A review on bioactive phytochemicals, ethnomedicinal and pharmacological importance of Purslane (Portulaca oleracea L.)

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Research Article

Keywords: Portulaca oleracea, traditional food crops, Purslane, omega-3-fatty acids, ethnobotanical knowledge

Posted Date: May 10th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-501982/v1

Version of Record: A version of this preprint was published at Heliyon on December 26th, 2021. See the published version at https://doi.org/10.1016/j.heliyon.2021.e08669.

Abstract

The Portulaca oleracea L. commonly known as Purslane is distributed all over the world and easily grows in diverse soil 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 very high concentration of omega-3- fatty acids especially α-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, gastroprotective, 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 emphasize its ethno medicinal importance across cultures and pharmacological potential.

1. Introduction

The *Portulaca oleracea* L. commonly known as Purslane is an important member in the family Portulacaceae Juss. (Ocampo and Columbus, 2012). 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 (Nyffeler and Eggli, 2010; Ocampo and Columbus, 2012). 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 (Masoodi et al., 2011; Chugh et al., 2019). Several studies show that Purslane is very important because of its nutritional (Petropoulos et al., 2019; Uddin et al., 2014; Mohamed and Hussein, 1994), medicinal (Okafor and Ezejindu, 2014; Miraj, 2016; Chugh et al., 2019), aesthetic value (Kichenaradjou et al., 2018), phytoremediation properties (Tiwari et al., 2008). Purslane has been used in various parts of the world as folk medicine and traditional food since ancient times (Chugh et al., 2019; Xiang et al., 2005). 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 (Younos et al., 1987; Chen et al., 2009; Zhu et al., 2010; Belcheff, 2012; Faruque et al., 2019; Nemzer et al., 2020). 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 (Mohamed and Hussein, 1994; Uddin et al., 2014; Okafor and Ezejindu, 2014; Negi, 2018). Using ethnobotanical leads, scientists have tested the efficacy of Purslane as medicinal plant using in vitro as well as in vivo studies and found impressive results (Huang and Dong, 2011; Wang and

Yang, 2010; Al-Sheddi et al., 2015; Bai et al., 2016; Yahyazadeh Mashhadi et al., 2018; Baradaran-Rahimi et al., 2019; Roozi, et al., 2019). 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 ω-3 and ω-6 fatty acids, ascorbic acid, tocopherols, glutathione and β-carotene (Simopoulos et al., 1992; Melilli et al., 2020) suggesting its nutraceutical potential. It is found that it contains nearly 300-400 mg of alpha-linolenic acid, 12.2 mg of α-tocopherol, 26.6 mg of ascorbic acid, 1.9 mg of β-carotene, and 14.8 mg of glutathione per 100 grams of fresh weight in its leaves (Simopoulos et al., 1992; Simopoulos et al., 2005). Purslane is also an important source of specialised metabolites such as alkaloids, catecholamines, phenolic acids, anthocyanins, flavonoids, lignans, terpenoids and betalains. Some of these metabolites have been proved to possess health promoting benefits on 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.

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 number of diseases such as diarrhoea and throat infections, diabetes, obesity, toothache, sthama, ulcers, snake bites, jaundice and dysentery (Younos et al., 1987; Singh et al., 2012; Joshi and Joshi, 2000; Faruque et al., 2019; Chen et al., 2009; Belcheff, 2012; Zhu et al., 2010). 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 (Osbaldeston, 2000; Iranshahy et al., 2017; Khare, 2017). It is also used in the Chinese and Persian Traditional Systems of Medicines (Iranshahy et al., 2017). 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 (Zhou et al., 2015; Iranshahy et al., 2017; Xiu et al., 2018; Kaur, 2020). Its use as traditional medicine is well documented recently by many researchers from various countries. Its use as a traditional medicine in treating diseases in different parts of the world is given in table 1.

Table 1: Ethno-medicinal uses of Purslane in treating various diseases across the globe.

Country	Ethnomedicinal use	Reference
Asia		
Afghanistan	Seeds are used against diarrhea and throat infections.	(Younos et al., 1987)
Armenia	Leaves and stem are used against liver, gastric, kidney, and bladder diseases and as a hypoglycemic agent.	(Nanagulyan et al., 2020)
Azerbaijan	Infusion of leaves is used against diabetes.	(Jafarirad and Rasoulpour, 2019)
Bangladesh	Dried seeds are used for toothache and asthma.	(Faruque et al., 2019)
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.	(Chen et al., 2009; Belcheff, 2012; Zhu et al., 2010)
India	Used as an ayurvedic medicine against diseases of lungs, liver, kidney, bladder and bowel burning sensation, coughing and neurasthenia.	(Anusha et al., 2011; Belcheff, 2012; Nadkarni, 1996; Sulthana and Rahman, 2013; Reddy et al., 2019; Prabhu et al., 2021)
Iran	Roots, leaves and seeds of Purslane are used for the treatment of diabetes mellitus.	(Ghahramani et al., 2016; Mosaddegh et al., 2012)
Jordan	Seeds are used as blood purifiers and as aphrodisiacs.	(Lev and Amar, 2002)
Myanmar	Leaves used for kidney disease treatment and as a laxative.	(DeFilipps and Krupnick, 2018)
Nepal	Leaves are used for scurvy, kidney and cardiovascular disorders. Juice is drunk for blood purification.	(Singh et al., 2012; Joshi and Joshi, 2000)
Pakistan	Aerial parts are used in the treatment of urinary and digestive problems. Seeds are demulcent, diuretic and vermifuge.	(Ullah et al., 2013; Aziz et al., 2016)
Philippines	Used for treatment of kidney infections.	(Olowa and Demayo, 2015)
Sri Lanka	Leaves are used against ulcers, wounds, burns and skin diseases.	(Belcheff, 2012)
UAE	Aerial parts are used as a medicine to reduce fever.	(El- Ghonemy, 1999; Iranshahy et al., 2017)
Vietnam	The whole plant is used as an antibacterial, anathematic and anti-inflammatory agent.	(World Health Organization, 1990)

Yemen	Leaves are used for gastric pain.	(Hussein and Dhabe, 2018)
Europe		
Albania	It is used to treat musculoskeletal disorders.	(Gonzalez- Tejero et al., 2008; Pieroni et al., 2005)
Italy	Used to treat headache, stomach, intestine and kidney pains.	(Bosi et al., 2009)
Greece	Used to cure inflammation.	(Simopoulos, 2004; Brussell, 2004)
Romania	External bath for weakness and sickness.	(Petran et al., 2020)
Spain	Consumption of aerial parts for blood pressure regulation.	(Carrio and valles, 2012)
Turkey	Leaves are used to cure diarrhoea, diabetes, headache, ulcers, urinary disorders, wounds and constipation.	(Cakilcioglu and Turkoglu, 2010; Sargin et al., 2021; Yeşil and İnal 2021)
Australia		
Australia	Aerial parts are eaten to cure scurvy, irritations, inflammations and as a diuretic and antibiotic agent.	(Belcheff, 2012)
Africa		
Algeria	It is used against dyspepsia and also as a diuretic.	(Baziz et al., 2020)
Angola	Whole plant is used for burns.	(Urso et al., 2016)
Cameroon	Shoot with leaves is used against headaches and poisoning.	(Jiofack et al., 2009)
Egypt	Used as a vegetable as well as medicinal plants and also spice.	(Sulthana and Rahman, 2013)
Kenya	Whole plant is crushed and boiled with other herbs and used against cancer.	(Kipkore et al., 2014)
Ethiopia	Cooked leaves are eaten for gastritis, peptic ulcers and constipation. Application of crushed leaves on skin is used to cure fungal infections.	(Belayneh et al., 2012)
Libya	Used against headache, migraine and as a revulsant and vermicide.	(El-Mokasabi et al., 2018)
Morocco	Cooked leaves are consumed to cure hypercholesterolemia.	(Chaachouay et al., 2019)
Nigeria	Used as a diuretic and for the treatment of burns.	(Belcheff, 2012)

South Africa	Crushed and taken orally with warm water against tuberculosis. Application of crushed leaves is used against lymphatic filariasis. *P. quadrifida* is also used against lice and sores. Other uses: infections, pain relief	(Komoreng et al., 2017; Adebayo et al., 2019; Mhlongo et al., 2019; Semenya and Maroyi, 2019)
Mauritius	Decoction of plants is used as an astringent against inflammation, worms, diuretic. Root and leaf decoction used as anthelmintics.	(Suroowan et al., 2019)
South America		
Argentina	Used as an antipyretic.	(Scarpa, 2004)
Bolivia	Raw leaves are eaten against nephrolithiasis.	(Fernandez et al., 2003)
Brazil	Used against hemorrhoids.	(Netala et al., 2014)
Ecuador	Aqueous infusion of fresh leaves used against internal inflammation, infections, gastritis and kidney diseases.	(Tene et al., 2007)
Peru	Bark, leaf and sap used against diarrhea, fever and liver problems.	(Jovel et al., 1996)
West Indies	Used for treatment of intestinal worms.	(Quinlan et al., 2002)
North America		
Republic of Trinidad and Tobago	Used against urinary problems, "cooling" and for lowering high cholesterol.	(Lans, 2006)
Jamaica	Used as “cooling” and moistening herb during fever.	(Sangeetha et al., 2020)
Cuba	used against kidney infections, inflammation and digestive disorders.	(Heredia-Díaz et al., 2018)

3. Phytochemical Richness Of Purslane

Various researchers have attempted phytochemical analysis of *P. oleracea* (Okafor and Ezejindu, 2014; Bhat and Al- Daihan, 2014; Negi, 2018). The qualitative and quantitative tools have been employed to study the phytoconstituents present in various parts of *P. oleracea* (Okafor and Ezejindu, 2014; Negi, 2018). It contains many important metabolites that provide health benefits (Okafor and Ezejindu, 2014; Chugh et al., 2019). The chemical composition of Purslane varies during its growth stages (Mohamed and Hussein, 1994). It has been revealed that Purslane contains abundant quantities of proteins, starch (Mohamed and Hussein, 1994) and essential amino acids (Zhou et al., 2015). Considerably higher levels of fat is found in leaf and stem and fiber content was found in leaves but not in stem (Ezeabara et al., 2014). Apart from being a source of primary metabolites, it contains varying quantities of specialised metabolites such as alkaloids, saponins, tannins, flavonoids, cardiac glycosides, terpenoids, phenolic

acids and organic acids (Okafor and Ezejindu, 2014; Nemzer et al., 2020). Large number of bioactive compounds are responsible for its multiple biological activities (Okafor and Ezejindu, 2014; Siriamornpun and Suttajit, 2010). Researchers have taken different parts of the Purslane for quantification of various bioactive compounds. It was 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 (Siriamornpun and Suttajit, 2010). The leaves also contain more β-carotene content than stem (Liu et al., 2000). Purslane is known for containing high amounts of omega-3-fatty acids (Omara-Alwala et al., 1991). Wild genotypes of *P. oleracea* contain nearly 188.48 ± 6.35 mg/100g of omega-3-fatty acid (Nemzer et al., 2020). Therefore Purslane is known as one of the richest sources of omega-3- fatty acids (Uddin et al., 2014). 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. granulatostellulata.* (Farag and Shakour, 2019). Farag et al. [85] reported, methoxylated flavone glycosides, O and C-flavonoids, and four cyclodopa alkaloids namely oleracein A, C, K and N from Purslane (Farag and Shakour, 2019). In addition to the identification of previously known oleraceins (oleraceins A, B, C, N, J, and U), Fernández-Poyatos et al. (2021) reported two new cyclo-dopa amides namely oleraceins X and Y from Purslane. Lei et al. (2015) isolated four new cerebrosides and five known compounds i.e. portulacerebroside A, B, C and D from *P. oleracea*. Nemzer et al. (2020) 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 (Farag et al., 2021). Some of the very important metabolites found in Purslane and their bioactivities are described below.

3.1 Alkaloids

Alkaloids are one of the most important groups of naturally occurring organic compounds with many pharmaceutical and medicinal uses (Kurek, 2019). Several alkaloids such as oleraceins, oleracins, trollisine, scopoletin (Chugh et al., 2019) and oleraisoindole (Jiang et al., 2018) have been reported in *P. oleracea*. Two new alkaloids namely (3R)-3,5-bis(3-methoxy4-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., 2014 and reported their moderate to high cytotoxic activity against different human cancer cell lines (Tian et al., 2014). Three phenolic alkaloids namely oleracein A, oleracein B and oleracein E isolated from *P. oleracea* showed antioxidant activities (Yang et al., 2009). oleracein E and oleracein L from *P. oleracea* shows hypoglycemic and antidiabetic activities (Roozi et al., 2019). Sun et al. (2017) found neuroprotective potential of oleracein E using in vitro and in vivo models. Xiu et al. (2019) isolated soyalkaloid A for the first time from *P. oleracea* and found its antioxidant activity using 1,1-diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging assay. In addition to several known compounds, Xiu et al. (2018) reported a new alkaloid named, oleraurea from *P. oleracea* and interestingly it showed anticholinesterase activity suggesting its important role in Alzheimer's disease as cholinesterase inhibitor (Xiu et al., 2018). Jin et al. (2018) 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 (Jin et al., 2018). Ten new oleraceins (H, I, K, L, N, O, P, Q, R, S) along with four indoline amide glucosides were characterized in *P. oleracea* by Jiao et al. (2015). The authors further found that oleraceins K and L showed higher antioxidant activities than vitamin C (Jiao et al., 2015). Zhao et al. (2018) 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 showed cytotoxic activity in human neuroblastoma SH-SY5Y cells (Zhao et al., 2018).

3.2 Catecholamines (CAs)

Catecholamines are a group of amines that are produced in humans as neurotransmitters (Kuklin, and Conger, 1995). However they are also synthesized in plants under stressful conditions and play diverse roles including growth and development (Kulma and Szopa, 2007). Dopamine is one of the most important catecholaminergic neurotransmitters synthesized in *P. oleracea* (Chugh et al., 2019). High concentration of noradrenaline (norepinephrine) is also found in *P. oleracea* leaves (Feng et al., 1961). Endress et al. (1984) have reported the existence of adrenaline (epinephrine), another important catecholamine from *P. grandiflora* callus. The presence of noradrenaline and dopamine in *P. oleracea* is further confirmed by several other studies (Chen et al., 2003; Weng et al., 2005; Yue et al., 2005). Hu et al. (2021) identified 22 compounds from a water extract of Purslane and nine of them were found to be catecholamine derivatives. Martins et al. (2016) found a neuroprotective effect of *P. oleracea* in wistar rats. Earlier studies have shown multiple benefits of dopamine against neurodegenerative diseases such as Parkinson's disease, Schizophrenia and Huntington's disease (Klein et al., 2019). Interestingly, dopamine and noradrenaline were detected in the *P. oleracea* extracts administered to the rats that showed neuroprotective effects (Martins et al., 2016) suggesting its role as an important neuroprotectant. Therefore, the existence of catecholamines in Purslane suggests its applications against neurodegenerative diseases.

3.3 Phenolic acids

Phenolic acids are important specialized metabolites found in plants that are derivatives of benzoic and cinnamic acids (Vincente et al., 2014; Chandrasekara, 2019). They are carboxylic acid groups possessing phenolic compounds (Kumar and Goel, 2019). 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 (Silva and Carvalho 2014; Sicari et al., 2018). The occurrence of caffeic, gallic, vanillic, ferulic and syringic acids was detected by Santiago-Saenz et al. (2018).

3.4 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 (Middleton, 1996). Flavonoids are known for various biological roles in humans because of their anti-oxidative, anti-inflammatory, antitumor, antiviral and antibacterial activities (Cushnie and Lamb, 2011). The flavonoids also play a protective role against coronary diseases and help in vascular activity (Cazarolli et al., 2008). Several flavonoids such as apigenin, kaempferol, luteolin, quercetin, isorhamnetin, kaempferol-3-O-glucoside and rutin have been isolated from Purslane (Sicari et al., 2018). Xu et al. (2006) have identified five flavonoids namely kaempferol, apigenin, myricetin, quercetin and luteolin using capillary electrophoresis with electrochemical detection. Quercetin isolated from Purslane significantly improved learning and memory in mice suggesting its neuroprotective effects (Lu et al., 2006). Santiago-Saenz et al. (2018) have quantified myricetin in puralane. Hesperidin, a flavanone glycoside was reported by Yang et al. (2007). Three flavonoids oleracone C, D and E were identified for the first time by Yang et al. (2018). Nayaka et al. (2014) have isolated apigenin, a flavonoid found its antibacterial properties against certain bacterial pathogens such as *Pseudomonas aeruginosa, Salmonella typhimurium, Proteus mirabilis, Klebsiella pneumoniae* and *Enterobacter aerogenes*.

3.5 Anthocyanins

Anthocyanins are polyphenolic compounds and are found in plants as red, purple or blue coloured pigments (Lila, 2004; Valavanidis and Vlachogianni, 2013; Khoo et al., 2017; Mukherjee, 2019). Anthocyanins are also very important for human health and have been found to play several beneficial roles against a number of diseases (Valavanidis and Vlachogianni, 2013; Mukherjee, 2019). 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 (Silva and Carvalho, 2014).

3.6 Homoisoflavonoids (HIFs)

Homoisoflavonoids are another important group of specialised plants found in plants (Castelli and Lopez, 2017). They are different from flavonoids as they possess one extra carbon which is absent in flavonoids (Kumar and Nayak, 2020) and more than 300 HIFs have been identified in plants (Lin et al., 2014). They are known for antimicrobial, antimutagenic, anti-inflammatory, antidiabetic and antioxidant activities (Abegaz et al., 2007; Siddaiah et al., 2006; Melilli et al., 2019). 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*. (2020). Nemzer et al. (2020) identified four HIFs viz. portulacanones A–D from aerial parts of Purslane. Yang et al. (2018) 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 β cells of pancreas

induced by glucose suggesting its antidiabetic properties (Park et al., 2019). 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 (Siddaiah et al., 2006). These studies suggest that *P. oleracea* is rich in HIFs and can play important roles against multiple diseases.

3.7 Lignans

Lignans are polyphenols formed by the dimerization of monolignols and play defensive roles in plants against microorganisms (Heldt and Piechulla, 2011). Ma et al. (2020) identified four lignans namely oleralignan, (+)-syringaresinol, (+)-lirioresinol A and monomethyl 3,3',4,4'-tetrahydroxy-δ-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 (Ma et al., 2020).

3.8 Terpenoids

Terpenoids also known as isoprenoids are isoprene derived organic compounds synthesised in many organisms including plants (Tholl, 2015). Elkhayat et al. (2008) 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 (Mir and Ali, 2016; Chugh et al., 2019).

3.9 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 (Simopoulos et al., 1986). Purslane is a nutritious vegetable crop rich in the polyunsaturated fatty acids (PUFA) and it is especially known for omega-3 (α-linolenic acid) and omega-6 (linoleic acid) fatty acids which are essential for human health (Palaniswamy et al., 2001; Chugh et al., 2019). It has been found that Purslane contains higher levels of α- linolenic acid than spinach (Uddin et al., 2014). 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 (Palaniswamy et al., 2001; Oliveira et al., 2009). Simopoulos and Salem (1986) have further reported the presence of eicosapentaenoic acid (EPA), another important omega-3 FA in *P. oleracea*. Omara-Alwala et al. (1991) reported that Purslane also contains docosahexaenoic acid (DHA) and docosapentaenoic acid (DPA) which are also omega 3 fatty acids.

3.10 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 (Azeredo, 2009; Villaño et al., 2016; Rodriguez-Amaya, 2019). Trezzini and Zrÿd (1991) 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 (Trezzini and Zrÿd, 1991; Gandía-Herrero et al., 2005).

3.11 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 (Oliveira et al., 2009; Zhou et al., 2014; Wang et al., 2017; Chugh et al., 2019). Oxalic acid and citric acid are the most abundant organic acids in Purslane (Oliveira et al., 2009; Petropoulos et al., 2015). Allantoin, an end product of purine catabolism is reported from Purslane (Selamoglu, 2018). Rasheed et al. (2004) reported N,N'-dicyclohexylurea, β-sitosterol and β-sitosteryl glucoside from Purslane (Rasheed et al., 2004).

4. 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 (Petropoulos et al., 2016). It has been used by people across the globe as a traditional food plant (Welcome and Van Wyk, 2019; Manzanero-Medina et al., 2020). The Purslane leaves contain 23-24 % of proteins (Aberoumand, 2009; Almasoud and Salem, 2014). It is observed that protein, ash and fiber content in Purslane is higher than that of wheat flour (Almasoud and Salem, 2014). Presence of considerable amounts of essential dietary minerals such as copper, iron, manganese, magnesium, potassium, calcium, magnesium and phosphorus is reported in Purslane (Aberoumand, 2009; Chugh et al., 2019). It is a rich source of potassium (494 mg/100 g), magnesium (68 mg/100 g) and calcium (65 mg/100 g) (Uddin et al., 2014). Results obtained by Santiago-Saenz et al. (2018) 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 (Santiago-Saenz et al., 2018). According to Mohamed and Hussein (1994) 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. Due to the presence of iron and copper in higher levels, Purslane has the potential to stimulate the production of red blood cells in humans (Kumar et al., 2018). Purslane is also a rich source of vitamins such as vitamin A, riboflavin, niacin, pyridoxine, vitamin C, thiamin, α-tocopherol and pantothenic acid (Guil-Guerrero and Rodríguez-García, 1999; Chugh

et al., 2019). It has been found that Purslane contains higher amounts of β-carotene, vitamin C and α-tocopherol than spinach (Simpoulous et al., 1992; Uddin et al., 2014; Santiago-Saenz et al., 2018). Occurence of antioxidant molecules suggests that intake of Purslane can help overcome oxidative stress (Arruda et al., 2004). Because of the presence of a number of important nutritional components, common Purslane is an important herb and possesses high nutritional potential (Simopoulos et al., 1995). Presence of omega-3 fatty acids in Purslane makes it one of the few terrestrial sources of omega-3-fatty acids (Simopoulos and Saleem, 1986; Alam et al., 2014). 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 (Simopoulos, 2004). Another species *P. quadrifida* is also used as a nutritious vegetable in some parts of the world (Korade and Deokule, 2015). The presence of vitamin A in Purslane makes it a good candidate for people with vision impairments and vitamin A deficiency (Nemzer et al., 2020). Islanders on Atolls in the South Pacific consume Purslane because of the presence of macro and micronutrients (Lyons et al., 2020).

Table 2. Main nutraceutical constituents and their concentration found in Purslane.

Nutritional constituent	Concentration	Reference(s)
Crude protein (% DW)	23. 47	(Aberoumand, 2009)
Carbohydrate (% DW)	40. 67	(Aberoumand, 2009)
Crude lipid (% DW)	5. 26	(Aberoumand, 2009)
Crude fibre (% DW)	8. 00	(Aberoumand, 2009)
Ash (% DW)	22. 66	(Aberoumand, 2009)
Zinc (mg/100g)	5.83±0.08	(Almasoud and Salem, 2014)
Calcium (mg/100g)	131.44±3.21	(Almasoud and Salem, 2014)
Iron (mg/100g)	72.14±505	(Almasoud and Salem, 2014)
Magnesium (mg/100g)	66.47±1.43	(Almasoud and Salem, 2014)
Sodium (mg/100 g)	571.41±16.63	(Almasoud and Salem, 2014)
Potassium (mg/100g)	2842.38±91.68	(Almasoud and Salem, 2014)
Manganese (mg/100g)	9.75±1.02	(Almasoud and Salem, 2014)
Phosphorus (mg/100g)	79.7	(Alam et al., 2021)
Carotenes (mg/100g)	89.2	(Guil-Guerrero et al., 1999)
Lipids (mg/100g)	3.81	(Guil-Guerrero et al., 1999)
B1 – thiamine (mg/100g)	0.047	(Uddin et al., 2014; Petropoulos et al., 2016)
B2 – riboflavin (mg/100g)	0.112	(Uddin et al., 2014; Petropoulos et al., 2016)
B3 – niacin (mg/100g)	0.480	(Uddin et al., 2014; Petropoulos et al., 2016)
B5 - pantothenic acid (mg/100 g)	0.036	(Uddin et al., 2014; Petropoulos et al., 2016)
B6 – pyridoxine (mg/100g)	0.073	(Uddin et al., 2014; Petropoulos et al., 2016)
B9 – folates (mg/100g)	.012	(Uddin et al., 2014; Petropoulos et al., 2016)
Ascorbic acid (mg/g)	2.27 (stem) to 3.99 (leaves)	(Uddin et al., 2014)
α-tocopherol (mg/100 g)	26.6 mg	(Uddin et al., 2014)
Omega-3-fatty acid (mg/100g)	188.48 ± 6.35	(Nemze r et al., 2020)
Linoleic acid (LA, mg/100g)	34.0±5.2	(Palaniswamy et al., 2001)

α-linolenic acid (LNA, mg/100g)	132.8±22.0	(Palaniswamy et al., 2001)
LNA/LA ratio	5.2±0.03	(Palaniswamy et al., 2001)
α-carotene (mg/100g)	0.009	(Petropoulos et al., 2016)
β-carotene (mg/g)	0.29 (stem) to 0.58 (leaves)	(Uddin et al., 2014)
Lutein (mg/100g)	5.4	(Petropoulos et al., 2016)
Zeaxanthin (mg/100g)	0.19	(Petropoulos et al., 2016)

5. Pharmacological Potential Of Purslane

Purslane is a medicinally important herb (Gills, 1992) as it possesses an array of medicinally important phytochemicals (Uddin et al., 2014; Sicari et al., 2018; Negi, 2018; Ojah et al., 2021). Ethnobotanical studies suggests that it has been an important part of traditional medicine among various cultures in different parts of this world (Sulthana and Rahman, 2013; Belcheff, 2012; Bosi et al., 2009; Sangeetha et al., 2020; Tene et al., 2007). The qualitative and quantitative analysis of phytochemical composition also supports its pharmacological value (Okafor and Ezejindu, 2014; Negi, 2018). Various metabolic studies have deciphered its phytochemical composition. 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. Following subheadings provide details about pharmacological roles and properties of Purslane.

5.1 Antioxidant potential

The phytochemical composition of Purslane points towards its antioxidant potential and various studies have proved this using various assays (Alam et al., 2021). Several parts of Purslane including its leaves, stem and flowers have been used to test its antioxidant potential. Lim and Quah (2007) 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, β-carotene and omega- 3 fatty acids (Siriamornpun and Suttajit, 2010). Antioxidants are very important for human health as they reduce risk of cell damage by free radicals (Korade and Deokule, 2015). Several studies have investigated and proved ant-oxidant potential of Purslane (Alam et al., 2014; Yang et al., 2018; Baradaran-Rahimi et al., 2019; Yahyazadeh Mashhadi et al., 2018). 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 (Yang et al., 2009). Comparative analysis of raw and steamed Purslane extracts showed reduction in the antioxidant activities following its steaming (Fernández-Poyatos et al., 2021). The extracts of the aerial parts of the *P. quadrifida* also showed DPPH radical scavenging activity (Desta and Cherie, 2018).

5.2 Muscle relaxant potential

Muscle relaxant properties of Purslane have been investigated by a number of researchers and found promising results (Okwuasaba et al., 1987a,b; Parry et al., 1987a,b; Habtemariam et al., 1993; Parry et al., 1993). The muscle relaxant properties and neuromuscular activities of Purslane extract may be due to the higher concentration of K^+ ions (Habtemariama, 1993).

5.3 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 (Greenwell and Rahman, 2015; Habtemariam and Lentini, 2018). 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 (Jin et al., 2017). It was also effective against ulcerative colitis in rats and mice (Huang and Dong, 2011; Kong et al., 2018). Use of a unique polysaccharide component (POP) from Purslane showed antitumor effects in *in vivo* models (Shen et al., 2012). Water soluble Purslane extract showed inhibitory role against cervical cancer cell growth in *vitro* and *in vivo* models (Zhao et al., 2013). It has also been proved effective against gastric cancer (Li et al., 2014). Seed oil of Purslane showed significant cytotoxicity against human liver cancer (HepG2) and human lung cancer (A-549) cell lines and inhibited cell growth (Al-Sheddi et al., 2015). Portulacerebroside A (PCA) isolated from Purslane showed effectiveness against acute myeloid leukemia (Ye et al., 2015).

5.4 Antimicrobial potential

Purslane is also known to possess antibacterial and antifungal properties (Elkhayat et al., 2008). 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* (da Silva et al., 2019). Cerebrosides such as portulacerebroside (A-D) showed significant antibacterial effects against the enteropathogenic bacteria suggesting its role against bacillary dysentery (Lei et al., 2015). Soliman et al. (2017) 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. (2021) found antifungal activities against three species of Aspergillus namely *A. flavus, A. ochraceus* and *A. parasiticus.* Recently Tleubayeva et al. (2021) showed that carbon dioxide extract of Purslane possess antibacterial activities against *E. coli*, *S. aureus*, *B. subtilis*, and antifungal activity against *C. albicans*.

5.5 Anti-inflammatory and immunomodulatory potential

Several studies have confirmed the anti-inflammatory activity of Purslane (Li et al., 2016; Meng et al., 2016; Allahmoradi et al., 2019; Miao et al., 2019; Gu et al., 2020; Hu et al., 2021). It is reported that Purslane also suppresses lung inflammation (Baradaran-Rahimi et al., 2019). Di Cagno et al. (2019) found effectiveness of fermented Purslane juice against intestinal inflammation and epithelial injury in caco-2 cell lines. Samarghandian et al. (2017) 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 (Kaveh et al., 2017). The Purslane showed promising results against oral lichen planus (OLP), a chronic inflammatory and immune-mediated disease (Agha-Hosseini et al., 2010).

5.6 Antiviral potential

Only a few studies have studied the antiviral potential of Purslane. Water extract of Purslane showed antiviral activity against influenza A virus (IAV) infection (Li et al., 2019). Dong et al. (2010) showed that pectic polysaccharide isolated from Purslane showed activities against herpes simplex virus type 2 (HSV-2).

5.7 Anti-obesity and antidiabetic potential

Li et al., (2019) confirmed the anti-obesity potential of Purslane by checking its anti-adipogenic activity in 3T3-L1 cells. Sicari et al. (2018) also observed antioxidant and hypoglycaemic potential or Purslane. Its anti-diabetic potential is evaluated by several researchers independently (Gong et al., 2009; Bai et al., 2016; Hu et al., 2019; Lee et al., 2020). 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 (Hu et al., 2019). Similar results were obtained by Park and Han (2018). It has been found that Purslane significantly improved injury of liver in streptozotocin-induced diabetic mice (Zheng et al., 2017; Park and Han, 2018). Park et al. (2021) 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.

5.8 Neuroprotective potential

Neuroprotective effect of seed and aqueous extract of Purslane in rats and mice was observed by several researchers (Hongxing et al., 2007; Abdel Moneim, 2013; Farag et al., 2021). Betacyanins from Purslane were found to be effective against the D-galactose induced neurotoxicity in mice (Wang et al., 2010). Truong et al., (2019) 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 (Tao et al., 2018). Several alkaloids such as oleracea (Xiu et al., 2019) and oleraisoindole (Ma et al., 2021) 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 (Hamedi et al., 2019). Catecholic isoquinolines have been known to show β 2-Adrenergic receptor agonist activity (Jin et al., 2018).

5.9 Gastro and hepatoprotective potential

Farkhondeh and Samarghandian (2019) have reviewed gastroprotective and hepatoprotective effects of Purslane. Detailed review of hepatoprotective role is given by Farkhondeh et al. (2019). Anusha et al., (2011) 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 (Mohamed et al., 2018; Gheflati et al., 2019).

5.10 Antiasthmatic potential

Purslane is known to possess bronchodilatory and anti-asthmatic effects (Malek et al., 2004; Khazdair et al., 2019). Iyekowa et al. (2012) 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.

5.11 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 (Rashed et al., 2003).

5.12 Other pharmacological properties

Purslane also possesses other pharmacological properties. Shobeiri et al. (2009) and Khanam et al. (2020) showed the effectiveness of Purslane seeds against abnormal uterine bleeding. It has also shown pancreatic protective roles (Ahangarpour et al., 2018). Polysaccharides from Purslane show anti fatigue results (Xu and Shan, 2014). Ethanolic extract of Purslane showed anti-nociceptive activity in rats (Radhakrishnan et al., 2001; He et al., 2021). It is well known for antiseptic, antispasmodic, diuretic, vermifuge, anti-scorbutic, analgesic, anti-inflammatory activities and, anti-ascorbic, antipyretic, and

antitussive effects (Islam, 1998; Chan et al., 2000; Xiang et al., 2005; Lim and Quah, 2007; Ojah et al., 2021).

6. Conclusions And Future Directions

Purslane is a very important nutritional vegetable with huge nutraceutical and pharmacological potential. Although Purslane is a wonder crop, it is highly utilized 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. Additionally, there is a scarcity of the water globally (FAO, 2018). Efforts are on across the globe to identify crops that can grow in water deficient conditions. In order to address the issue of water scarcity, Global Framework on Water Scarcity in Agriculture of FAO suggested sustainable and saline agriculture (FAO, 2018). Purslane is an important crop tolerant to salinity conditions and can be promoted as a biosaline crop for future food and nutritional security. Purslane being rich in omega -3-fatty acids 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 the vegetarians. 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 (Domingo, 2007). Therefore, omega-3-fatty acid rich diets supplied by Purslane can improve the health of the people (Muthoni and Nyamongo, 2010). 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.

Declarations

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

AK and NR: Conceptualisation; AK, AKK, SR, PS and NR: Original draft preparation; AK, SR, AKK, NR: visualisation. All authors read the original manuscript and improved before publication.

Funding

This study has not received any specific funding from any institution/funding agency.

Acknowledgements

The authors acknowledge Central University of Kerala for their support during this study.

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Figures

Figure 1

Purslane plant in its natural habitat.

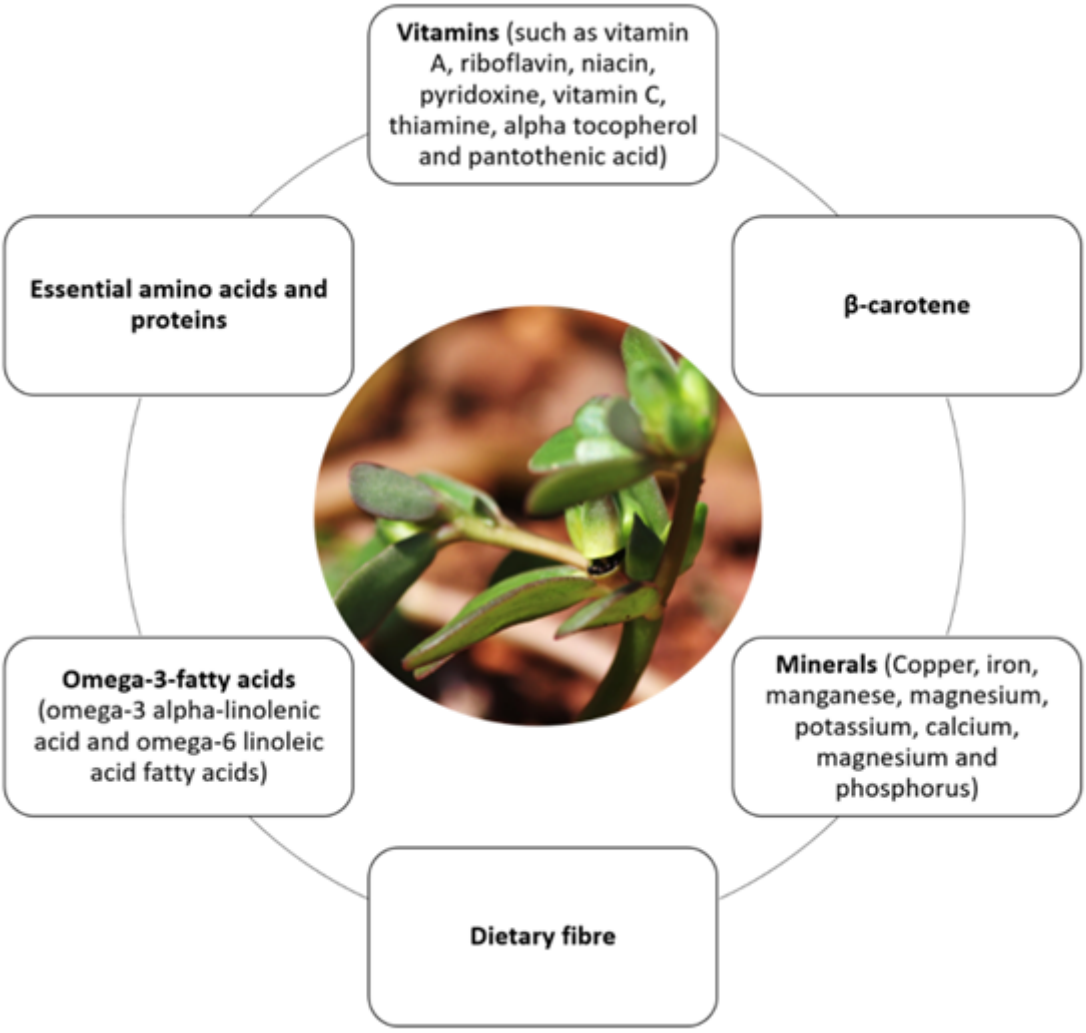

Figure 2

Main nutraceutical constituents found in Purslane.

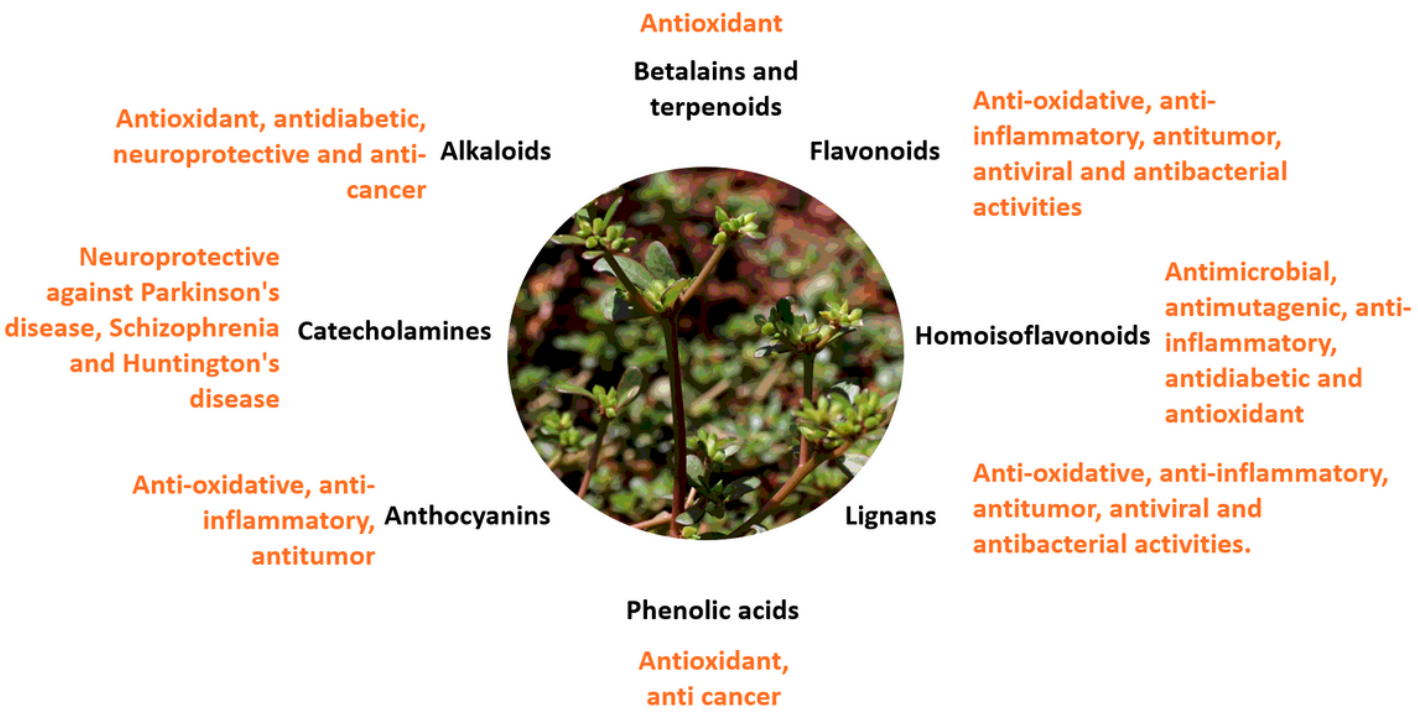

Figure 3

Pharmacological properties of the main phytochemicals found in Purslane.

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