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Food and nutraceuticals value of purslane *(Portulaca oleracea* L.): An overview

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Abstract
Purslane is believed to be the earliest vegetable consumed by human and known for its delicacy and medicinal benefits since long back. It is a rich source of nutrients, omega-3 fatty acids (especially alpha-linolenic and gamma-linolenic acids), terpenoids and sterols and has also been reported as the super food for the future. It contains large amounts of mucilage which is the most important active ingredient, giving it emollient, anti-inflammatory and laxative properties. The typical tangy flavor and gum producing ability of purslane could make it an important ingredient for food industry. However, presence of high oxalate content in purslane poses certain health risks and needs to be addressed by the research community through suitable approaches. Although much of the emphasis has been put on the phytochemistry and pharmacology of the purslane till date but studies on culinary aspects of purslane are still lacking. Utilization of purslane as functional food ingredients might help us to conserve this potential plant as well as encourage sustainable agriculture. Hence the present review provides the insights about the various aspects of purslane as a food and an ingredient of food industry for its full exploration by the research community.

Keywords: Purslane, *Portulaca oleracea*, nutraceuticals, omega-3-fatty acids, functional food

1. Introduction
In recent decades, wild horticultural crops have become an important source of income for local people, due to their high nutritional value (Pal *et al*., 2013) [29]. Purslane *(Portulaca oleracea L.)* is a widespread wild herbaceous plant that is used not only as an edible plant, but also as a traditional medicine for alleviating a wide spectrum of diseases. It is distributed widely in the tropical and subtropical areas of the world including many parts of the United States. It is eaten extensively as a potherb and is added to soups and salads around the Mediterranean and tropical Asian countries. Its soft stem and leaves are used raw, alone or with other greens (Palaniswamy *et al*., 2002) [30]. Purslane is also used for cooking or used as a pickle.

Purslane also provides a source of nutritional benefits owing to its rich ω-3 fatty acids and antioxidant properties (Palaniswamy *et al*., 2001) [32]. It has been used as a folk medicine in many countries as a febrifuge, antiseptic, vermifuge and in the treatment of burns, headache, and diseases related to the intestine, liver, stomach, cough, shortness of breath, arthritis so forth (Lee *et al*., 2012) [18]. The nutritional quality of Purslane has also been reported to be better than the major cultivated vegetables as it possesses comparatively higher β-carotene, ascorbic acid, alpha-linolenic acid (ALA) and antioxidant properties (Liu *et al*., 2000; Simopoulos *et al*., 1995) [21, 41]. It has been reported to contain 5 times higher ω-3 fatty acids than spinach. Omega-3 fatty acids belong to a group of polyunsaturated fatty acids essential for human growth, development, prevention of numerous cardiovascular diseases and maintenance of a healthy immune system (Gill and Valivety, 1997) [10]. Generally, fish is the considered as the richest source of ω-3 fatty acids and is recommended to be consumed on regular basis to meet the ω-3 fatty acid requirement of the body while others sources have been reported to be limiting in ω-3 fatty acids (Nestel, 1987) [25]. Purslane has recently been identified as the richest vegetable source of alpha-linolenic acid, an essential omega-3 fatty acid (Simopoulos and Salem, 1986) [39] and hence can be considered as an important substitute of fish for vegetarian and vegan people. Besides its nutritional importance, its widespread distribution in different biogeographical locations and highly adaptable nature against many adverse conditions *i.e.* drought, salinity etc. substantiate its importance to be introduced as new cultivated vegetable (Uddin *et al*., 2012; Yazici *et al*., 2007; Jin *et al*., 2016) [43, 50, 16]. It is listed by the World Health Organization as one of the most used medicinal plants and has been given the term "Global Panacea" which makes purslane a highly potential pharmacological agent to be used as human and animal food and in medicine (Xu *et al*., 2006) [49].

Much of the efforts have been put for the exploitation of pharmacological properties of the purslane owing to its rich phyto-constituents however very less attention has been given to its food related aspects. The medicinal value of the plants lies in some chemical substances that produce a definite physiological action on the human body (Sumitra *et al*., 2013), the aim of the present review is to provide insights about food related prospects of Purslane and translational research using purslane extracts. The article also address the safety concerns associated with the extensive use of purslane in food and the future thrusts related to the improvement and popularization of purslane as a food.

1.1. Botanical Classification and description

Purslane (*Portulaca oleracea L*.) is an ancient, cosmopolitan species which belongs to genus *Portulaca* and family Portulacaceae with 21 genera and 580 species (Table 1). It is mostly an annual, but may be perennial in the tropics. It has smooth, reddish and mostly prostrate stem, up to 30 cm long and 2-3 mm in diameter. Leaves are flat, fleshy, having variable shapes, obovate, 1–5 cm long, green or green with red margin, may be alternate or opposite and are clustered at stem joints and ends. Depending upon rainfall, the flowers appear at any time during the year. Flowers originate as single or cluster of two to five at the tips of stems. The flowers are minute or small having orange yellow, purple, or white pink color. Fruit consists of almost round to egg-shaped capsules, usually about 4–8mm long that open around the middle to release the seeds. Seeds are formed in a tiny pod, which opens when the seeds are mature. Purslane has a taproot with fibrous secondary roots and is able to tolerate poor compacted soils and drought.

Table 1: Classification of P. oleracea (USDA, 2012).

Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Caryophyllidae
Order	Caryophyllales
Family	Portulacaceae
Genus	Portulaca L.
Species	Portulaca oleracea L.

1.3. Habitat

P. oleracea is common in fields, gardens, vineyards, lawns, driveways, dunes, beaches, salt marshes, waste areas, eroded slopes, bluffs and riverbanks.

1.4. Distribution

Purslane grows from sea level to 2600m and is the most common plant in the temperate and subtropical regions, although it extends into the tropics and higher latitudes too (Vengris *et al*., 1972) [45]. It is reported that purslane was a common vegetable of the Roman Empire. The center of origin is uncertain, and is often considered as arid regions like North Africa (Chapman *et al*., 1974) [5]. Although spread to the New World was thought to have been due to post-Columbian humans (Matthews *et al*., 1993) [23], archaeological evidence (pollen analysis) suggests that Purslane arrived in the New World in pre-Columbian times. The succulent stems and fleshy leaves of purslane reflect that it may have originated and adapted to desert climates of the Middle East and India. It can be found in Europe, Africa, North America, Australia, and Asia (Rashed *et al*., 2003) [35].

Uses of purslane in traditional culinary system

With global consumer demand shifting towards the consumption of healthier foods, it is crucial to discover new sources of foods with high nutritional value and low cost. Unique edible plants such as purslane have the potential to be used as an untapped source of unconventional food with diverse nutrients and beneficial bioactive properties. Purslane has been included in the list of "World Economic Plants" and is believed to be the earliest vegetable ever consumed by the human being (Wiersema and Leon, 1999) [47]. It is used as a food in many ways all over the world. It can be eaten raw as salad or can be cooked as a curry. In some parts of Northern India, purslane leaves are cooked in curries or stirred and fried with garlic, green chilies, mustard oil and salt. Purslane has been reported as a good source of nutraceutical compounds with a positive impact on human health and nutrition, for example ω-3 fatty acids, vitamin A and E, essential amino acids as well as polyphenols. Therefore, it could be used as an alternative source of some nutrients (especially ω-3 fatty acid) for human consumption. In a few studies it was found that the addition of purslane increased the nutritional quality of extruded snacks and crackers (Hussein and Salem, 2016) [15]. The flour of purslane seeds is an important ingredient for mush bread (Mohammed and Hossein, 1994) [24]. Uses of purslane as a food in different countries have been presented in table 2.

Table 2: Use of Purslane in Global Food System.

Country	Uses of purslane as a food	Reference
Spain	A soup called *sop salem korkat* is made from purslane by boiling it with local celery, leek, citrus and sweet soy sauce.	(Tarkergari *et al*., 2013) [42]
Java	Leaves are cooked with tamarind. *Oseng-oseng:* A typical dish prepared by stirring and frying young leaves and stems of purslane with sliced shallot, garlic, red chilies, palm sugar, salt, salem leaves and galangal. *Pecel:* Steamed leaves are served with other vegetables and sprouts and poured with peanut sauce	(Heyne, 1950) [14]
China	Leaves are stirred and fried with garlic, sesame oil and light soy sauce	Solomon, 1998 [40]
Srilanka	Leaves are stir fried with Maldive fish, garlic, leek, chilli powder and lemon juice.	Solomon, 1998 [40]
France	Leaves are mixed with sorrel to make a fresh soup called *Bonne femme.*	Hernando-Bernejo and Leon, 1994 [13]
Italy	Eaten I nsalads, soups, cooked (like spinach), but believed best eaten with oil and vinegar.	(Bosi, Guarrera *et al*., 2009) [3]

Nowadays consumers have increased desire for nutritional and healthy foods with high sensory attributes. Purslane has also been tried by a few researchers for the development of healthy nutritional snacks/ foods rich in omega-3-fatty acids. Dawkins and Ward (2010) [7] incorporated 5% and 10% freeze dried purslane into high protein vegetable patties and reported that product had a good mineral content with low sodium profile. In a similar study, 10 most commonly consumed foods of south India were enriched with purslane in order to explore the possibility of utilizing fresh and dehydrated leaves of purslane in common dishes to enhance nutritional value of foods (Tarkergari *et al*., 2013) [42]. The fortification with 2% purslane showed to be the most preferable fortified extrudes sample. Therefore, purslane could successfully be used to enrich snacks, giving an alternative utilization and healthy choice (Hussein and Salem, 2016) [15]. A number of novel value added products using Purslane has been developed and patented such as beverage of *Portulaca oleracea* containing antitumor and antimicrobial (Bae and Bae, 2004) [2], edible oil of *Portulaca oleracea* (Li, 2007) [19], purslane teabags (Yougen, 2016), purslane vinegar (Wang, 2015) [46], chewable tablets (Xiaofeng, 2013) [48] etc.

Potential in food industry

Not merely as food, *P. Oleracea* is also a potent source of food additive. *P. oleracea* leaves and stems have arabinoglycan gum that functions as good emulsifier. The physico-chemical properties of *Portulaca oleracea* gum has been reported to similar to gum arabic (Garti, 1999) [9]. Besides, a typical sour flavor of purslane leaves makes it suitable for use as a souring agent in the food industry. Despite of high nutraceutical and functional properties as well as usage of purslane as a food from ancient times, systematic studies on utilization of purslane in food system are limited and therefore, need to be researched.

Uses as animal feed

Due to high protein content purslane has a wide scope in the food industry too. Ezekwe *et al*., (1999) [8] reported a high level of protein (up to 22-25%) which is comparable to other forage or vegetable food crops traditionally used as protein sources, suggests purslane as substitute for both animal and human consumption. Chen *et al*., (2015) [6] developed and patented a feed additive containing *Portulaca oleracea* L. extract as a natural plant feed additive. It was reported to be capable of improving the animals metabolism, increasing the animals relative weight gain, improving the animal's survival rate, reducing the disease incidence of various diarrhea symptoms, decreasing the animals stress response and increasing the animal productivity.

Translational research with *Portulaca oleracea*

The literature searchon the intellectual property rights regarding *Portulaca oleracea* shows an increasing interest of researchers in novel technological applications of potential future products derived from *Portulaca oleracea*. A number of patents have been granted related to the use of *Portulaca oleracea* till date owing to its diverse potential applications in the field of pharmaceutical industry, cosmetic industry and food and feed industry. The literature searches also revealed that Purslane has been very extensively exploited by Chinese and Korean researchers for the development of diverse products in various fields but not much work could be noticed from Indian researchers. A list of few patents related to food industry has been given in table 3.

Table 3: Patents granted for the use of *Portulaca oleracea* L.

Patent Number	Date of issue	Title	Description	Inventors	Applicant
US2015/0297657A1	October 22, 2015	*Portulaca oleracea*, L. extract feed additive and preparation method thereof	The *Portulaca oleracea* L. extract feed additive as a natural plant feed additive is capable of improving the animals metabolism, increasing the animals relative weight gain, improving the animal's Survival rate, reducing the disease incidence of various diarrhea symptoms, decreasing the animals stress response and increasing the animal productivity.	Jiaming Chen, Xuefeng Chen, Ling Lu, Ting Shu, Zili Chen, Ziqiang Chen, Danrong Zheng, Shunjie Huang,	Shanghai Zhao Xiang Biological technology Co., LTD, Shanghai (CN)
KR100442683B1	02 August, 2004	Beverage of *Portulaca oleracea* containing antitumor and antimicrobial effect	Patent was provided for developing a functional drink containing *Portulaca oleracea* extract that has effects on antibacterial, anticancer and nicotine removal. *Portulaca oleracea* L. extract in the higher concentration than 500 ug/ml is effective on uterine cancer (HeLa), stomach cancer (SNU-16), colon cancer (SNU-C2A) and liver cancer (SNU-449). The extract has an effect of removing 89% of nicotine chemical. *Portulaca oleracea* L. extract drink is manufactured by heating in a pressure cooker of 90 deg.C for 1 hour and compressing to extract.	Bae Ji Hyun, Bae Hyo Jin	Bae Ji Hyun
CN102578566B	18 September, 2013	*Portulaca oleracea* linn chewable tablet	The present invention relates to the use of *Portulaca oleracea* plant, in particular the production of chewable tablets that has acquired the therapeutic, prophylactic, the effectiveness of health care.	Xie Xiaofeng	Xinjiang Yuansen Agricultural Development Co., Ltd.

Safety concerns

Purslane leaves and extracts have a long-standing use in traditional foods and medicinal system and is generally considered as safe. A number of authors have promoted the

positive attributes of purslane (Palaniswamy *et al*., 2004; Gonnella *et al*., 2005) [31, 11] but a limited data and literature on the toxic properties of purslane is available which have been discussed under this heading.

One of the risk factors associated with purslane is high level of oxalate in the plant. Oxalate is found in many plant families (Libert and Franceschi, 1987) [20] and the oxalate content of a wide range of vegetables, fruits, nuts and wild edible plants have been determined in a number of comprehensive studies (Judpresong *et al*., 2006; Santamaria *et al*., 1999; Noonan and Savage, 1999) [17, 37, 26]. A few authors have measured high levels of oxalates in either the whole plant or leaves of purslane ranging from 2.55 to 12.94 g total oxalate kg-1 fresh weight (FW) (Guil *et al*., 1997; Prakash and Pal, 1991) [12, 34]. This range of oxalate values in the edible portions of purslane is higher in comparison to Thai vegetables, such as bamboo shoots with 1.63 g kg-1 FW (Judpresong *et al*., 2006) [17] spinach grown in Italy with 5.43 g kg-1 FW (Santamaria *et al*., 1999) [37] taro leaves grown in New Zealand with 5.89 g kg-1 FW (Oscarsson and Savage, 2007) [28] and oca tubers grown in New Zealand with 1.62 g kg-1 FW (Savage *et al*., 2008) [28].

As oxalate has no metabolic use in the body after absorption it is transported to the kidneys and excreted in the urine as a waste product. The amount of oxalate excreted in the urine is an important risk factor in the development of calcium oxalate crystals, the most common component of kidney stones. Obied *et al*., (2003) [27] reported the adverse effect of raw purslane on Nubian goats consuming large amounts of it. Goats fed with a diet, containing only purslane showed significant liver and kidney damage and died within 15 to 45 days of starting the diet. Oxalate can be found as soluble and insoluble forms in plants. Soluble salts are formed when oxalate binds with potassium, sodium and magnesium while insoluble salts are produced when the oxalate binds with calcium and iron. Finally

oxalate can also be found as free oxalic acid (Noonan and Savage, 1999) [26]. Soluble oxalate content in purslane can be reduced by cooking but insoluble oxalate can't be removed. If the cooking water containing some of the leached soluble oxalate is discarded (Judpresong *et al*., 2006) [17]. Purslane is commonly eaten raw as a garnish on foods or mixed into a salad because of its characteristic tangy flavour. It is also cooked lightly. This process is likely to result in losses of soluble oxalates into the cooking water. The positive nutritional characteristics of purslane are underexploited and underutilized in Western diets but its high oxalate content may limit its wider use particularly for people who have a tendency to form kidney stones. Gonnella *et al*., (2005) [11] suggested that the consumption of purslane every day is inadvisable. Moreover, information about the oxalate content of various parts of the plant is scarce.

Poeydomenge and Savage (2007) [33] studied the effect of boiling and pickling on the soluble oxalate content of purslane. They reported that fresh leaves, stems and buds of purslane contained 23.45±0.45, 5.58±0.18 and 9.09±0.12 g total oxalates kg-1 fresh weight, respectively. The stems and buds of the plant contained 75.0% soluble oxalates while the leaves contained only 27.5% soluble oxalates. They also reported that boiling resulted in a loss of soluble oxalates from the tissue with an overall 27% reduction in total oxalate. Pickling the whole plant resulted in a loss of soluble oxalates from the tissue by leaching into the vinegar, resulting in a reduction of total oxalate content of the pickled tissue by 16%. Larger leaves possessed 40% more total oxalates than the smaller ones while the oxalate content of the stems ranged between 4.9 and 6.2 g total oxalates kg-1 fresh weight. In this study it was found that purslane stem contain more oxalate content than leaves. Overall, the results of this experiment confirm that cooking and pickling purslane reduces the soluble oxalate content of the processed tissue. Reduction in the soluble oxalate concentration of the tissue will reduce the potential of this high oxalate containing plant to increase urinary oxalate output which could then lead to an increased incidence of kidney stones. This is particularly important as purslane has a number of positive nutritional attributes which suggest that it should be part of a healthy diet.

Earlier studies have reported a reduction in soluble oxalates in spinach (Brogren and Savage, 2003) and taro (Oscarsson and Savage, 2007) [28] from 49 to 73% when cooked with a milky product. Consuming purslane with a calcium rich food such as milk or sour cream would allow a reduction in the absorption of soluble oxalate since calcium binds with soluble oxalate forming insoluble oxalates which will not be absorbed in the gastrointestinal tract. Therefore, the oxalate bioavailability from purslane would be significantly reduced if it was cooked with a milky product. Pregnant women should not use the herb in therapeutic doses as it may have a contracting effect on the uterus.

Future thrusts

Genetic improvement

Purslane is considered as the richest green source of omega-3 fatty acids especially ALA and GLA. This ALA is utilized by human body to synthesize EPA and DHA. ALA is also found in other plant foods such as flax, hemp and pumpkin seeds and walnuts. However, research clearly indicates that the conversion of ALA to EPA and DHA is extremely limited. Less than 5% of ALA gets converted to EPA and less than 0.5% (one-half of one percent) of ALA is converted to DHA. A common misconception, especially amongst vegetarians and vegans, is that our need for EPA and DHA can be met by consuming plant sources of ALA. This trait of purslane could be improved through genetic improvement/engineering for the effective conversion of ALA (obtained from a plant source) to EPA and DHA.

Use in food system

In spite of its delicate tangy flavor and rich nutritional benefits value added products of purslane are limited. Although a few researchers have worked on the use of purslane as a food ingredient to supplement some traditionally consumed foods but most of such studies are not systematic. Therefore, efforts are needed to utilize this crop for development of value added products like snacks, functional and medicinal beverages. Processing properties of purslane also need to be tested thoroughly. Besides, one researcher has reported the gum producing properties of the purslane which makes it a suitable substrate for the gum extraction. This gum is the most important active ingredient, giving purslane, emollient, anti-inflammatory and laxative properties. Purslane gum has also been reported to possess the emulsifying properties similar to gum Arabic. Studies on such aspects of purslane and its utilization as a food additive also need to be studied. Gum producing properties of purslane can also be improved through genetic engineering or suitable varieties with enhanced gum producing quality can be developed.

Conclusion

Keeping in view the significant potential of *Portulaca oleracea* in the food and feed industry and considering the number of patents being developed using the extracts of purslane, one would not hesitate to conclude that this is indeed a wonder plant of the 21st century if well harnessed. The nature and benefits of this plant herein exposed is a wake- up call to researchers to do more in its exploitation for its best use in diverse dimensions along with pharmacology. This review concludes that *Portulaca oleracea* has tremendous nutritional, functional, medicinal and industrial potential provided that adequate studies are conducted.

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