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Review

Jerusalem artichoke (*Helianthus tuberosus*), a medicinal salt-resistant plant has high adaptability and multiple-use values

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Jerusalem aritichoke (*Helianthus tuberosus*) is an Angiosperm plant species of the Compositae family, and a C-3 warm-season species of sunflower. This herbaceous plant shows significant ecological and commercial importance for its strong stress tolerance, very high yield potential and more application areas such as chemicals, pharmaceuticals and industrial applications. The morphologic, bio-ecological characteristics, the utilization and applied values of *H. tuberosus* are introduced in the present review and put forward the problems that need to be studied further in the future for its wider application. Many wild plants besides *H. tuberosus* can be planted as medicinal plants in saline-alkali soil for their remarkable saline-alkali tolerance as well as economic values.

Key words: *Helianthus tuberosus*, medicinal plant, ecological improvement, salinization.

INTRODUCTION

The Jerusalem artichoke (*Helianthus tuberosus*), which is also called the sunchoke, sunroot, topinambur or earth apple, is an Angiosperm plant species of Compositae family (Monti et al., 2005; Tassoni et al., 2010) and a C-3 warm-season species of sunflower native to temperate regions of North America and has been grown in Europe since the 17th century (Slimestad et al., 2010). Now it is also cultivated widely in China for its high adaptability and multiple tuber usability options. In Shanxi, Helongjiang, Shandong, Jiangsu Province, the plant has been extensively cultivated for improving salt-alkaline soils, oil-polluted soils and coal-mining soils at large scale. These practices have obtained significant ecological,economic and social effects, especially,the coal-mining soils quality have been improved much (Zhang et al., 1988; Ma et al., 2004). This herbaceous plant grows under different pedoclimatic conditions and shows good tolerance to frost, drought and other adverse conditions, as well as resistance to pests and diseases (Slimestad et al., 2010).

H. tuberosus has many application areas such as green or ensiled forage, a cover crop in marginal area, source of sugars and inulin for foods, crude material for production of various chemicals, pharmaceuticals and industrial applications, etc. (Baldini et al., 2004; D'egidio et al., 1998; Fuchs, 1993; Meijer and Mathijssen, 1992). In addition, it was used as a raw material for the production of motor fuel alcohol during the Second World War and has been sporadically used for this purpose until now (Chekroun et al., 1996).

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More importantly, as *H. tuberosus* possesses prophylactic and medicinal properties for sufferers of sugar diabetes, and act as a biogenetic factor for the development of natural intestinal microflora after disbacteriosis (Rakhimov et al., 2003), it has been becoming an interesting research topic and it is even labeled as a new cultivated crop (Terzic and Atlagic, 2009).

MORPHOLOGIC CHARACTERS

H. tuberosus is a large, gangly, multibranched herbaceous perennial plant with rough, hairy, sandpapery leaves and stems, and numerous yellow flower heads. It can get 1.5 to 3 m tall. The leaves are opposite on the lower part of the stem and alternate near the top of the stem. The lower leaves are larger and broad ovoid-acute and can be up to 30 cm long, while the higher leaves smaller and narrower. The stems are stout, ridged and can become woody over time. Branches vary from none to many. Flower heads occur separately or in groups at the ends of main stems and alar branches. Each flower head is 5 to 7.5 cm wide and made up of many small, yellow, tubular disk flowers in the center, surrounded by 10 to 20 yellow ray florets. The root system is fibrous with thin cord-like rhizomes that grow as long as 127 cm (Ohio Agricultural Research and Development Center, 2008). The tubers vary from knobby to round clusters, range from pale brown to white, red and purple in color (Duke, 1983; Huxley et al., 1992), are elongated and uneven, with a crisp texture when raw, typically 7.5 to 10 cm long and 3 to 5 cm thick, and vaguely resembling ginger root.

BIO-ECOLOGICAL CHARACTERS

Jerusalem artichoke is reported to tolerate an annual precipitation of 31 to 282 cm, and average annual temperature of 6.3 to 26.6°C and a pH in the range of 4.5 to 8.2 (Duke, 1983). As a very easily-grown plant, it is a suitable crop that adapts well to a wide range of soil types and pH levels in a sunny position where corn will grow (Chittendon, 1951; Duke, 1983), but the plant artichoke production is favored by slightly alkaline soils. The tubers are easily damaged when harvest, so lighter well-drained sandy loams are more suitable for their growth (Huxley et al., 1992), although the plants are more productive when grown in a rich soil (Chittendon, 1951). *H. tuberosus*, which are particularly suited to dry regions and poor soils, have more yield of tubers than potatoes (Huxley et al., 1992). Dry stem tubers of *H. tuberosus* are reported to be produced in quantities of up to 18 tons ha^{-1}, and contain inulin in concentrations greater than 50% (Hua et al., 2007). Tuber and top yields will be limited when soil moisture is less than 30% of field capacity during the tuber formation period. So, it is necessary to irrigate for the seed germination and tuber production in dry areas and times. But on the other hand, yields are poor on heavy clays, particularly if there is waterlogging.

H. tuberosus tolerates sub-zero to hot temperatures (Duke, 1983). The tubers can withstand freezing for months even if the frost kills the stems and leaves (Duke, 1983). So the tubers are very cold-tolerant and can be safely left in the ground during the winter to be harvested as required. Once the tubers are stored in the ground or refrigerated, the tubers will develop a much sweeter taste for the inulin is converted to fructose. *H. tuberosus* require longer periods of light from seedling to maturation, and shorter periods for tuber formation in late summer, as they are sensitive to day-length hours (Huxley et al., 1992). But they do not grow where day-lengths vary little (Duke, 1983). *H. tuberosus* are generally considered to be moderately tolerant to salinity and to exhibit genotypic variability in salinity tolerance (Long et al., 2008; Newton et al., 1991), so they could be safely grown in salt-affected land with 25 and 50% seawater irrigation (Zhao et al., 2008).

It is good for the utilization of weak sandy, drought soils and can be used as a protective and an alternative plant against deflation and erosion. As the plant makes so dense a shade, that few other plants can compete (Duke, 1983), it is a good weed eradicator and can be invasive (Chittendon, 1951).

DEVELOPMENT VALUES

Human food

Traditionally, *H. tuberosus* has been planted for the tubers utilization and it has been harvested in late autumn when the carbohydrates migrated completely from the aerial part of the plant to underground tubers (Negro et al., 2006). Similar to water chestnuts in taste, the tuber is traditionally used as a gourmet vegetable. Fresh *H. tuberosus* tubers contain about 75 to 80% water, 2 to 3% protein and 15 to 16% carbohydrates, of which the D-fructose polymer inulin, with a glucose unit at the end of the chain (Chekroun et al., 1996), can constitute 80% or more (Kays and Nottingham, 2007; Negro et al., 2006). Jerusalem artichoke tubers resemble potatoes except that, the tubers contain 75 to 80% of carbohydrates in the form of inulin while potatoes in the form of starch. Compared with potato, they are also high in iron (Cieslik, 1998), and contain 10 to 12% of the US RDA of fiber, niacin, thiamine, phosphorus and copper. There are appropriate amount of macro elements such as Ca, Mg and K etc., while it has a surplus of sodium compared to other root cultivars (Terzic and Atlagic, 2009). Proteins contain almost all essential amino acids such as threonine and tryptophan (Table 1). They can be found in tubers in larger content than in other similar root crops, so *H. tuberosus* is considered as a quality food (Rakhimov et al., 2003). Thus, the tubers of *H. tuberosus*

Table 1. Indispensable amino acid content of Jerusalem artichoke (%) (Committee of Chinese Forage Plant, 1989).

Item	Lys.	Try.	Met.	Thr.	Ile.	His.	Arg.	Phe.
Fresh tuber	0.09	0.24	0.09	0.80	0.09	0.06	0.12	0.13

can be utilized as human food very widely. They can be used to make soups, sauces, salads and pickle. Due to the presence of inulin, starch which cannot be digested by the human enzyme system, the tubers are also considered as good source of dietary fibers and provide a bulk of food without many calories. The roasted tubers are a coffee substitute (Facciola, 1990). Dehydrated and ground tubers can be stored for a long time while their protein and sugar cannot deteriorate.

Forage production

H. tuberosus is an economically important crop species, with aerial parts and the tubers are used as forage for cattle (Long et al., 2008). Tubers contain adequate amounts of macro and micro elements for use as cattle feed. Chemical composition of fresh and dry tubers used as forage in China is listed in Table 2. Compared with green part of ensiling, the green part has higher water, crude protein, ash and lower crude fat, crude fiber and extraction without nitrogen (Table 3). Some authors (Incoll and Neales, 1970; Meijer and Mathijssen, 1991) have suggested that *H. tuberosus* can be utilized as a stalk crop, which can be harvested at the beginning of flowering, since its above-ground biomass is high and stores temporary amounts of fructans in the stalk. Then tops can be fed fresh or ensiled, although the forage does not ensile well because of its high concentration of soluble sugars and high moisture content. So, optimal forage quality can be obtained by harvesting tops during mid-September, when protein levels will also be at their maximum. However, tuber yields will be reduced at this time, because the smaller size of the plant may make the tubers unharvestable. It is more advantageous to harvest the tops after a hard frost to get greater tuber production. However, then the forage quality has no advantage over other forage crops such as alfalfa, as both crude and digestible protein concentrations are low, but will still provide an acceptable feed. Thus, the above-ground part of *H. tuberosus* should be classified as maintenance feed and roots, tubers and tops can be fed as a combined ratio.

Medicinal uses

Previous phytochemical studies showed that *H. tuberosus* contain many compounds, including coumarins (Cabello-Hurtado et al., 1998), unsaturated fatty acids (Matsuura et al., 1993), polyacetylenic derivatives (Matsuura et al., 1993; Yoshihara et al., 1991), and sesquiterpenes (Baba et al., 2005; Miyazawa and Kam/eoka, 1983; Morimoto et al., 1966; Spring, 1991). These extracts of *H. tuberosus* were found to possess antimicrobial and antifungal activities, and heliangin, which is a germacrane sesquiterpene lactone isolated from the leaves of the plant, indicated significant activity *in vitro* against Ehrlich ascites carcinoma cells (Ahmed et al., 2005).

Nakagawa et al. (1996) found that crude extract of *H. tuberosus* callus, which can be easily induced from tissues and proliferated in a liquid medium, have a strong activity for hemagglutination. Some authors reported that *H. tuberosus* have aperient, aphrodisiac, cholagogue, diuretic, spermatogenic, stomachic, and tonic effects and has been utilized as a folk medicine for the treatment of rheumatism (Ohio Agricultural Research and Development Center, 2008; Duke, 1983; Kays and Nottingham, 2007). Due to its low polyamine levels and the presence of inulin, which can be converted into fructose, it was recently suggested, the preferential utilization of this tuber in the diet of people with special needs (Barta and Rosta, 1958; Uphof, 1968), such as patients treated by chemotherapy and patients with diabetes (Righetti et al., 2008). Yildiz et al. (2008) suggested that inulin extracted from *H. tuberosus* may play a role in modulation of intestinal characteristics, blood metabolites and liver enzymes. These dishes come from *H. tuberosus* tubers are also excellent for treatment of obese patients suffering from diseases of cardio-vascular system. Wounds of *H. tuberosus* can excrete the bioactive metabolites from a variety of structural classes, which show good resistance to some human tumour cell lines and especially the human mammary tumour cells MDA-MB-231 (Griffaut et al., 2007).

Fuel production

The commercialization of liquid biofuel has been strongly promoted by the growth of automotive transport and decline of petroleum supply (Cheng et al., 2009). *H. tuberosus* is one of the important raw materials for biofuel production. Pan et al. (2009) reported that the tubers of *H. tuberosus* have been utilized as a raw material in the bioethanol industry for its high content of inulin, a fructan that can be easily hydrolyzed. It has been demonstrated that ethanol made from the tubers can be used as a fuel for vehicles after blending with petrol (Liu et al., 2003;

Table 2. Chemical composition of tuber in the Jerusalem artichoke (Committee of Chinese Forage Plant, 1989).

Item	Water/%	% of absolute dry matter weight					Ca/%	P/%	Samples source
		Crude protein	Crude fat	Crude fiber	Extraction of without nitrogen	Crude ash			
Fresh tuber	72.8	11.76	3.61	11.76	60.29	12.58	0.05	0.04	Wuhan
	72.5	12.63	4.90	7.37	70.88	4.21	0.05	0.03	Yangzhou
	87.4	11.11	5.08	7.94	55.55	10.32	0.05	0.02	Guizhou
Dry tuber	7.5	10.16	1.95	29.95	46.7	11.24			Liaoning
	5.3	11.83	1.37	27.88	46.88	12.04			Jilin

Table 3. Comparison on chemical composition of green part of green part and ensiling part of Jerusalem artichoke (Committee of Chinese Forage Plant, 1989).

Item	Water/%	% of absolute dry matter weight				
		Crude protein	Crude fat	Crude fiber	Extraction of without nitrogen	Ash
Green part	84.1	9.59	1.61	17.16	49.16	13.61
Green part of ensiling	82.8	8.02	2.27	18.90	51.39	11.57

Rawson et al., 1988) and the alcohol fermented from the tubers is said to be of better quality than that from sugar beets (Duke, 1983). It is mainly a biomass crop for ethanol production that commonly yields around 7 and potentially up to 14 t ha^{-1} of carbohydrates (Long et al., 2008) and the sugars from 1 acre of *H. tuberosus* can produce 500 gallons of alcohol, which is about double the amount produced by either corn or sugar beet. This makes the plant an attractive species for biofuel production.

Over the past decades, Jerusalem artichoke has received interest for the production of ethanol from tubers (Margaritis et al., 1981; Szambelan et al., 2004), but the high cost of the harvesting and the infesting nature of tubers left in the soil limit the expansion of the crop. On the other hand, tuber growth proceeds at a slow rate during the vegetative stage, and inulin accumulates in the stems (Meijer and Mathijssen, 1991). So, the possibility to harvest the tops when the sugar content in the stalk reaches a maximum and use the stalks as feedstock for ethanol production is now envisaged as an interesting option, thereby avoiding the harvesting of the tubers. In this case, the harvesting equipment and procedures are essentially the same as for harvesting sweet sorghum or corn for ensilage, reducing operation costs (Negro et al., 2006).

There have been many years since *H. tuberosus* was proposed as a possible substrate for ethanol production. However, thus far *H. tuberosus* feedstock for biofuel application has been restricted to rather ethanol than biodiesel production. Compared with bioethanol, biodiesel has higher heating value and lower water absorption, and it can be used directly in vehicles without engine modification. Cheng et al. (2009) suggested the feasibility of an alternative method of producing biodiesel from *H. tuberosus* tuber using microalgae cultivation, and a cost reduction of carbon source feed in algal oil production can be expected.

Industrial raw materials

Unlike most tubers, as mentioned previously, but in common with other members of the Asteraceae, the tubers store the carbohydrate inulin rather than starch. For this reason, *H. tuberosus* tubers are an important source of fructose for industry. It can be used to make sweetening and inulin-rich floury products (Izsaki, 2006). The other chemical composition of *H. tuberosus* tubers includes monosaccharides, fructooligosaccharides, and proteins. Such a combination of components enables *H. tuberosus* tubers to be proposed as a biologically active food additive (Rakhimov et al., 2003). The plant can be transformed into a multi-year crop by harvest stalks as the raw material for sugar extraction, avoiding the sowing of tubers in the next year (Caserta and Cervigni, 1991; D'egidio et al., 1998; Voltolina, 1994).

FUTURE PERSPECTIVES

With socioeconomic development and population growth in the world, environmental problems such as greenhouse effect, prolonged drought, desertification and frequent flooding are more and more critical, of which soil salinization is one of the types of natural and human-induced degradation in all over the world. There is 0.95 billion ha salt-affected soils on earth, of which nearly one tenth of it is in China.

Saline-alkali soils are important land resources and should pay crucial role to speed up socioeconomic development for vast population and limited farmland in China. In this kind of situation, the improvement, amelioration and exploitation of salt alkaloid has extremely vital significance. It becomes more difficult for plants to extract water from soil as soluble salt levels increase.

Salinity affects many morphological, physiological, and biochemical processes, including seed germination, plant growth, and water and nutrient uptake (Long et al., 2010). In addition, salinity affects plants by causing osmotic stress, mineral deficiencies, and physiological and biochemical alterations (Zhao et al., 2007). So, the effective way to reclaim and utilize saline soil is salt-tolerant plants selection and breeding. Many plants such as *H. tuberosus* are salt-tolerant and drought-tolerant species that are easily grown in coastal arid and semi-arid areas (Liu et al., 2003; Long et al., 2008; Newton et al., 1991). It can grow on poor land and is more resistant to frost than corn and sugar beet. Planting of this drought-resisting vegetation may contribute to improvement of soil and water conservation in desertified areas (Cheng et al., 2009). More importantly, as mentioned previously, *H. tuberosus* has multiple use values; including resource exploitation and ecological function. In the future, more agricultural feedstocks will be used for their special properties, which attract consumers; for example, they are renewable resources, have better degradability and being natural than synthetic products. *H. tuberosus* is one of the most important candidates for use as a raw material for the industrial production of biological fructose and inulin (Baldini et al., 2004), especially in low-requirement environments. In addition, studies should be continued to determine the most effective dose, as well as diet and feeding period according to the animal species when they are utilized as forage.

The sprouting screening indicated that different genotypes had different salinity sensitivities (Long et al., 2010). Given that the K^+/Na^+ ratio is an indicator of salinity tolerance of plant, further work to elucidate the relationship between the cation ratios in *H. tuberosus* genotypes differing in salt tolerance is warranted. Additionally, some results indicate that the stronger for species to salt tolerant, the higher the values of some physiological parameters such as proline content, bound-water percentage, relative electrical conductivity, photosynthesis productivity and relative growth rate (RGR) (Zhang, 2008; Shao et al., 2005, 2006, 2008a, b, 2009; Long et al., 2010). So these indexes can be considered to select and breed more salt-tolerant species. At present, there has been considerable interest of using wastewater/ effluent instead of the traditional ways of discharging into waterways of river. Parameswaran (1999) indicated that *H. tuberosus* suffered little or no ill effects due to wastewater irrigation and the biomass yields recorded are equal to and in many cases higher than those obtained for crops grown elsewhere under more favorable conditions. In arid and semi-arid areas, it has the extremely vital significance for conservation of freshwater. While study should be conducted to discuss whether *H. tuberosus* absorb pollutant such as heavy metals, which will do harm to human and animals. As a medicinal plant, *H. tuberosus* has aperient, aphrodisiac, cholagogue, diuretic, spermatogenic, stomachic, and tonic effects. It also possesses prophylactic and medicinal properties for sufferers of sugar diabetes, diseases of cardio-vascular system and human tumour. But research on the bioactive principles of this species is still limited thus far. It should endeavor to isolate and identify more compounds have medicinal values.Plants usually produce secondary metabolite, which make the plants have medicinal value, under stressful environments (e.g. arid, nutrient limitation and salinization). Besides *H. tuberosus*, many wild plants over saline-alkali soil can be used as raw materials for medicine production. For example, there are lots of wild medicinal plants in Shandong Province, China, with large-scale saline-alkali soil distribution. Some of them and their functions and indicators are listed in Table 4. More important medicinal plants, which show good resistance to salinization, can be selected from these wild resources in the saline-alkali soil. Then, the salt-affected soils will present a broad prospect because of its high economical and ecological values.

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Table 4. Resources of wild medicinal plants over saline-alkali soil in Shandong Province, China.

Species	Family	Functions and indication
Cyrtomium falcatum (L. f.) Presl	Dryopteridaceae	Clear heat, hemostasis, worm expulsion
Ephedra sinica Stapf	Ephedraceae	Diaphoresis, antiasthmatic, diuresis
Phragmites communis (L.) Trin.	Poaceae	Invigorating the stomach, diuresis, engender liquid
Imperata cylindrica (L.) Beauv. var. major (Nees) C. E. Hubb.	Poaceae	Cool clearing, diuresis, cool the blood and stanch bleeding, treatment for acute nephritis
Rumex japonicus Houtt.	Polygonaceae	Resolve toxin and disperse swelling, antipruritic and toxoplasmacidal
Atriplex centralasiatica Iljin	Chenopodiaceae	Dispelling wind-evil, brighten the eyes, course the liver, resolve depression
A. sibirica L.	Chenopodiaceae	Dispelling wind-evil, brighten the eyes, course the liver, resolve depression
Kochia scoparia (L.) Schrad.	Chenopodiaceae	Diuresis, detumescence, dispelling wind and eliminating dampness
Tamarix chinensis Lour.	Tamaricaceae	Antithermic, diuresis, course wind, deintoxication
Lycium chinese Mill.	Solanaceae	Clear heat and cool the blood, nourishing liver and kidney, strengthen sinew and bone, boost essence and brighten the eyes
Apocynum venetum L.	Apocynaceae	Clear heat and calm the liver, strengthen the heart, diuresis, tranquilization, lower blood pressure, calm panting
Artemisia capillaris Thunb.	Asteraceae	Clear and disinhibit liver and gallbladder damp-heat, diaphoresis, antithermic, diuresis
Limonium sienense (Girad) Kuntze	Plumbaginaceae	Treatment for menoxenia, dysfunctional uterine bleeding and pelvic inflammatory disease
Aeluropus littoralis (Gouna) Parl. Var.	Poaceae	Clear heat and diuresis, treatment for hepatocirrhosis and liver ascites
Taraxacum officinale Hand. Mazz.	Compositae	Treatment for acute mastitis, clearing heat and detoxication
Ghycyrrhiza uralensis Fisch.	Leguminosae sp.	Clearing heat and detoxication, brighten the eyes, lower blood pressure
Plantago aristata Michx.	Plantaginaceae	Clear heat, brighten the eyes, diuresis, lower blood pressure, check diarrhea, settle cough, dispel phlegm
Cnidium monnieri (L.) Cuss.	Umbelliferae	Warm the kidney and strengthen yang, dispel wind and dry dampness, kill worms
Xanthium sibiricum Patrex Widd.	Compositae	Dispel wind-damp, resolve the exterior, brighten the eyes, treatment for rheumarthritis, nasitis and nasosinusitis
Datura stramonium L.	Solanaceae	Anesthesia and acesodyne, eliminate wind-damp, calm panting

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