Glasswort *(Salicornia spp)* As A Source of Bioactive Compounds and Its Health Benefits: A Review

Gouda, M. S. & Elsebaie, E.M

Food Technology Dept., Fac. of Agric., Kafrelsheikh University, Egypt

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ABSTRACT

Glasswort (*Salicornia spp*) belonging to *(Chenopodiaceae)* family is widely distributed in salt marshes on beaches and among mangroves. It shows great biotechnological potential as a salt-water irrigated crop. Glasswort has been prescribed in traditional medicines to treat a variety of diseases like nephropathy, hepatitis, intestinal ailments, atherosclerosis, hyperlipidemia, diabetes and cancer. A variety of pharmacological experiments have revealed that glasswort solvent extract has anti-oxidative, anti-microbial, anti-proliferative, and anti-inflammatory activities. Many bioactive compounds have been isolated from *Salicornia* such as tungtungmadic acid, quercetin 3-O-glucoside, isorhamnetin 3-O-glucoside and betalain. Due to easy collection of the plant and its remarkable biological activities, this genus has been used nearly worldwide as food and folk medicine. The present review focuse on bioactive compounds isolated from *Salicornia* species and its pharmacological aspects.

Keywords: Salicornia, anti-oxidative effect, anti-inflammatory activity, Chenopodiaceae, betalain

INTRODUCTION

Salicornia is a genus of succulent, halophyte (salt tolerant) plants that grow in salt marshes, on beaches, and among mangroves. *Salicornia* species are native to North America, Europe, South Africa, and South Asia. Common names for the genus include glasswort, pickleweed, and marsh samphire; these common names are also used for some other species which do not belong to Salicornia (Ball & Peter, 2004). These species are occasionally sold in grocery stores or appear on restaurant menus as 'sea beans'. *Salicornia* species are members of the *Chenopodiacea* family, which includes about 1300 species worldwide range from annual herbs to trees. The family of these species is mostly temperate to subtropical with its center of distribution around the Mediterranean, Caspia and Red sea. Many of the species are somewhat weedy and occur near habitation. The *Chenopodiaceae* includes table beets and sugar beets *(Beta vulgaris)*, spinach (*Spinacea oleracea*), and quinoa (*Chenopodium quinoa*) (Mark, 2004, Trebbi & Grath, 2004).

The *Salicornia* species are small, usually less than 30 cm tall, succulent herbs with a jointed horizontal main stem and erect lateral branches. The leaves are small and scale like, and as such, the plant may appear leafless. Many species are green, but their foliage turns red in autumn. The hermaphrodite flowers are wind pollinated, and the fruit is small and succulent and contains a single seed (Ball & Peter, 2004).

The genus *Salicornia* is occasionally utilized as a vegetable in Europe, specially the tetraploid species. The seeds are rich in oil and several trails have been undertaken in the United States to harvest tetraploid species, especially *S. bigelovii* on a large scale as a commercial source of vegetable oils (Imai *et al.*, 2004).

Bioactive compounds in *Salicornia* species

Salicornia species are rich in natural minerals including Mg, Ca, Fe, K, and dietary fibres (Tikhomirova *et al.,* 2008) and many bioactive substances, such as oils (Eganathan *et al.,* 2006), protein (Rhee *et al.,* 2009), polysaccharides (Im *et al.,* 2007), betalain (Lee *et al.,* 2004) and phenolic compounds mainly flavonoids and phenolic acids (Kim *et al.*, 2008, Kim *et al.*, 2010). These bioactive substances have been described in details in the following items.

Salicornia oils

Salicornia spp are an important halophyte used as conventional oilseed crops, for direct seawater irrigation in coastal areas of arid regions (Alsaeedi and Elprince, 2000).The results of physical and chemical analysis of oils showed that their fatty acid composition is similar to other common edible vegetable oils. Anwar *et al.* (2002) stated that oil content of *Salicornia* seed represents 28%, of the seeds.

Fatty acids analysis of *Salicornia fruticosa* lipid revealed the presence of 11 fatty acids in which plamitic acid (32.4%) and linoliec acid (14.16%) were found to be the most predominant fatty acids (Radwan *et al.*, 2007).

Elsebaie *et al.* (2013a) evaluated the methods of oil extraction from glasswort seeds and reported that chloroform and methanol mixture (2:1 v:v) gave the maximum amount of extracted from seeds (28.59%). The physical and chemical characteristics of *Salicornia fruticosa* seed oil were also analyzed. The results were as follows: the iodine value 84.5 gI/100 g oil, acid value 1.84 mgKOH/g oil and saponification value 195.6 mgKOH/g oil. The unsaturated fatty acids accounted for 78.05%, in which oleic acid accounted for 56.58 %, linoleic acid accounted for 17.40 %, and linolenic acid accounted for 3.98 %.

Polyphenols

One of the active constituents in *Salicornia herbacea* is tungtungmadic acid (3-caffeoyl-4 dihydrocaffeoyl quinic acid), and chlorogenic acid derivative (Chung *et al.*, 2005). Chlorogenic acid, an ester of caffeic acid with quinic acid, is found in many plants and recognized as an antioxidant (Bonita *et al.*, 2007, Medina *et al.*, 2007). Indeed, tungtungmadic acid was found to have higher antioxidative activity in 1, 1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging test and in the iron-induced liver microsomal lipid peroxidation assay. In addition, tungtungmadic acid was shown to be effective in protecting the plasmid DNA against strand breakage induced by $Fe3+$-nitrilotriacetic acid-hydrogen peroxide (Chung *et al.*, 2005). In addition, other active compounds, such as sitosterol, stigmasterol, uracil, quercetin 3-O-α-D-glucopyranoside, and isorhamnetin 3-O-α-D-glucopyranoside, were isolated from the methanol extract of *Salicornia herbacea* (Lee *et al.*, 2004, Park & Kim, 2004).

Essaidi *et al.* (2013) studied the composition of *Salicornia herbacea* methanolic extract and revealed the presence of eight phenolic acids (chlorogenic, sinapic, ferulic, caffeic, salicylic, syringic, β-coumaric, and trans-cinnamic acids) and eight flavonoids (myricetin, quercetin, kaempferol, rhamnetin, isorhamnetin, hesperetin, galangin and acacetin).

Elsebaie *et al.* (2014) evaluated different solvents for poly phenols extraction from *Salicornia* air parts. They stated that the best solvent for extracting polyphenolic compounds was methanol followed by ethanol, chloroform and water. HPLC analysis of the total polyphenols extracted from the air part of *salicornia* indicated the presence of high percentages of pyrogallol, ellagic, B-OH benzoic and Catechin. The extracted phenolic acids were tested for corn oil keeping quality. Their results showed that the peroxide value and TBA values of the treated corn oil by different types of extracts at different levels were lower than those of the control.

Betalain

Betalains are water-soluble nitrogen-containing pigments, which are synthesised from the amino acid tyrosine into two structural groups: the red-violet betacyanins and the yellow-orange betaxanthins. Betalanic acid is the chromophore common to all betalain pigments (Strack *et al.*, 2003).

Lee *et al.* (2004) reported that methanol extract of *Salicornia herbacea* contained 4.85 mg/ml of betaine. Betalains attract increased attention because of their marked use for food colouring, their antioxidant and radical scavenging properties against certain oxidative stress-related disorders, anticancer, antiviral and antiparasitosis properties (Biswas *et al.*, 2013).

Pharmacology activity

Several workers demonstrated the different biological activities of glasswort in various *in vitro* and *in vivo* test models. Different solvent extracts or various compounds of the plant have exhibited antioxidative, anti-microbial, anti-hyperlipidemic, and antidiabetic activities. These biological activities have been described in details in the following sections.

Anti-oxidative effect

An antioxidant is defined as 'any substance that, when present at low concentrations compared to those of an oxidizable substrate, significantly delays or prevents oxidation of that substrate' (Mates *et al.*, 1999). Antioxidants are of interest to biologists and clinicians because they help to protect the human body against damage induced by reactive free radicals caused in cancer, atherosclerosis and aging (Halliwell *et al.*, 1995, Mates *et al.*, 1999). There are many reports that natural products and their derivatives have efficient anti-oxidative characteristics, consequently linked to anti-cancer, hypolipidemic, anti aging and anti inflammatory activity (Aruoma, 2003, Cho *et al.,* 2010).

The antioxidative activity of isorhamnetin 3-O-β-D-glucopyranoside, which contains methoxyl group at ring B, was lower than that of 3-O-β-Dglucopyranoside.

Tungtungmadic acid (3-caffeoyl-4- dihydrocaffeoyl quinic acid) is a new chlorogenic acid derivative that was isolated from the *Salicornia herbacea*. Chung *et al.* (2005) determined the structure of tungtungmadic acid using chemical and spectral analysis. They evaluated the antioxidant activity of tungtungmadic acid using various antioxidant assays, including free radical scavenging, lipid peroxidation and hydroxyl radical-induced DNA strand breaks assays. Tungtungmadic acid (IC_{50}=5.1 μM and 9.3 μM) was found to have higher antioxidant activity in the DPPH scavenging assay as well as in the iron-induced liver microsomal lipid peroxidation system. In addition, the tungtungmadic acid was also effective in protecting the plasmid DNA against strand breakage induced by hydroxyl radicals.

The water extract of glasswort was found to protect against oxidative stress under ovariectomy conditions (Ha *et al.,* 2006). The malondialdehyde levels in the liver total homogenate and mitochondrial fractions were markedly increase in the ovariectomized rats and were also found to decrease by glasswort up to almost the control level. The levels of superoxide dismutase, catalase, and glutathione peroxidase also decreased in the ovariectomized rats, which were reversed significantly by the administration of *S. herbacea.* Interestingly, the decreased level of 17 β-estradiol in ovariectomy rats was ecovered by glasswort treatment. These results imply that estrogen-like mechanism of glasswort could play a protective role in overiectomic conditions against free radical production.

The anti-oxidative activities of water and ethanol extracts from glasswort prepared by enzymatic treatments were evaluated by *in vitro* assays against DPPH, superoxide and hydroxyl radicals (Oh *et al.,* 2007). The ethanol extract from viscozyme-treated glasswort displayed the strongest radical scavenging activity against DPPH, superoxide and hydroxyl radicals. Five phenolic compounds, including procatechuic acid, ferulic acid, caffeic acid, quercetin, and isorhamnetin, were isolated and identified by antioxidant assay-guided fractionation and purification. Most of these phenolic compounds exhibited considerable DPPH, superoxide, and hydroxyl radical scavenging activities. In particular, caffeic acid and ferulic acid more strongly scavenged the reactivity of superoxide and hydroxyl radicals than (+)-catechin, a well-known antioxidant. The levels of five phenolic compounds detected in the ethanol extract of viscozymetreated glasswort were highly observed in 1 - 12 mg ranges in one hundred grams of this plant.

Antimicrobial activity

Lellau & Liebezeit (2003) reported the high activity of *Salicornia herbacea* against fungi, yeasts and algae. Meanwhile, Chandrasekaran *et al.* (2008) reported that the results of phytochemical screening of *Salicornia herbacea* extract stem indicated the presence of several phenolic compounds which could have antimicrobial activity.

The antimicrobial activity of *Salicornia brachiata* shoot extracts prove to be very effective against gram positive bacteria and this antibacterial activity is related to the presence of phenols (flavones and the related flavonoids) and polysaccharides compounds found in *S. herbacea* extract. Phenolic substances tend to be water soluble, since they most frequently combined with sugar as glycosides and they are usually located in the cell vacuole. Fouling bacteria are particularly sensitive to the action of the crude methanolic extracts of mangrove halophytes (Kumar *et al.,* 2009, Manikandan *et al.,* 2009).

Kim *et al.* (2010) stated that *Salicornia herbacea* methanol extract activity was not only related to phenols but also to other components such as fatty acids and the osmotic compound (betaine). Jayalakshmi *et al.* (2011) found that *Staphylococcus aureus* was the most inhibited gram positive bacterium (inhibition diameter 10 mm at 100 mg/L) and *Salmonella enteritidis* was the most sensitive gram negative bacterium (inhibition diameter 7 mm at the same concentration) by methanol extract of *Salicornia herbacea.*

The methanol extract of *Salicornia herbacea* exhibited an antibacterial effect with all strains but strains resistance was variable. The gram positive bacteria were significantly more susceptible to the extract ($P < 0.05$) and showed greater inhibition zone than the gram negative bacteria (Essaidi *et al.,* 2013).

Elsebaie *et al.* (2013b) noted that, glasswort (*Salicornia*) air part juice and methanolic extract had considerable effectiveness in decreasing aerobic plate count (APC), yeast and moulds count, as well as chemical indices as pH and thiobarbituric acid (TBA) values. Results indicated that the bacterial counts, yeast and moulds count, pH and TBA values decreased as the concentration of the glasswort *(Salicornia fruticosa)* air part juice and methanolic extracts increased, since the concentration (1.5% methanolic extract) gave the best effect. The antioxidant and antibacterial activities of the added compounds followed the order 1.5% methanolic extract > 1.5% juice> 1% methanolic extract > 1% juice > 0.5% methanolic extract > 0.5% juice. The treated chilled minced beef samples had longer shelf life than the control samples after 9 days of storage at 4°C.

Anti-hyperlipidemic and anti-hyperglycemic effects

The effect of glasswort powder on weight gain and the modulation of relevant serum parameters were investigated by Jo *et al.* (2002). The rats were fed on vehicle (control), 10 and 20% of the plant powder for 4 weeks. It has been clearly observed that the administration of glasswort powder was capable of reducing the weight gain. Total and LDL cholesterol contents in serum significantly decreased by the administration of the herb, whereas HDL cholesterol content was significantly higher than the control group. Moreover, total lipid and triglyceride contents were found to decrease by the administration of glasswort. The overall results suggest that glasswort administration can not only prevent diseases of arteriosclerosis, hyperlipidemia and fatty liver but also inhibit the weight gain.

The anti-diabetic effect of glasswort powder and its underlying mechanism were indeed continuously examined. The administration of glasswort powder alleviated hyperglycemia symptom seen in streptozotocin-induced diabetic rats (Bang *et al.*, 2002). Male Sprague-Bawler rats were blocked into four groups where normal rats were fed the basal diet (NC) diabetic rats were fed basal diet (DC), normal rats were fed Hamcho powder diet (NH), and diabetic rats were fed Hamcho powder diet (DH). Diabetes was induced by single injection of streptozotocin (60 mg/kg B.W. i.p.). The animals were fed adlibitum for 5 weeks. Malondialdehyde (MDA), glucose 6-phosphtase (Gspase), glutathione S-transferase (GST) glutathione peroxidase (GPx), and glutathione reductase (GR) activities were measured in the homogenates of liver and kidney. Total lipids, total cholesterol, triglyceride, and HDL-cholesterol concentrations were determined in the blood serum. Food and water intakes were markedly higher in diabetic groups than those of normal groups and were not significantly decreased by Hamcho powder supplementation. But, FER (Feed efficiency ratio) of DH blood was higher than that of U group. Total cholesterol level of DH group was found to decrease in the second and the third week, and the weekly change of blood sugar was also found to lower in the 5th week. Dietary Hamcho intake showed 41.2% of hypoglycemic effect in diabetic's rats. Levels of total lipid and triglycerides of DH group were lower than those of DC group. Hepatic GR activity of DH group was higher than those of other groups. However, renal GR activity was lower than those of other groups. Hepatic G6Pase activity was significantly high in DH group and reduced by Hamcho powder supplementation. The GST was reduced by Hamcho diet in diabetic rats. In conclusion, Hamcho supplementation lowered serum lipid and glucose concentration in STZ-induced diabetic rats and this effects of Hamcho might exert antidiabetic effect of Hamcho powder diet.

Park *et al.* (2009) screened that glasswort was able to prevent the onset of hyperlipidemia and weight gain induced by high fat diet in mice. Meanwhile, the ethanol extract of glasswort similarly modulated the expression levels of lipogenesis-related genes [e.g., sterol regulatory element binding protein, fatty acid synthase, glycerol-3-phosphate acyltransferase, steroyl-CoA desaturase-1] and gluconeogenesis-related genes [e.g., phosphoenolpyruvate carboxykinase, glucose 6-phosphatase] in liver.

CONCLUSION

In conclusion, *Salicornia* is a promising herb which can be cultivated in dessert area irrigated with sea water. Glasswort herbs contain some biovital compounds such as oils, polyphenols and betalains. Due to the presence of these bioactive compounds this herb has been used to treat a variety of diseases like nephropathy, hepatitis, intestinal ailments, atherosclerosis, hyperlipidemia, diabetes and cancer.

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أنواع جنس الساليكورنيا كمصدر لمركبات حيوية ذات فوائد صحية: إستعراض مرجعي

محمود صابر جوده، عصام محمد السباعي

قسم الصناعات الغذائية، كلية الزراعة - جامعة كفرالشيخ - كفرالشيخ- مصر

عشب جنس الساليكورنيا يعد واحدا من أكثر الانواع نموا و إنتشارا في الأراضي الملحية و علي الشواطئ و حول البرك و المستنقعات ولذلك فهو يعتبر واحدا من المحاصيل التي يمكن زراعتها و ريها بمياه البحار. استخدم عشب جنس الساليكورنيا في الطب التقليدي في علاج العديد من الأمراض و منها الفشل الكلوي و إلتهاب الكبد و ألام الأمعاء و تصلب الشرايين و إرتفاع مستوي الدهون في الدم و مرض السكر و السرطان. و قد كشفت مجموعة متنوعة من التجارب الدوائية أن لمستخلص عشب جنس الساليكورنيا نشاطا مضادا للأكسدة و لنمو الميكروبات و الإلتهابات. وقد تم عزل العديد من المركبات الحيوية من عشب الساليكورنيا مثل حامض Tung-tungmadic وquercetin 3-O-glucoside وisorhamnetin 3-O-glucoside وBetalain. و نظرا لسهولة جمع هذا العشب وما له من أنشطة بيولوجية رائعة فقد أستخدم كغذاء ودواء شعبي علي نطاق واسع من العالم. هذا الإستعراض المرجعي يركز علي المركبات الحيوية التي يمكن عزلها من عشب جنس الساليكورنيا و ما لها من فوائد صحية.