1 Saltbush (*Atriplex* sp.)

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Abstract

Salinity and shrinkage of water tables are among the major crises in the world which adversely affect food production. It has been reported that about one-fifth of total farming land (45 million ha) is salt-affected worldwide. Currently, immense attention is granted to the domestication of halophytes (salt-tolerant plants) due to their evolved adaptive mechanisms to salinity including the production of secondary compounds. Halophytes are ecologically important plants, of which saltbush (*Atriplex* sp.) has been traditionally used as medicine, food, animal feed and as a 'tool' for rehabilitation of degraded land. This plant species has the potential to be used as a source of functional food/functional food ingredients, but is underutilized due to lack of popularity or limited knowledge. This chapter will give an overview of the traditional use of saltbush, an important edible halophyte, its nutritional composition, bioactive properties and potential food applications.

Introduction

Indigenous plants have gained immense interest as a source of nutrients and bioactive phytochemicals, satisfying both food demand and health needs (Pinela *et al.*, 2017; Sõukand, 2016). One such is saltbush (Fig. 1.1), an indigenous edible halophyte, member of the genus *Atriplex*, of which 400 species are found around the world (Ortíz-Dorda *et al.*, 2005). The highest number of saltbush species was found in South America (70–80 species), while the lowest number was reported in the Mediterranean basin and Europe (40–50 species) (O'Leary and Glenn, 1994; Osmond *et al.*, 1980). *Atriplex* species belong to the subfamily Chenopodioideae of the family Amaranthaceae and are distributed in arid and semi-arid regions with 200 to 400 mm of mean annual rainfall (Ortíz-Dorda *et al.*, 2005). Most species are halophytes and are found in salt marshes, salt deserts, mangroves and sand dunes near coastal areas (Wei *et al.*, 2019). *Atriplex* species are ecologically important plants and have been used for rehabilitation of degraded land (saline/alkaline soils, mine waste, shallow soils and bare saline soil) due to

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Fig. 1.1. Saltbush (*Artiplex* sp.).

their ability to tolerate salinity-stressed environments through various biological mechanisms. However, they can also absorb salt from the soil to improve soil structure and increase soil fertility (Le Houérou, 1992; Ortíz-Dorda *et al*., 2005; Piovan *et al*., 2014). Though they have been used as human food or animal feed since ancient times, information on their dietary relevance is very limited. Therefore, this chapter reviews the nutritional profiles and dietary relevance of *Atriplex* species and safety issues related to their utilization in the human diet.

Botany

The most common saltbushes are shown in Table 1.1. *Atriplex* species consist of various sizes (1.0–2.5 m) and morphology (Table 1.1). These saltbush species are generally dioecious or monoecious. However, *Atriplex* sp. have specialized salt bladders on their leaves for storing surplus NaCl (Glenn *et al*., 1998). Most of the *Atriplex sp.* leaves have a green/grey colour (including *A. cinera*, *A. nummularia* and *A. lentiformis*), while leaves of *A. hortensis* can be green, yellow-green, faintly red, dark red and purple. This makes *A. hortensis* an especially attractive addition to salads (Carlsson and Hallqvist, 1981). It is interesting to note that the fruits of *Atriplex* sp. occur in different shapes, from triangular (*A. amnicola*, *A. cinera*) to flat and round (*A. lentiformis*) (Table 1.1).

Traditional Use

Atriplex species have had diverse applications for food and non-food uses from ancient times. For instance, *A. cinera* was popular as a potherb among the Indigenous people of Australia (Maiden, 1889). Furthermore, *Atriplex* sp. have been used in traditional cuisine and as bush food, and are still used raw or cooked in modern recipes. For instance, leaves of *A. hortensis* are used in stews, salads and vegetable spread (Carlsson and Hallqvist, 1981; Bussmann *et al*., 2017). Some of the *Atriplex* species were consumed not only by humans but also by livestock (*A. nummularia, A. halimus, A. amnicola* and *A. semibaccata*), with two species identified as nitrogen-rich fodder (*A. halimus* and *A. nummularia*) (Mehdiyeva *et al*., 2017). It has also been reported that saltbushes have been widely utilized as fodder reserves, particularly in famine periods or periods of forage shortage (in either drought or cold season) and as a supplementary fodder in arid and semi-arid regions (Ortíz-Dorda *et al*., 2005; Abbeddou *et al*., 2011). Furthermore, these shrubs have been used as 'emergency' livestock fodder due to their favourable crude protein content (Khan *et al*., 2000) in addition to their use as a source of fuel wood (Belkheiri and Mulas, 2013). The most important *Atriplex* sp. used for the rehabilitation of degraded lands are *A. nummularia* and *A. canescens*, respectively. These species are also used in ornamental plantations, particularly in seaside resorts (Le Houérou, 1992).

Table 1.1. Botanical information about selected *Atriplex* species.

Scientific name	Common name	Botany	References
Atriplex halimus	Mediterranean saltbush	A perennial native shrub, 1–3 × 3 m, monoecious, inflorescences are in dense spikes, male flowers are at the top of the spike and female flowers at the base	(Ortíz-Dorda *et al*., 2005; Clauser *et al*., 2013)
Atriplex amnicola	River saltbush	A perennial shrub, 1 × 1–2.5 × 4 m, dioecious, elongated and spear-shaped leaves (1–3 cm), fruits may be woody (2–6 mm), triangular or spherical	(Barrett-Lennard, 2003)
Atriplex cinera	Grey saltbush	Sprawling, semi-erect, woody, heavily branched, leafy shrub, 1.5 × 4 m and dioecious or subdioecious. Branchlets stout, rooting freely on contact with soil; stems at first ridged and angular, soon becoming terete and woody with age, grey-green leaves (2 cm), hard, fruits (2–6 mm), triangular	(De Lange *et al*., 1998; Barrett-Lennard, 2003)
Atriplex hortensis	Garden orache or simply orache, red orache, mountain spinach, French spinach or orache	Shrub, 1–2.5 m, large leaves, (14 × 10 cm), flowers in leafless spikes, leaves can be green, yellow-green, faintly red, dark red and purple	(Carlsson, 1975; Carlsson and Hallqvist, 1981; Mehdiyeva *et al*., 2017)
Atriplex nummularia	Oldman saltbush	Upright shrub, 2 × 1.5 m, irregularly shaped grey-green leaves (2–4 cm), fruits (6 mm), fan shape	(Barrett-Lennard, 2003)
Atriplex semibaccata	Australian saltbush, berry saltbush or creeping saltbush	Sprawling undershrub, xero-hypo halophyte	(Le Houérou, 1992)
Atriplex cana	-	A perennial shrub, multi-branched, 20–50 cm, stems become more or less woody	(Cai *et al*., 2015; Wei *et al*., 2019)
Atriplex mollis	-	Shrub, 1 m, pink, erect panicles of bladdery, fruit bracts (1 cm)	(Le Houérou, 1992)
Atriplex undulata	Wavy leaf saltbush	A perennial shrub, 1 × 2 m, wavy or crinkly leaves (0.5–1.5 cm), fruits (1–3 mm), soft and round	(Barrett-Lennard, 2003)
Atriplex lentiformis	Quailbrush	A perennial shrub, 2.5 × 2.5 m, silvery blue-green leaves (2 cm), fruits (2–5 mm), flat and round	(Barrett-Lennard, 2003)

It is interesting to note that *A. hortensis* can be used as part of landscaping gardens and parks since these plants are decorative and beautiful, particularly during the period of fructification (Mehdiyeva *et al*., 2017). These plants are also considered as annual spinach in North and Middle Asia (Mueller, 1880). According to Shinn (1899), the Australian saltbushes were mentioned for the first time in the Report of the College of Agriculture in 1882. Seeds of *A. vesicaria* and *A. nummularia* were sent from Australia to California for propagation. According to Mueller (1880), *A. nummularia* was mentioned as ‘one of the tallest, more fattening and wholesome of Australian pastoral saltbushes, recommended for artificial rearing' and was found from Queensland through the desert tracts to Victoria and South Australia (Shinn, 1899). In 1894, the nutritional analyses on saltbush were compared with those of other green fodders and the findings suggested that the nutrients were comparable with alfalfa.

Nutritional Composition

A. halimus can be a complement forage with favourable nutritive value during the drought and famine period (Benhammou *et al*., 2009). Humans have consumed this *Atriplex* sp. since ancient times, but only a few studies have explored its nutritional composition. The leaves of *A. halimus* were found to have 25.1 g/100 g (dry weight: DW) carbohydrate and 16.2 g/100 g (DW) protein (Abbeddou *et al*., 2011). Interestingly, *Atriplex* species are rich sources of fibre irrespective of their growing locations. The fibre content of *A. halimus* was reported to range from 25.8 to 36.7 g/100 g DW (neutral detergent fibre) and 16.5 to 23.1 g/100 g DW (acid detergent fibre), which is comparable to olive leaves (Abbeddou *et al*., 2011).

A. nummularia and *A. amnicola* are the most important species utilized for grazing and land rehabilitation in Australia (Kumara Mahipala *et al*., 2009). As for *A. halimus*, only very little scientific information is available on its nutritional profile and dietary relevance. A recent study with Australian grown Oldman saltbush (*A. nummularia*) showed that saltbush leaves were rich in protein (20.1 g/100 g DW), fibre (41.5 g/100 g DW) and minerals (particularly Ca (1.4 g/100 g DW), Na (4.1 g/100 g DW), Mg (0.9 g/100 g DW) and Fe (11.7 mg/100 g DW); Srivarathan *et al*., 2020). The reported protein content in *A. nummularia* ranged from 13.4 to 25.2 g/100 g DW and was comparable to that of Australian grown Oldman saltbush (Khalil *et al*., 1986; Yousif *et al*., 1994; Ben Salem *et al*., 2010; Revell *et al*., 2013; Srivarathan *et al*., 2020). However, *A. amnicola* and *A. cinera* had a considerably lower protein content (9.0–9.7 g/100 g DW) than *A. nummularia*, whereas their fibre contents were in the same range as found in other *Atriplex* sp. (neutral detergent fibre (25.2–48.8 g/100 g DW); acid detergent fibre (16.1–33.5 g/100 g DW); Warren and Casson, 1993; Kumara Mahipala *et al*., 2009; Revell *et al*., 2013).

A. hortensis is considered to be one of the ancient cultivated plants, originated in Europe (Stevens, 1994), and has been used as a potherb in conventional medicine. Although it has been used in the food and pharmaceutical industry (Livadariu, 2013; Bussmann *et al*., 2017), its nutritional composition and bioactive properties are not well reported (Wright *et al*., 2002). According to Carlsson and Clarke (1983), leaves of *A. hortensis* are a rich source of protein. The content of crude protein in the leaves was higher than that of spinach (*Spinacia oleracea*) and *A. hortensis* has the potential to be used as a substitute for spinach due to its high yield and prolonged harvest season. Palmitic, oleic, linoleic and α-linolenic acids could be identified as the main fatty acids in the leaves of *A. hortensis* (Carlsson and Clarke, 1983).

The seeds of *A. hortensis* were found to have a relatively high content of carbohydrate (62.0 g/ 100 g DW), followed by protein (28.3 g/100 g DW) and dietary fibre (13.3 g/100 g DW) (Wright *et al*., 2002). The fibre and protein content of *A. hortensis* seeds was higher than that of sweet and bitter quinoa (Wright *et al*., 2002). The protein content in the seeds was also higher than that found in the main 'food-cereals' including rice (7.6 g/100 g DW), wheat (14.3 g/100 g DW), maize (10.2 g/100 g DW) and barley (10.8 g/100 g DW) (Duke and Atchley, 1986; Wright *et al*., 2002). Furthermore, the amino acid profile in both, seeds and leaves, was found to be favourable compared to maize, rice and wheat, having a higher content of lysine, the limiting amino acid in cereals (Wright *et al*., 2002).

Phytochemicals and Bioactive Properties

The presence of different phytochemicals including saponins, flavonoids (especially glycosides), tannins, terpenoids and alkaloids were reported for *Atriplex* sp. (Table 1.2) (Boutaoui *et al*., 2018). Halophytes can have relatively high levels of phenolic compounds since they develop

Table 1.2. Bioactive compounds/phytochemicals identified in selected *Atriplex* species.

Plant species	Bioactive compounds/phytochemicals	Bioactive properties	Ethnopharmacological use/ general applications	References
A. halimus	Saponins, betaines, mineral salts, alkaloids, phytoecdysteroids, flavonoids (isorhamnetin-3-*O*-glucopyranoside, rutin-4',7-dimethylether and kaempferol-3,7-dirhaminoside-4'-methyloxide, isoorientin, 4'-methoxy-7-glucoside-5-hydroxyisoflavone, naringenin-4'-*O*-rhamnopyranoside, hesperidin), phenolic acids (*p*-hydroxybenzoic acid, chlorogenic acid, cinnamic acid, ferulic acid and salicylic acid)	Antioxidant, anti-acetylcholinesterase, hypoglycaemic	Leaves are used to treat heart disease, diabetes, rheumatism	(Bayoumi and El-Shaer, 1992; Dinan *et al*., 1998; Said *et al*., 2008; Benhammou *et al*., 2009; Emam, 2011; Clauser *et al*., 2013)
A. mollis	Rutin, catechin, epicatechin, naringenin, *p*-coumaric acid, gallic acid, chlorogenic acid, *p*-hydroxybenzoic acid, sinapinic acid, syringic acid, ferulic acid and vanillic acid	Anti-inflammatory, antioxidant, hepatoprotective	Phytopharmaceutical use	(Boutaoui *et al*., 2018)
A. hortensis	Condensed tannins and other phenolic compounds	Antioxidant	Potherb in traditional medicine, used as diuretic and anastasis	(Carlsson and Hallqvist, 1981; Stevens, 1994; Wright *et al*., 2002; Mehdiyeva *et al*., 2017)
A.nummularia	Vitamin E, β-carotene	Antioxidant	-	(Pearce *et al*., 2005; Ben Salem *et al*., 2010)
A. lentiformis	Quercetin, kaempferol, quercetin and kaemferol glycosides	Antioxidant	-	(Awaad *et al*., 2012)

a biological antioxidant system as a response to abiotic stress (Ramani *et al*., 2004; Ksouri *et al*., 2012; Boutaoui *et al*., 2018).

A. halimus has been used as a medicinal plant in conventional Arabic medicine for glycaemic control in diabetic patients and to treat heart disease (Table 1.2) (Said *et al*., 2002). It has also been used as a treatment for rheumatism and to combat parasites in veterinary use (Bayoumi and El-Shaer, 1992). Decoction and/or a remedy bath are the usual administration. *A. hortensis* is used as a diuretic, anastasis and against haemorrhage (Mehdiyeva *et al*., 2017). It was also reported that it has higher levels of total phenolics and condensed tannins than *S. oleracea* (Carlsson and Hallqvist, 1981). Microwave-assisted extraction of *A. mollis* recovered several phytochemicals including gallic acid, catechin, chlorogenic acid, p-hydroxybenzoic acid, rutin, sinapinic acid, ferulic acid, naringenin and benzoic acid (Boutaoui *et al*., 2018). No reported bioactivities or therapeutic application of *A. mollis* could be found in the literature. *A. mollis* and *A. nummularia* could be also identified as valuable sources of antioxidants having relatively high levels of vitamin E (139 mg/kg dry matter (DM)) and beta carotene (34.5 mg/kg DM) (Pearce *et al*., 2005; Ben Salem *et al*., 2010). According to White and Rewell (2007), *A. nummularia* was used in Australia to treat weaner sheep with vitamin E deficiency. A recent study on *A. lentiformis* showed that the isolated polyphenols, quercetin-6,4′-dimethoxy-3-fructo-rhamnoside and quercetin-4′-methoxy-3-fructo-rhamnoside, exhibited a strong antioxidant activity in rats with no side effects on liver and kidney function (Awaad *et al*., 2012).

Antinutritive Compounds

According to Watson *et al*. (1987), oxalate presents an important anti-nutrient in *Atriplex* leaves. For instance, *A. hortensis* was reported with an oxalate content of up to 8.7% DM (Carlsson and Hallqvist, 1981). However, the toxicity of saltbush is regarded as low since its high salt content can control the intake of oxalate before toxicity is attained (Ben Salem *et al*., 2010). As for other plant ingredients, oxalate levels can vary significantly, depending on the maturity, harvest season and specific environmental conditions (Abu-Zanat *et al*., 2003). It was also reported that oxalate might have lowered the calcium absorption in tilapia fish fed with dehydrated *Atriplex* leaves, resulting in suppressed growth (Yousif *et al*., 1994). Osmond (1963), Sandberg *et al*. (1967) and Duke and Williams (1977) reported low levels of quaternary alkaloids in *Atriplex* sp. in addition to saponins, tannins and flavonoids. However, it was surprising that no saponins could be found in the seeds of *A. hortensis* (Wright *et al*., 2002).

Bioaccessibility and Bioavailability

Several *in vitro* studies on the digestibility of halophytes in the context of their 'efficiency' as livestock feed have been conducted (Weston *et al*., 1970; Abbeddou *et al*., 2011; Tosto *et al*., 2015). However, no reports about human studies to assess the actual bioaccessibility and/or bioavailability of the main nutrients and phytochemicals in halophytes could be found.

Products/Formulations/Applications

Based on their nutritional composition, *Atriplex* sp. have the potential to be used as functional foods/functional food ingredients. The seeds of *A. hortensis* could be used to produce saponin-free food products. *A. hortensis* seeds and leaves, with their high protein content and well-balanced amino acid profiles, may have the potential to be used as a novel/alternative protein source (Carlsson and Clarke, 1983; Wright *et al*., 2002). Since *Atriplex* sp. are generally rich in protein and most of them can be consumed raw, the addition to a meal as a complementary vegetable or incorporation into salads are other possible food 'applications'. Furthermore, due to their salty taste and unique aroma, leaves (fresh and dried) of *Atriplex* sp. can be added to a meal as a potential salt substitute or served together with seafood. Another 'avenue' is the typical functional food and/or phytopharmaceutical applications of *Atriplex* sp., due to their broad range of bioactive phytochemicals such as chlorophylls, carotenoids, betalains and phenolic compounds (Suhaj, 2006; Ksouri *et al.*, 2012).

Conclusions and Future Trends

This chapter has provided an overview of *Atriplex* sp., from their botany to potential (functional) food applications, to showcase their nutritional and bioactive potential to a broader audience. However, the showcased potential needs to be investigated further in human (clinical) studies to substantiate the actual bioavailability and health benefits of the main nutrients, bioactive phytochemicals and derived products. Another focus should be led on the development of different *Atriplex* sp.-based products suitable for the mainstream food market (e.g. salt replacement), but also for specific functional food and/or phytopharmaceutical applications (e.g. supporting diabetes management).

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