding (AUB), bleeding of hemorrhoids, erysipelas, and eczema. It is also used against snake bites and insect bites.	[15, 16, 20]
India	Used as an Ayurveda medicine against diseases of lungs, liver, kidney, bladder and bowel burning sensation, coughing and neurasthenia.	[53, 54, 55, 56]
Iran	Roots, leaves and seeds of purslane are used for the treatment of diabetes mellitus.	[57, 58]
Jordan	Seeds are used as blood purifiers and as aphrodisiacs.	[59]
Myanmar	Leaves used for kidney disease treatment and as a laxative.	[60]
Nepal	Leaves are used for scurvy, kidney and cardiovascular disorders. Juice is drunk for blood purification.	[42, 43]
Pakistan	Aerial parts are used in the treatment of urinary and digestive problems. Seeds are demulcent, diuretic and vermifuge.	[61, 62]
Philippines	Used for treatment of kidney infections.	[63]
Sri Lanka	Leaves are used against ulcers, wounds, burns and skin diseases.	[15, 64]
UAE	Aerial parts are used as a medicine to reduce fever.	[44]
Vietnam	The whole plant is used as an antibacterial, anathematic and anti-inflammatory agent.	[65, 66, 67]
Yemen	Leaves are used for gastric pain.	[68]
<b>Europe</b>		
Albania	It is used to treat musculoskeletal disorders.	[69, 70]
Italy	Used to treat headache, stomach, intestine and kidney pains.	[71]
Greece	Used to cure inflammation.	[72, 73]
Romania	External bath for weakness and sickness.	[74]
Spain	Consumption of aerial parts for blood pressure regulation.	[75]
Turkey	Leaves are used to cure diarrhoea, diabetes, headache, ulcers, urinary disorders, wounds and constipation.	[76, 77, 78]
<b>Australia</b>		
Australia	Aerial parts are eaten to cure scurvy, irritations, inflammations and as a diuretic and antibiotic agent.	[15]
<b>Africa</b>		
Algeria	It is used against dyspepsia and also as a diuretic.	[79]
Angola	Whole plant is used for burns.	[80]
Cameroon	Shoot with leaves is used against headaches and poisoning.	[81]
Egypt	Used as a vegetable as well as medicinal plants and also spice.	[56]
Kenya	Whole plant is crushed and boiled with other herbs and used against cancer.	[82]
Ethiopia	Cooked leaves are eaten for gastritis, peptic ulcers and constipation. Application of crushed leaves on skin is used to cure fungal infections.	[83]
Libya	Used against headache, migraine and as a revulsant and vermicide.	[84]
Morocco	Cooked leaves are consumed to cure hypercholesterolemia.	[54]
Nigeria	Used as a diuretic and for the treatment of burns.	[15]
South Africa	Crushed and taken orally with warm water against tuberculosis. Application of crushed leaves is used against lymphatic filariasis. <i>P. quadrifida</i> is also used against lice and sores. Other uses: infections, pain relief	[85, 86, 87, 88]

**Table 1 (continued)**

Country	Ethnomedicinal use	Reference(s)
Mauritius	Decoction of plants is used as an astringent and diuretic. Also used against inflammation and worms. Root and leaf decoction used as anthelmintics.	[89]
<b>South America</b>		
Argentina	Used as an antipyretic.	[90]
Bolivia	Raw leaves are eaten against nephrolithiasis.	[91]
Brazil	Used against hemorrhoids.	[92]
Ecuador	Aqueous infusion of fresh leaves used against internal inflammation, infections, gastritis and kidney diseases.	[93]
Peru	Bark, leaf and sap used against diarrhea, fever and liver problems.	[94]
<b>North America</b>		
Dominica, West Indies	Used for treatment of intestinal worms.	[95]
Republic of Trinidad and Tobago	Used against urinary problems, "cooling" and for lowering high cholesterol.	[96]
Jamaica	Used against urinary diseases.	[96]
Cuba	Used against kidney infections, inflammation and digestive disorders.	[97]

alkaloids, saponins, tannins, flavonoids, cardiac glycosides, terpenoids, phenolic acids and organic acids [18, 102]. The presence of diverse bioactive compounds in varying concentrations should be essentially responsible for its multiple biological activities [22, 44, 89]. The different parts of the purslane have been subjected to the quantification of various bioactive compounds. It has been found that water extract of purslane flowers have greater phenolic content than stem and leaves and the leaves show higher concentrations of total flavonoids and ascorbic acid [22]. The leaves also contain higher  $\beta$ -carotene content than stem [104]. Purslane is known for very high amounts of omega-3-fatty acids [105]. Wild genotypes of *P. oleracea* contain nearly  $188.48 \pm 6.35$  mg/100 g of omega-3-fatty acid [18]. Therefore purslane is known as one of the richest terrestrial sources of omega-3- fatty acids [7]. A total of 85 metabolites belonging to different classes such as alkaloids, fatty acids, phenolic acids and amino acids were identified in three species namely *P. oleracea*, *P. rausii* and *P. granulostellulata* [106]. This study reported methoxylated flavone glycosides, O and C-flavonoids, and four cyclo-dopa alkaloids namely oleracein A, C, K and N from purslane [106]. In addition to the identification of previously known oleraceins (oleraceins A, B, C, N, J, and U), Fernández-Poyatos et al. [107] reported two new cyclo-dopa amides namely oleraceins X and Y from purslane. Lei et al. [108] isolated four new cerebrosides and five known compounds viz. portulacerebroside A, B, C and D from *P. oleracea*. Nemzer et al. [18] identified widely known flavonoids, such as quercetin, kaempferol, isorhamnetin and naringenin in purslane. Several other phytoconstituents including 48 fatty acyl/lipids, 11 flavonoids and its derivatives, seven carbohydrates, two glycosylated hydroxy-cinnamic acid derivatives and miscellaneous terpenoids, steroids, lignan and purine nucleosides were identified [100]. The two dimensional structures of the main important metabolites found in purslane are presented in Table 2. The following subheadings explain various classes of specialized metabolites with individual metabolites that have been reported from purslane.

#### 4. Diverse metabolites belonging to different classes of specialised metabolites reported in purslane and their individual bioactivities

##### 4.1. Alkaloids

Alkaloids are one of the most important groups of naturally occurring organic compounds with numerous pharmaceutical and medicinal uses [118]. Several alkaloids such as oleraceins, oleracins, trollisine,

scopoletin and oleraisoindole have been reported in *P. oleracea* [39, 40, 48, 109, 119, 120]. Two new alkaloids namely (3R)-3,5-bis(3-methoxy-4-hydroxyphenyl)-2,3-dihydro-2(1H)-pyridinone and 1,5-dimethyl-6-phenyl-1,2-dihydro-1,2,4-triazin-3(2H)-one were characterized from purslane by Tian et al. [121] and reported their moderate to high cytotoxic activity against different human cancer cell lines [122]. Three phenolic alkaloids namely oleracein A, oleracein B and oleracein E isolated from *P. oleracea* showed antioxidant activities [123]. Oleracein E and oleracein L from *P. oleracea* show hypoglycemic and antidiabetic activities [28]. Sun et al. [124] have demonstrated neuroprotective potential of oleracein E using in vitro and in vivo models. Xiu et al. [49] isolated soyalkaloid A for the first time from *P. oleracea* and reported its antioxidant activity using 1,1-diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging assay. In addition to several known compounds, Xiu et al. [48] reported a new alkaloid named, oleraurea from *P. oleracea* and interestingly it possesses anticholinesterase activity suggesting its important role in Alzheimer's disease as cholinesterase inhibitor [48]. Jin et al. [125] isolated three new isoquinoline alkaloids namely 1-(5'-hydroxymethyl furan-2-yl)-6,7-dihydroxy-3,4-dihydroisoquinoline, 1-(furan-2-yl)-6,7-dihydroxy-3,4-dihydroisoquinoline and 2-(furan-2-ylmethyl)-6,7-dihydroxy-3,4-dihydroisoquinoline-2-ium from purslane [125]. Ten new oleraceins (H, I, K, L, N, O, P, Q, R, S) along with four indoline amide glucosides have been characterized from *P. oleracea* by Jiao et al. [110]. The authors further found that oleraceins K and L showed higher antioxidant activities than vitamin C [110]. Zhao et al. [120] isolated a new lactam alkaloid namely oleraciamide D from *P. oleracea* in addition to five known alkaloids namely indole-3-aldehyde, portulacatone, N-trans-feruloyloctopamine, N-trans-feruloyl-3'-O-methyldopamine and N-trans-feruloyltyramine. The oleraciamide D possesses cytotoxic activity in human neuroblastoma SH-SY5Y cells [120].

#### 4.2. Catecholamines (CAs)

Catecholamines are a group of amines that are produced in humans as neurotransmitters [126]. They are also synthesized in plants under stressful conditions and play diverse roles including growth and development [127]. Recent studies show that purslane is a rich source of a number of CAs with potential benefits. Dopamine is one of the most important catecholaminergic neurotransmitters synthesized in purslane [3]. High concentration of noradrenaline (norepinephrine) is found in purslane leaves [111]. Endress et al. [128] have reported the existence of adrenaline (epinephrine), another important catecholamine from *P. grandiflora* callus. The presence of noradrenaline and dopamine in

purslane is further confirmed by several other studies [16, 129, 130]. Hu et al. [131] identified 22 compounds from a water extract of purslane and nine of them were found to be catecholamine derivatives. Martins et al. [132] have demonstrated neuroprotective effect of purslane in wistar rats. Earlier studies have shown multiple benefits of dopamine against neurodegenerative diseases such as Parkinson's disease, Schizophrenia and Huntington's disease [133]. Interestingly, dopamine and noradrenaline were detected in the purslane extracts administered to the rats that showed neuroprotective effects [132] suggesting its role as an important neuroprotectant. The existence of catecholamines in purslane provides evidence in favour of its neuroprotective activities and suggests its potential applications against neurodegenerative diseases. However, further clinical studies must be done to clearly understand the neuroprotective effects and its application for various neurodegenerative diseases in humans.

#### 4.3. Phenolic acids

Phenolic acids are important specialized metabolites found in plants that are derivatives of benzoic and cinnamic acids [134, 135]. They are carboxylic acid groups possessing phenolic compounds [136]. Number of phenolic acids such as caffeic acid, p-coumaric acid, ferulic acid, gallic acid, gentisic acid, benzoic acid and anisic acid have been reported from purslane [114, 115]. The occurrence of caffeic, gallic, vanillic, ferulic and syringic acids was detected by Santiago-Saenz et al. [113].

#### 4.4. Flavonoids

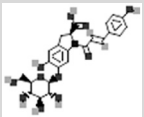
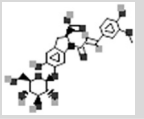
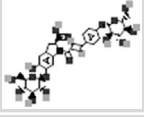
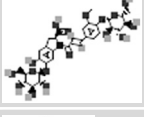




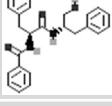
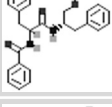
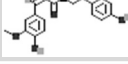
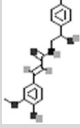
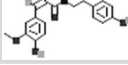
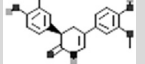
Plant flavonoids are a large group of naturally occurring phenyl chromones found in various parts of a plant such as root, stem, flower and fruit [137]. Flavonoids are known for various biological roles in humans because of their anti-oxidative, anti-inflammatory, antitumor, antiviral and antibacterial activities [138]. The flavonoids also play a protective role against coronary diseases and help in vascular activity [139]. Several flavonoids such as apigenin, kaempferol, luteolin, quercetin, isorhamnetin, kaempferol-3-O-glucoside and rutin have been isolated from purslane [114]. Xu et al. [140] have identified five flavonoids namely kaempferol, apigenin, myricetin, quercetin and luteolin using capillary electrophoresis with electrochemical detection. Use of quercetin isolated from purslane significantly improved learning and memory in mice suggesting its neuroprotective effects [141]. Santiago-Saenz et al. [113] have quantified myricetin in purslane. Three flavonoids oleracone C, D



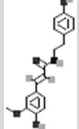


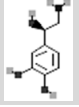
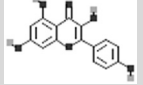
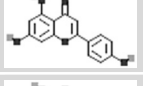
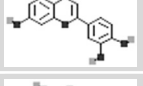
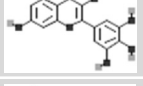
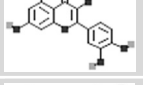
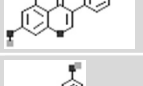
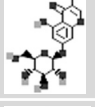
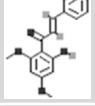
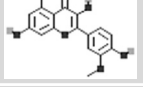
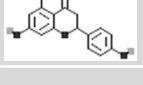
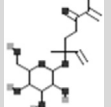
Figure 2. World map showing ethnomedicinal reports of purslane in 44 countries against various diseases.



**Table 2.** Important phytochemicals reported from purslane with their two dimensional structures.

Phytochemical	Structure	Reference
<b>Alkaloids</b>		
Oleracein A		[109]
Oleracein B		[109]
Oleracein C		[109]
Oleracein D		[109]
Oleracein E		[109]
Oleracein K		[110]
Oleracein L		[28]
Scopoletin		[50]
Aurantiamide		[50]
Aurantiamide acetate		[50]
N-cis-Feruloyloctopamine		[50]
N-trans-Feruloyloctopamine		[50]
N-cis-Feruloyltyramine		[50]
(3R)-3,5-Bis(3-methoxy-4-hydroxyphenyl)-2,3-dihydro-2(1H)-pyridinone		[50]

**Table 2 (continued)**

Phytochemical	Structure	Reference
N-trans-Feruloyltyramine		[50]
Indole-3-aldehyde		[50]
<b>Catecholamines</b>		
Dopamine		[3]
Noradrenaline		[111]
<b>Flavonoid</b>		
Kaempferol		[50]
Apigenin		[50]
Luteolin		[50]
Myricetin		[50]
Quercetin		[50]
Genistein		[50]
Genistin		[50]
2,2'-Dihydroxy-4',6'-dimethoxychalcone		[50]
Isorhamnetin		[18]
Naringenin		[18]
<b>Terpenoids</b>		
Portuloside A		[50]

(continued on next page)

Table 2 (continued)

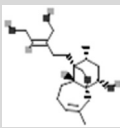
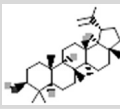
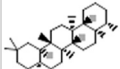
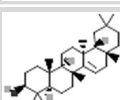
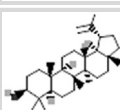
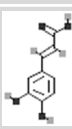
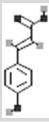
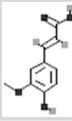
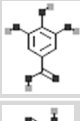



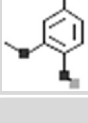
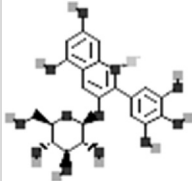
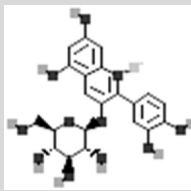
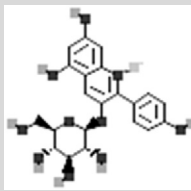
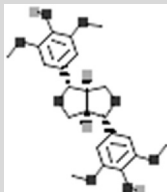
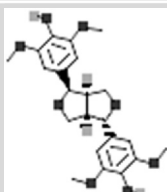

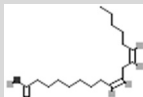
Phytochemical	Structure	Reference
Portulene		[38]
Lupeol		[50]
Friedelane		[50]
Taraxerol		[112]
Lupeol		[3]
<b>Phenolic acids</b>		
Caffeic acid		[113]
p-coumaric acid		[114]
Ferulic acid		[113]
Gallic acid		[113]
Gentisic acid		[115]
Benzoic acid		[115]
Anisic acid		[115]
Vanillic acid		[113]
<b>Anthocyanins</b>		
Delphinidin-3-glucoside		[115]

Table 2 (continued)

Phytochemical	Structure	Reference
Cyanidin-3-glucoside		[115]
Pelargonidin-3-glucoside		[115]
<b>Lignans</b>		
(+)-Syringaresinol		[116]
(+)-Lirioresinol A		[116]
<b>Fatty acids</b>		
Α-linolenic acid		[7]
Linoleic acid		[117]

and E were identified for the first time by [142]. Nayaka et al. [143] isolated apigenin, a flavonoid from purslane and proved its antibacterial properties against certain bacterial pathogens such as *Pseudomonas aeruginosa*, *Salmonella typhimurium*, *Proteus mirabilis*, *Klebsiella pneumoniae* and *Enterobacter aerogenes*.

#### 4.5. Anthocyanins

Anthocyanins are polyphenolic compounds that are found in plants as red, purple or blue coloured pigments [144, 145, 146, 147]. Anthocyanins are also very important for human health and have been found to play several beneficial roles against a number of diseases [146, 147]. Anthocyanins that have been reported from purslane are Delphinidin-3, 5-glucoside, Cyanidin-3,5-glucoside, Pelargonidin-3,5-glucoside, Delphinidin-3-glucoside, Cyanidin-3-glucoside and Pelargonidin-3-glucoside [115].

#### 4.6. Homoisoflavonoids (HIFs)

Homoisoflavonoids are another important group of specialised plants found in plants [148]. They are different from flavonoids as they possess one extra carbon which is absent in flavonoids and more than 300 HIFs have been identified in plants till date [149]. They are known for antimicrobial, antimutagenic, anti-inflammatory, antidiabetic and antioxidant activities [150, 151, 152]. The purslane is known to synthesize several important HIFs. Two new HIFs identified as

3-(2-hydroxybenzyl)-6,8-dimethoxy-4H-chromen-4-one (oleracone J) and 3-(2-hydroxybenzyl)-6,8-dimethoxychroman-4-one (oleracone K) were recently isolated by Duan et al. [153]. Nemzer et al. [18] identified four HIFs viz. portulacanones A–D from aerial parts of purslane. Yang et al. [142] isolated a unique HIF namely oleracone C. Another important HIF known as (E)-5-hydroxy-7-methoxy-3-(20-hydroxybenzyl)-4-chromanone (HM-Chromanone) isolated from *P. oleracea* showed protective effect against apoptosis of  $\beta$  cells of pancreas induced by glucose suggesting its antidiabetic properties [154]. It has also been found that HIFs show inhibitory activity against 5-lipoxygenase enzyme, which is responsible for inflammation in patients with asthma, allergic rhinitis, and osteoarthritis [152]. These studies suggest that *P. oleracea* is rich in HIFs and can play important roles against multiple diseases.

#### 4.7. Lignans

Lignans are polyphenols formed by the dimerization of monolignols and they play defensive roles in plants against microorganisms [155]. Ma et al. [116] identified four lignans namely oleralignan, (+)-syringaresinol, (+)-lirioresinol A and monomethyl 3,3',4,4'-tetrahydroxy- $\delta$ -truxinate and it was found that oleralignan was altogether new lignan reported from it. Further, evaluation of DPPH scavenging assay of the four lignans suggested good antioxidant activity [116].

#### 4.8. Terpenoids

Terpenoids also known as isoprenoids are isoprene derived organic compounds synthesised in many organisms including plants [156]. Elkhayat et al. [38] reported portulene as a new diterpene from purslane. Apart from that, a number of other terpenoids identified in purslane are portuloside A, portuloside B, portulene, lupeol, friedelane, taraxerol, portaraxeroic acid A and portaeaxeroic acid B [3, 112].

#### 4.9. Fatty acids (FAs)

A number of fatty acids have been isolated and identified from various parts of purslane plants. Studies have shown that purslane contains higher total fatty acid content than commonly used vegetables such as spinach, red leaf lettuce, mustard and buttercrunch lettuce [35]. Purslane is a nutritious vegetable crop rich in the polyunsaturated fatty acids (PUFA) and it is especially known for omega-3 ( $\alpha$ -linolenic acid) and omega-6 (linoleic acid) fatty acids which are essential for human health [3, 117]. It has been proved that purslane contains higher levels of  $\alpha$ -linolenic acid than spinach [7]. It is recommended that healthy diets should be enriched with foods having higher Omega 3/Omega 6 ratio. Interestingly, the leaves of purslane have a very high Omega 3/Omega 6 ratio [117, 157]. Simopoulos and Salem [34] have further reported the presence of eicosapentaenoic acid (EPA), another important omega-3 FA in purslane. Omara-Alwala et al. [105] reported that Purslane also contains docosahexaenoic acid (DHA) and docosapentaenoic acid (DPA) which are also omega 3 fatty acids. The presence of essential fatty acids in purslane is highly beneficial for vegan and vegetarians whose diets generally lack essential omega-3-fatty acids. Few studies have also suggested enrichment of vegan and vegetarian diets with purslane for omega-3-FA requirements [7, 158].

#### 4.10. Betalains

Betalains such as betacyanins and betaxanthins are water soluble nitrogenous plant pigments that impart red-violet and the yellow-orange coloration to fruits and vegetables [159, 160, 161]. Trezzini and Zrýd [162] reported the presence of two new betalains namely portulacaxanthin II and portulacaxanthin III from the petals of *P. grandiflora*. Other betalains reported from *P. grandiflora* are portulacaxanthin, dopaxanthin, vulgaxanthin I, miraxanthin V and betanin [162, 163].

#### 4.11. Other phytoconstituents

Purslane also contains many other phytoconstituents. Studies have shown the presence of organic acids such as oxalic acid, butanedioic acid, phenylpropionic acid, p-hydroxybenzoic acid, lauric acid, vanillic acid, myristic acid, pentadecanoic acid, palmitoleic acid, palmitic acid, heptadecanoic acid, oleic acid, stearic acid, arachidic acid, behenic acid, 3-Quinolinecarboxylic acid, Indole-carboxylic acid, catechol, lonchocarpic acid, fumaric, aconitic, citric, malic and oxalic acids and phenolic compounds such as 3-caffeoylquinic acid and 5-caffeoylquinic acid from different parts of *P. oleracea* plant [3, 29, 50, 157, 164]. Oxalic acid and citric acid are the most abundant organic acids in purslane [157, 165]. Allantoin, an end product of purine catabolism, has been reported from purslane [166]. A study reported the presence of N,N'-dicyclohexylurea,  $\beta$ -sitosterol and  $\beta$ -sitosteryl glucoside in purslane [167].

### 5. Purslane is nutritionally rich traditional food plant with huge nutraceutical potential

Purslane is a nutritionally rich plant with nutraceutical potential because of the presence of health promoting phytoconstituents [168]. It has been used by people across the globe as a traditional food plant [169, 170]. The purslane leaves contain 23–24 % of proteins [171, 172]. It is observed that protein, ash and fiber content in purslane is higher than that of wheat flour [172]. Presence of considerable amounts of essential dietary minerals such as copper, iron, manganese, magnesium, potassium, calcium, magnesium and phosphorus is reported in purslane [171]. It is a rich source of potassium (494 mg/100 g), magnesium (68 mg/100 g) and calcium (65 mg/100 g) [7]. Results obtained by Santiago-Saenz et al. [113] also suggest that purslane contains significant amounts of protein, fibre and inorganic nutrients such as Fe, Cu, Mn, Zn, B, P, Ca, Mg and K [113]. Mohamed and Hussein [5] found the presence of significant amounts of total solids in roots. The total solids and protein levels vary in different growth stages. Significant variation in total phosphorus, calcium, potassium, iron, manganese, and copper found in relation with growth stages. Purslane is also a rich source of vitamins such as vitamin A, riboflavin, niacin, pyridoxine, vitamin C, thiamin,  $\alpha$ -tocopherol and pantothenic acid [3, 173]. It has been found that purslane contains higher amounts of  $\beta$ -carotene, vitamin C and  $\alpha$ -tocopherol than spinach [7, 113]. Occurrence of antioxidant molecules suggests that intake of purslane can help overcome oxidative stress [174]. Because of the presence of a number of important nutritional components, common purslane is an important herb and possesses high nutritional potential [175]. Presence of omega-3 fatty acids in purslane makes it one of the few terrestrial sources of omega-3-fatty acids [34, 176]. It is known as a superfood as omega-3-fatty acids play an important role in prevention of coronary artery diseases, diabetes, arthritis, cancer, and other inflammatory and autoimmune disorders [73]. The presence of vitamin A in purslane makes it a good candidate for people with vision impairments and vitamin A deficiency [18]. Islanders on Atolls in the South Pacific consume purslane because of the presence of macro and micronutrients [177]. The main nutraceutical constituents of purslane are presented in Figure 3 and their individual concentrations are shown in Table 3.

### 6. Ethnopharmacological potential of purslane

Purslane is a medicinally important herb [103] as it possesses an array of medicinally important phytochemicals [7, 21, 114]. The use of purslane as a medicine and food in China have a history of thousands of years [47]. There are also clues regarding use of purslane for respiratory diseases in ancient Iranian medical books [179]. Ethnobotanical studies suggest that it has been an important part of traditional medicine among various cultures in different parts of this world [71, 78, 93, 96]. The qualitative and quantitative analysis of phytochemical composition also supports its pharmacological value. Various metabolic studies have deciphered its phytochemical composition [99, 100, 102, 106]. Because

of its importance in various cultures as an important ethnomedicinal plant, scientists have taken strides to prove its pharmacological potential against various diseases such as diabetes, cancers, neural diseases, asthma, obesity and bacterial and viral diseases using various models including *in vivo* studies and cell lines [24, 73, 100, 180]. Main ethnopharmacological properties of purslane are depicted in Figure 4. Following subheadings provide details about ethnopharmacological roles and properties of purslane.

### 6.1. Antioxidant potential

The phytochemical composition of purslane points towards its antioxidant potential and various studies have proved this using various assays [178]. Several parts of purslane including its leaves, stem and flowers have been used to test its antioxidant potential. Lim and Quah [181] showed that methanolic extract of six cultivars of purslane showed strong antioxidant activity. However, it was found that flowers show highest antioxidant activity and it is linked with higher total phenolic content, ascorbic acid,  $\beta$ -carotene and omega-3 fatty acids [22]. Antioxidants are very important for human health as they reduce risk of cell damage by free radicals [7]. Several studies have investigated and proved the antioxidant potential of purslane [27, 30, 142, 176]. Several compounds have been isolated from purslane and their antioxidant activities have been proved. For example, phenolic alkaloids such as oleracein A, oleracein B and oleracein E showed antioxidant activities [123]. Comparative analysis of raw and steamed purslane extracts showed reduction in the antioxidant activities following its steaming [107]. The extracts of the aerial parts of the *P. quadrifida* also showed DPPH radical scavenging activity [182]. Dkhil et al. [183] showed antioxidant potential of *P. oleracea* using adult Wistar albino male rats. The study further found inhibition in lipid peroxidation, nitric oxide in liver, kidney and

testis of rats. Taken together all these results suggest that purslane has health promoting effects and gives protection against the free radicals.

### 6.2. Muscle relaxant potential

Muscle relaxant properties of purslane have been investigated by a number of researchers and found promising results [184, 185, 186, 187, 188, 189, 190, 191]. The muscle relaxant properties and neuromuscular activities of purslane extract may be due to the higher concentration of  $K^+$  ions [192].

### 6.3. Anticancer potential

Cancer is one of the leading causes of deaths globally. Many researchers in the world are working on the prospecting of anticancer diseases against a variety of cancer types. Many drugs currently used against cancer such as taxol, epipodophyllotoxin, Vincristine, Vinblastine, paclitaxel, docetaxel, camptothecin and irinotecan have plant based origins [193, 194]. Therefore, it is not surprising if purslane also contains many such important anticancer molecules. Purslane has shown promising results as an anticancer plant against several cancer types. It was found that extract of purslane has an inhibitory effect on nodule formation in colon cancer stem cells [195]. It was also effective against ulcerative colitis in rats and mice [26, 196]. Use of a unique polysaccharide component (POP) from purslane showed antitumor effects in *in vivo* models [197]. Water soluble purslane extract showed inhibitory role against cervical cancer cell growth in *in vitro* and *in vivo* models [198]. It has also been proved effective against gastric cancer [199]. Seed oil of purslane showed significant cytotoxicity against human liver cancer (HepG2) and human lung cancer (A-549) cell lines and inhibited cell growth [24]. Portulacerebroside A (PCA) isolated from purslane showed

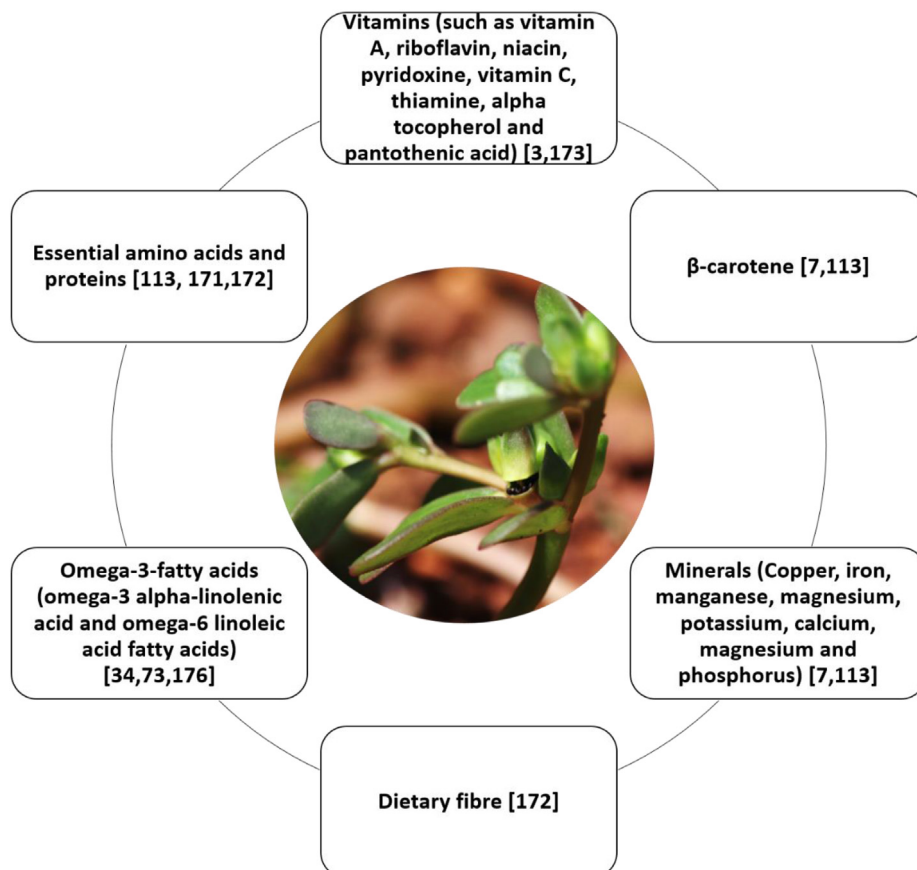


Figure 3. Main nutraceutical constituents found in purslane.



**Table 3.** Main nutraceutical constituents and their concentration found in purslane.

Nutritional constituent	Concentration	Reference(s)
Crude protein (% DW)	23.47	[172]
Carbohydrate (% DW)	40.67	[172]
Crude lipid (% DW)	5.26	[172]
Crude fibre (% DW)	8.00	[172]
Ash (% DW)	22.66	[172]
Zinc (mg/100 g)	5.83 ± 0.08	[172]
Calcium (mg/100 g)	131.44 ± 3.21	[172]
Iron (mg/100 g)	72.14 ± 505	[172]
Magnesium (mg/100 g)	66.47 ± 1.43	[172]
Sodium (mg/100 g)	571.41 ± 16.63	[172]
Potassium (mg/100 g)	2842.38 ± 91.68	[172]
Manganese (mg/100 g)	9.75 ± 1.02	[172]
Phosphorus (mg/100 g)	79.7	[178]
Carotenes (mg/100 g)	89.2	[173]
Lipids (mg/100 g)	3.81	[173]
B1 – thiamine (mg/100 g)	0.047	[7, 168]
B2 – riboflavin (mg/100 g)	0.112	[7, 168]
B3 – niacin (mg/100 g)	0.480	[7, 168]
B5 – pantothenic acid (mg/100 g)	0.036	[7, 168]
B6 – pyridoxine (mg/100 g)	0.073	[7, 168]
B9 – folates (mg/100 g)	0.012	[7, 168]
Ascorbic acid (mg/g)	2.27 (stem) to 3.99 (leaves)	[7]
α-tocopherol (mg/100 g)	26.6 mg	[7]
Omega-3-fatty acid (mg/100 g)	188.48 ± 6.35	[18]
Linoleic acid (LA, mg/100 g)	34.0 ± 5.2	[117]
α-linolenic acid (LNA, mg/100 g)	132.8 ± 22.0	[117]
LNA/LA ratio	5.2 ± 0.03	[117]
α-carotene (mg/100 g)	0.009	[168]
β-carotene (mg/g)	0.29 (stem) to 0.58 (leaves)	[7]
Lutein (mg/100 g)	5.4	[168]
Zeaxanthin (mg/100 g)	0.19	[168]

effectiveness against acute myeloid leukemia [200]. Rahimi [201] showed NF-κB inhibitor activity of the purslane extract. The extract also showed cytotoxicity and apoptogenic activity on human glioblastoma cancer cell line (U-87). The anticancer activities of purslane proves its

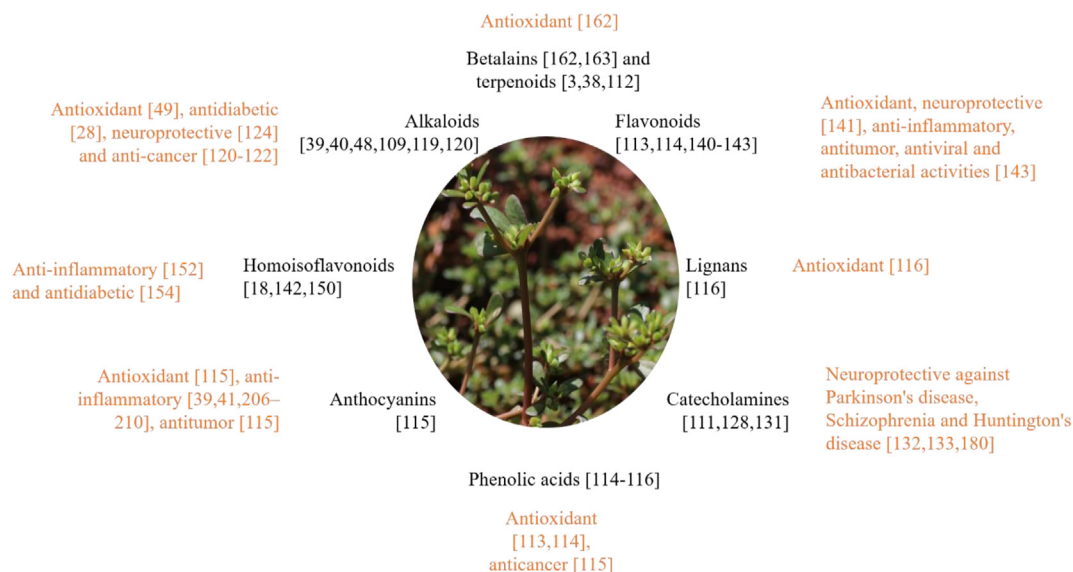
potential in the development of future drugs against various types of cancer.

#### 6.4. Antimicrobial potential

Purslane is also known to possess antibacterial and antifungal properties [38]. A lectin from the roots of *P. elatior* showed bacteriostatic activity against *Enterococcus faecalis*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* and antifungal properties against *Candida albicans*, *C. parapsilosis*, *C. krusei*, and *C. tropicalis* [202]. Cerebrosides such as portulacerebroside (A-D) showed significant antibacterial effects against the enteropathogenic bacteria suggesting its role against bacillary dysentery [108]. Soliman et al. [203] showed antibacterial activities of purslane extract against *S. aureus*, *P. aeruginosa*, *E. coli*, including *Acinetobacter baumannii* and *Klebsiella pneumoniae*, a multidrug resistant bacteria. Same study showed antifungal activity of purslane extract against *C. albicans*. El-Desouky et al. [204] found antifungal activities against three species of *Aspergillus* namely *A. flavus*, *A. ochraceus* and *A. parasiticus*. Recently Tleubayeva et al. [205] showed that carbon dioxide extract of purslane possess antibacterial activities against *E. coli*, *S. aureus*, *B. subtilis*, and antifungal activity against *C. albicans*.

#### 6.5. Anti-inflammatory and immunomodulatory potential

Several studies have confirmed the anti-inflammatory activity of purslane [39, 41, 206, 207, 208, 209, 210]. It is reported that purslane also suppresses lung inflammation [27]. Di Cagno et al. [211] found effectiveness of fermented purslane juice against intestinal inflammation and epithelial injury in caco-2 cell lines. Samarghandian et al. [212] observed the effectiveness of aqueous extract of purslane against inflammation in streptozotocin induced diabetic mice through prevention of oxidative stress. purslane extract also exerts immunomodulatory effects in rats [213]. The purslane showed promising results against oral lichen planus (OLP), a chronic inflammatory and immune-mediated disease [214]. Subsequent to receiving a stimuli, degranulation of mast cells occur and pro-inflammatory cytokines tumor necrosis factor (TNF), interleukin-1 (IL-1) and interleukin-6 (IL-6) are released from mast cells, which in turn lead to stimulation of macrophages that produce inflammatory cytokines and chemokines. They stimulate tissue cells to produce cytokines, chemokines and non-cytokine inflammatory mediators such as prostaglandins (PGs), Nerve growth factor (NGF), and nitric oxide (NO). Then the inflammatory cytokines and non-cytokine inflammatory



**Figure 4.** Ethnopharmacological properties of the main phytochemicals found in purslane.

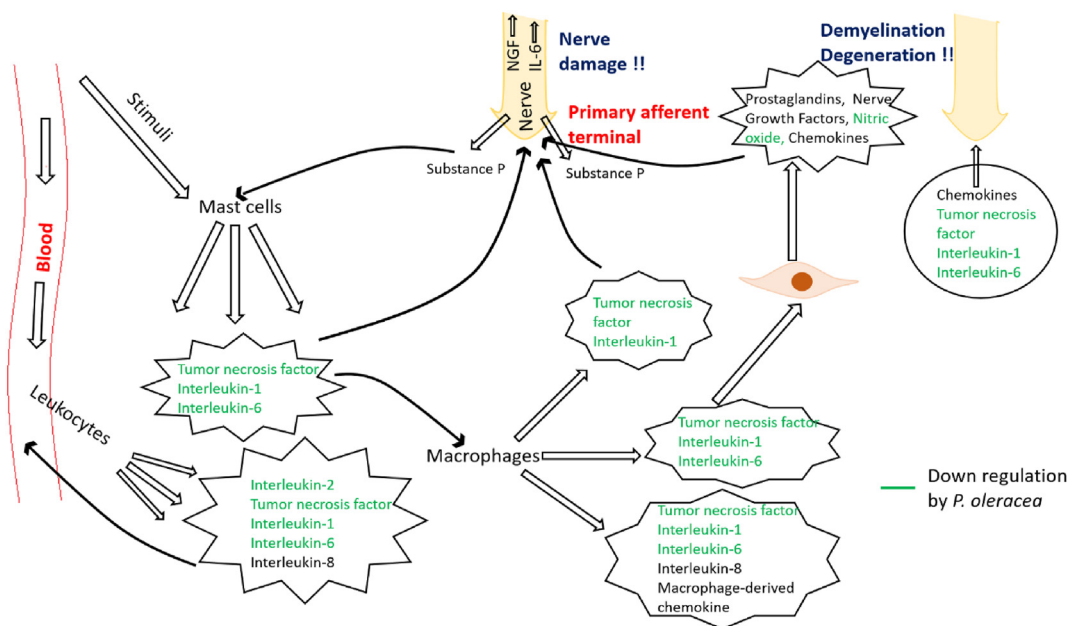


Figure 5. Regulation of inflammatory cytokines by polysaccharides present in purslane.

mediators activate nociceptor terminals of the nerve cells to release neurotransmitters such as Substance P (SP) leading to neurogenic inflammations such as demyelination and degeneration. Polysaccharides from *P. oleracea* down regulate the inflammatory cytokines (TNF, IL-1 and IL-6) and NO. Furthermore, it upregulates production of anti-inflammatory cytokines (Figure 5). Polysaccharides complexes isolated from aerial parts of purslane shown to be stimulate CD4<sup>+</sup>/CD25<sup>+</sup> and CD8<sup>+</sup>/CD25<sup>+</sup> (human T-cells), CD14<sup>+</sup> and CD64<sup>+</sup> cells (activated phagocytes) and also enhanced IL-6 production from human white blood cells and Peyer's patch cells [215]. Few other studies have also shown immunomodulatory activities of purslane using various models and cell lines [216, 217]. The immunomodulatory activities of various bioactive components of purslane suggest its high value for the discovery of novel drugs that are immunomodulatory and anti-inflammatory.

### 6.6. Antiviral potential

Only a few studies have reported the antiviral potential of purslane. Water extract of purslane showed antiviral activity against influenza A virus (IAV) infection [218]. Dong et al. [219] showed that pectic polysaccharide isolated from purslane showed activities against herpes simplex virus type 2 (HSV-2).

### 6.7. Anti-obesity and antidiabetic potential

Li et al. [220] confirmed the anti-obesity potential of purslane by checking its anti-adipogenic activity in 3T3-L1 cells. Sicari et al. [114] also observed antioxidant and hypoglycaemic potential of purslane. Its anti-diabetic potential is evaluated by several researchers independently [25, 221, 222, 223]. Polysaccharides from purslane were found to induce the secretion of insulin in insulin-secreting β-cell line cells (INS-1 cells) suggesting its important potential roles in diabetic patients [222]. Similar results were obtained by Park and Han [224]. It has been found that purslane significantly improved liver injury of liver in streptozotocin-induced diabetic mice [224, 225]. Park et al. [226] have shown the molecular mechanisms that govern HM-chromanone induced antidiabetic potential of purslane. Their study further found that HM-chromanone promotes glucose uptake and glycogen biosynthesis through the activation of PI3K/AKT, CaMKKβ-AMPK and GSK3 α/β pathways respectively. Figure 6 represents HM-chromanone mediated antidiabetic properties of purslane. Shift from glucose tolerance state to impaired glucose tolerance leads to diabetes. Closure of ATP-sensitive K<sup>+</sup> channels and activation of Na<sup>+</sup> and Ca<sup>2+</sup> channels increase Ca<sup>2+</sup> influx into the cell thus secretion of insulin also increases leading to reduced blood glucose levels. Polysaccharides from purslane enhance ATP

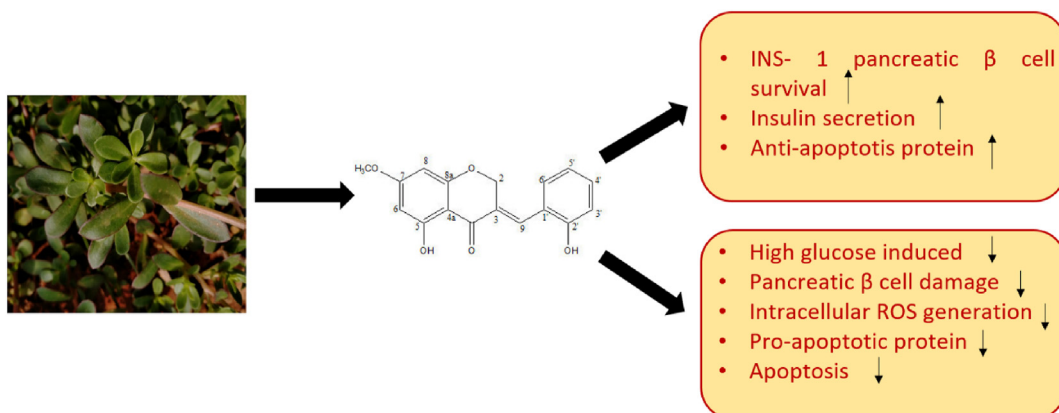
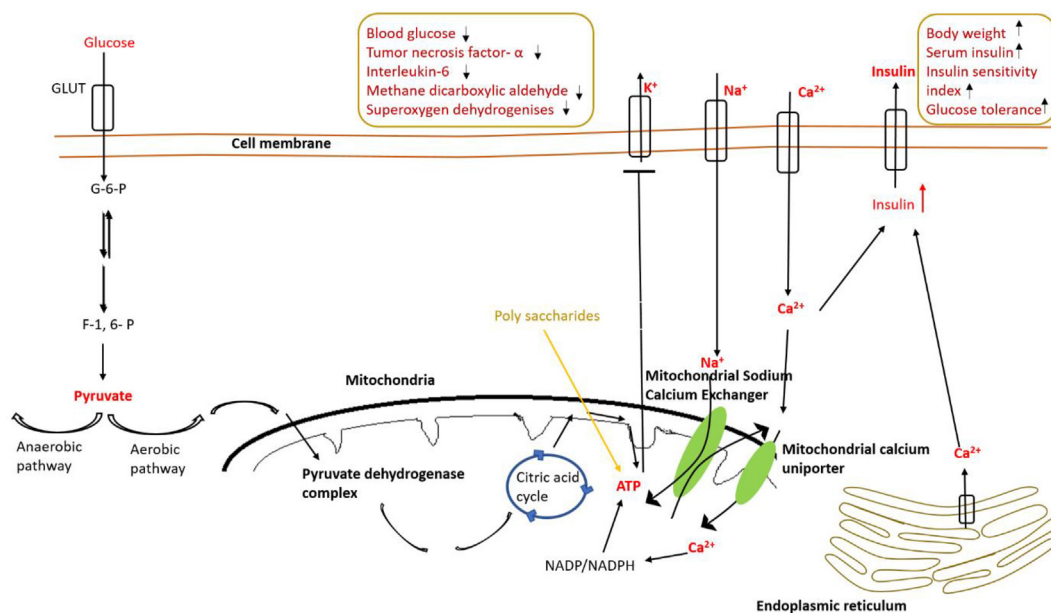


Figure 6. HM-chromanone mediated antidiabetic activities of purslane.



**Figure 7.** Regulation of insulin secretion from INS-1 pancreatic  $\beta$  cells and antidiabetic activities of purslane polysaccharides.

production which improves depolarized cell membrane potential via closure of  $K^+$  channels. Subsequent increase in  $Ca^{2+}$  entry improves insulin secretion. Polysaccharides from purslane also result in body weight, serum insulin, insulin sensitivity index and glucose tolerance and decrease the risk of diabetes by decreasing the level of TNF- $\alpha$  (Tumor necrosis factor- $\alpha$ ), Interleukin-6 (IL-6), Methane dicarboxylic aldehyde (MDA) and Superoxygen dehydrogenases (SOD). The detailed mechanism of action is represented in Figure 7.

### 6.8. Neuroprotective potential

Neuroprotective effect of seed and aqueous extract of purslane in rats and mice was observed by several researchers [100, 227, 228]. Betacyanins from purslane were found to be effective against the D-galactose induced neurotoxicity in mice [29]. Truong et al. [180] have found that purslane extract acts as a neuroprotectant against Parkinson's disease because of the presence of levodopa and dopamine. Polysaccharides extracted from Purslane played protective roles against lead induced memory impairment in rats [229]. Several alkaloids such as oleracea [48] and oleraisoindole [119] showed anticholinesterase activity. The hydroalcoholic extract of purslane showed potential of sleep improvements and may be an important plant for the insomnia patients in future [230]. Catecholic isoquinolines have been known to show  $\beta$  2-Adrenergic receptor agonist activity [125].

### 6.9. Gastro and hepatoprotective potential

Farkhondeh and Samarghandian [231] have reviewed gastro-protective and hepatoprotective effects of purslane [231]. Detailed review of hepatoprotective role is given by Farkhondeh et al. [232]. Anusha et al. [53] found that aqueous extract of purslane in combination with lycopene showed hepatoprotective results against carbon tetrachloride induced hepatotoxicity in rats. The seeds of purslane are very effective against nonalcoholic fatty liver disease which is the most common form of chronic liver disease [233, 234]. The gastro and hepatoprotective properties of purslane also suggest its use in the treatment of lung and liver related diseases.

### 6.10. Antiasthmatic potential

Purslane is known to possess bronchodilatory and anti-asthmatic effects [179, 235]. Iyekowa et al. [236] found improvement of bronchial

asthma in histamine dihydrochloride induced asthmatic guinea pigs. The phytochemical analysis of the extract administered showed the occurrence of tannins, steroids, flavonoids, saponins, and alkaloids suggesting their antiasthmatic potential.

### 6.11. Wound healing potential

Topical application of crude extract of aerial parts of the purslane in excised wounds of house mouse (JVI-1) showed healing activity suggesting its role in healing [237].

### 6.12. Other pharmacological properties

Purslane also possesses other pharmacological properties such as effectiveness against abnormal uterine bleeding [238, 239]. It has also shown pancreatic protective roles [240]. Polysaccharides from purslane show anti fatigue results [241]. Ethanolic extract of purslane showed anti-nociceptive activity in rats [207, 242]. It is well known for anti-septic, antispasmodic, diuretic, vermifuge, antiscorbutic, analgesic, anti-inflammatory activities and, anti-ascorbic, antipyretic, and antitussive effects [109, 181, 243, 244].

## 7. Conclusions and future directions

Purslane is a very important nutritional vegetable with huge nutritional and pharmacological potential. Due to the presence of very important traits it possesses, it is considered as an important crop for the future. Although purslane is a wonder crop, it remains one of the underutilized crops across the world, but there is evidence for its usage in traditional foods and ethnomedicinal systems in various countries. Being the eighth most distributed plant in the world, its consumption as an important food and medicine can improve the health of the people besides providing nutrition. The existence of an array of important bioactive compounds and nutritional components makes it a nutraceutical plant. There are global efforts to discover new water efficient crops due to the scarcity of the water globally [245]. In order to address the issue of water scarcity, the Global Framework on Water Scarcity in Agriculture of FAO has suggested saline agriculture as one of the important strategies under water scarce situations in the future [245]. Purslane is highly tolerant to salinity conditions and can be promoted as a biosaline crop for future food and nutritional security. The purslane cultivation must be

attempted using saline water. Purslane is rich in omega-3-fatty acids that can be further exploited to reduce pressure on the sea ecology due to overfishing for omega-3-resources. Additionally it is an important source of omega-3-fatty acids for vegetarians and vegans as their diets lack omega-3-fatty acids which is very crucial for the health of humans. Increasing pollution in the seas and risks posed by the seafoods on human health, purslane can act as an alternative source of omega-3 fatty acids [246]. Therefore, omega-3-fatty acid rich diets supplied by purslane can improve the health of the people [247]. In nutshell, purslane is an important future crop for achieving sustainable development goals 1, 2 and 3 on no poverty, zero hunger and good health and wellbeing of the people respectively. The pharmacological studies show multiple medicinal uses of purslane. The results also suggest that novel drugs can be obtained from purslane in future against many diseases. The phytochemical richness of purslane can therefore be exploited for prospecting future plant derived drugs.

## Declarations

### Author contribution statement

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No data was used for the research described in the article.

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The authors declare no conflict of interest.

### Additional information

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