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Nutritional potential of a novel sea asparagus, *Salicornia neei* Lag., for human and animal diets

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Resumo

Potencial nutricional de uma nova variedade de aspargo marinho, *Salicornia neei* Lag., para dietas humana e animal. O perfil mineral e o valor nutricional para a alimentação humana e animal de uma nova variedade de aspargo marinho brasileiro, *Salicornia neei* Lag., foram caracterizados por espectrofotometria. As plantas da progênie F4 da variedade pura denominada BTH1, cultivada com efluente salino da carcinicultura, possuem alto conteúdo mineral, particularmente N, K, P, Ca, Fe e Mn. A ingestão diária de 20, 200 e 5 g de caules secos de BTH1-F4 pode ser inserida e suplementada nas dietas, respectivamente, do homem, ovelhas e peixes cultivados comercialmente.

Palavras-chave: Alimento saudável; Agricultura salina; Nutrição mineral

Abstract

The mineral profile and nutritional value of a novel variety of the Brazilian sea asparagus, *Salicornia neei* Lag., was characterized for feeding humans and animals using spectrophotometry. Plants of the F4 progeny of the purebred variety named BTH1 cultivated with saline shrimp farm effluent have high mineral content, particularly N, K, P, Ca, Fe and Mn. Daily intakes of 20, 200 and 5 g of dried shoots of BTH1-F4 could be added to and supplement human, sheep and commercial fish diets, respectively.

Key words: Health food; Mineral nutrition; Saline agriculture

Introduction

Food production from saline agriculture is practiced in coastal areas, arid regions and on solodic soils and human induced salinized soils, through the conscious use of natural resources and for economic benefit. This cultivation system requires using plants with morphological and/or physiological mechanisms that tolerate high salinity levels (*i.e.*, halophytes). Due to their high salt tolerance, high nutritional value and long tradition of consumption by humans, the genera *Salicornia* and *Sarcocornia* (Amaranthaceae, subfamily Salicorniodeae) are among the most promising halophyte crops. Species of these genera have been cultivated with saline water (VENTURA et al., 2011; VENTURA; SAGI, 2013; COSTA et al., 2014b; VENTURA et al., 2015) and saline effluent from shrimp farms (COSTA, 2006; GREIS, 2009; COSTA et al., 2014a; DONCATO; COSTA, 2018). They have typical succulent young shoots and are sold in the gourmet food market because of their peculiar salty taste and health value. Common names for the two genera include sea asparagus, glasswort, pickleweed, and marsh samphire. Piirainen et al. (2017) showed that *Sarcocornia* is paraphyletic in relation to *Salicornia* and proposed a new taxonomic classification, merging *Sarcocornia* in three subgenera under *Salicornia*. In the present study, we followed the nomenclature proposed by these authors.

A recent phylogenetic analysis using ETS sequences confirmed the identity of Brazilian accessions of sea asparagus as *Salicornia neei* Lag. (COSTA et al., 2018). This species is widely distributed and occurs along the coasts of Brazil, Uruguay and Argentina, as well as on the Pacific coast of Chile and Peru. Due to its reduced morphology and great phenotypic plasticity, *S. neei* was previously described as many taxa [synonym of *Sarcocornia ambigua* (Michx.) M.A. Alonso & M.B. Crespo, *Salicornia gaudichaudiana* Moq., *Sarcocornia perennis* (Miller) Scott or *Sarcocornia fruticosa* (L.) Scott] (ALONSO; CRESPO, 2008; STEFFEN et al., 2015; COSTA; HERRERA, 2016). In the last decade, studies of *S. neei* have highlighted the high nutritional and chemical quality of its seeds and shoots, as well as its potential for human (COSTA, 2006; BERTIN et al., 2014; TIMM et al., 2015) and animal diets (D'OCA et al., 2012; COSTA et al., 2014a; BERTIN et al., 2014), biofuel production (D'OCA et al., 2012; COSTA et al., 2014a) and use by the pharmaceutical industry (EPAGRI, 2008; BERTIN et al., 2014). Additionally, according to Doncato and Costa (2018), green salt (*i.e.,* biosalt) of this species is richer in some minerals than other species within the same genus; moreover, the amount of sodium chloride in commercial salt is three times more than *S. neei* (DIAS, 2015). All information cited above was obtained from non-selected wild plants and, except for an *in vitro* study on the bioaccessibility of minerals of wild shoots of sea asparagus ingested by humans (BERTIN et al., 2016), no study has evaluated the daily intake of *S. neei* required for human and animal diets.

Since 2010, the Laboratório de Biotecnologia de Halófitas (BTH) at the Federal University of Rio Grande (FURG, Rio Grande – RS, Brazil) has carried out a breeding program of *S. neei* by identifying and crossing pure lineages of ecomorphotypes native to the Patos Lagoon estuary (RS) (FREITAS; COSTA, 2014). The F4 progeny of the breeding program generated a novel variety named BTH1, which is characterized by a red shoot phenotype at maturity, prostrate growth form and high reproductive investment. Recently, Steffen et al. (2015), in a molecular-phylogenetic analysis, pointed out that the prostrate growth form arose multiple times in *Salicornia* and *Sarcocornia* and might represent different stages of speciation. Plant field trials of this novel *S. neei* are needed to evaluate its nutritional quality under saline irrigation. Thus, in order to characterize the mineral content and the nutritional potential of this novel variety for feeding humans and animals (*i.e.*, sheep and fish), we analyzed shoot macrominerals and microminerals of a field crop irrigated with saline effluent from shrimp farming and assessed how well BTH1 met daily intake requirements of minerals stated by the Institute of Medicine – IOM (U.S. National Academy of Medicine) and the National Research Council (NRC).

Material and Methods

Seeds of the *S. neei* F4 progeny of the lineage BTH1 (BTH1-F4) were obtained from germplasm at the Laboratório de Biotecnologia de Halófitas and germinated following the protocol of Freitas and Costa (2014). Seedlings were maintained for a total of 25 weeks in an unheated greenhouse before being transplanted at the cultivation site.

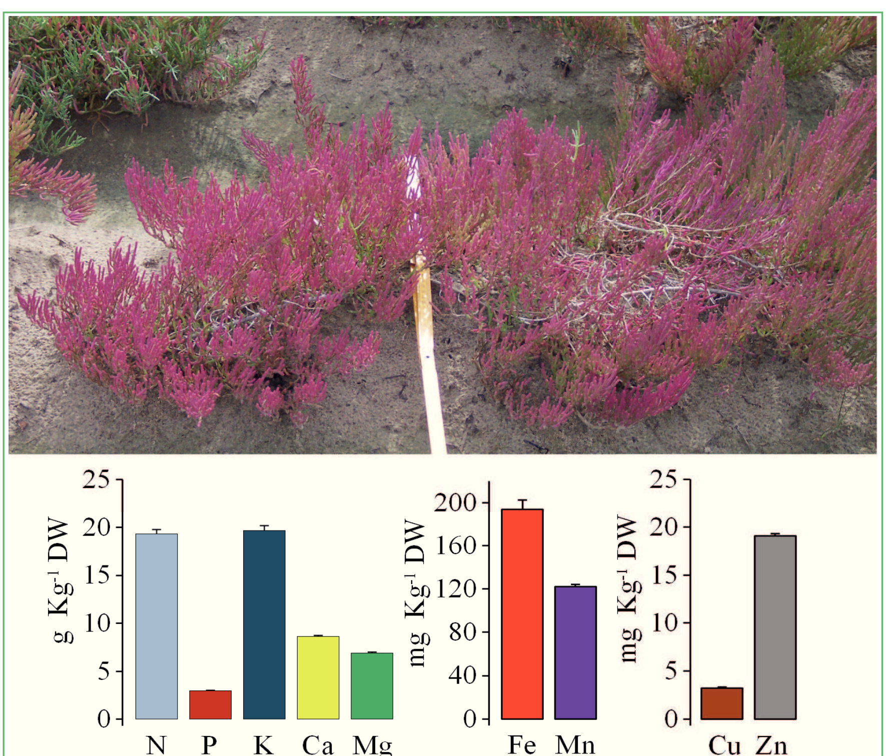
From February to June 2014, plants of BTH1-F4 were grown in a plot located at the Marine Station of Aquaculture (EMA, FURG) in Rio Grande – RS, Brazil. A total of 20 plants were distributed in two adjacent rows spaced 60 cm apart with 25 cm between each plant. The plants were irrigated by filling up drainage ditches between the rows four times a day (25 L per minute for 15 minutes) with saline effluent from a tank of *Litopenaeus vannamei* (stocked with 120 shrimp.m^2) cultivated in a Biofloc Technology System (BFT). The measured water parameters during cultivation (mean ± standard error; n = 9) were the following: salinity 7.67 ± 0.27 g.L^{-1} NaCl (≈ 11.40 dS.m^{-1}), pH 8.42 ± 0.01, dissolved oxygen 8.05 ± 0.04 mg.L^{-1}, nitrate 4.00 ± 5.66 mg.L^{-1}, total ammonia nitrogen 0.04 ± 0.03 mg.L^{-1} and phosphate 1.21 ± 0.04 mg.L^{-1}.The soil of the plot was Orthic Quartzarenic Neosol and the saline effluent was the main source of nutrients and water for the *S. neei* plants.

At the end of cultivation (June 2014), five plants were randomly chosen and harvested just above ground level, bagged and transported to the laboratory. Shoot samples were washed to remove soil, weighed on a precision scale to determine the fresh weight, oven dried at 60°C for 48 h and weighed again to determine the dry weight (DW). The macrominerals and microminerals were determined from the dry mass (n = 5) of BTH1-F4 shoots, according to Tedesco et al. (1995), using spectrophotometry. The shoot biomass chemical analyses were performed by the Departamento de Solos of Federal University of Pelotas (UFPel, RS, Brazil).

Results

Shoots of *S. neei* had an average succulence of 86.6% water. The mineral composition of dry shoots of the novel *S. neei* is shown in Figure 1 and represents

FIGURE 1: Photograph of the novel *Salicornia neei* BTH1-F4 and average values (± standard-error) of macro- and microminerals in its shoot (DW: dry weight of shoot).



a great food source of minerals. Notably, this species accumulated a considerable amount of minerals, particularly N, P, K, Ca, Fe and Mn.

The comparison of the mineral profile of *S. neei* BTH1-F4 with the daily mineral requirement standards for humans (IOM, 2005) and farm animals, such as sheep (NRC, 1985) and fish (particularly carp and tilapia; NRC, 1993), highlights the high nutritional quality of this plant obtained from relatively small recommended daily intakes (Table 1).

Discussion

Most minerals that were quantified in the shoots of *S. neei* BTH1-F4 cultivated with saline effluent irrigation showed higher concentrations than tissues of wild plants of this species and common vegetables. BTH1-F4 showed higher concentrations of N, P, K and Ca than wild plants of *S. neei* (N = 15.4 $g.kg^{-1}$ DW; P = 1.0 $g.kg^{-1}$ DW; K = 9.7-15.8 $g.kg^{-1}$ DW and Ca = 2.4-4.6 $g.kg^{-1}$ DW) (MEDINA et al., 2008; BERTIN et al., 2014), and ranked in the mid-upper range of these macrominerals compared to other species of the subfamily Salicorniodeae (*i.e.*, *Salicornia bigelovii* and *Salicornia stricta*) and vegetables, such as asparagus (*Asparagus officinalis*) and spinach (*Spinacia oleracea*) (N = 11.6-53.0 $g.kg^{-1}$ DW; P = 1.6-7.8 $g.kg^{-1}$ DW; K = 7.0-32.8 $g.kg^{-1}$ DW and Ca = 2.1-12.5 $g.kg^{-1}$ DW) (GORHAM; GORHAM, 1955; MAKUS, 1994; LU et al., 2010; SHEIKHI; RONAGHI, 2012). In contrast, the average Mg content in BTH1-F4 was near (6.9 $g.kg^{-1}$ DW) (MEDINA et al., 2008) or lower than wild *S. neei* and other Salicorniodeae species (10.2-11.4 $g.kg^{-1}$ DW) (LU et al., 2010; BERTIN et al., 2014).

The micromineral composition of BTH1-F4 shoots showed high levels of Fe and Mn (Figure 1). Except for Fe content in spinach (Fe = 249.1 $mg.kg^{-1}$ DW) (SHEIKHI; RONAGHI, 2012), which was approximately 20% higher than that of BTH1-F4, the average contents of these minerals in the novel variety were higher than found in the Salicorniodeae species and vegetables cited above (Fe = 50.0-99.9 $mg.kg^{-1}$ DW and Mn = 20.0-104.8 $mg.kg^{-1}$ DW) (GORHAM; GORHAM, 1955; MAKUS, 1994; LU et al., 2010; SHEIKHI; RONAGHI, 2012). The concentrations of Cu and Zn in BTH1-F4 shoots were lower than those cited for cultivated plants of *S. bigelovii* (Cu = 7.9 $mg.kg^{-1}$ DW and Zn = 35.0 $mg.kg^{-1}$

TABLE 1: Daily mineral requirement standards and the percentage of these recommended intakes (PI; inside brackets) for an adult man, an adult sheep and a commercial-sized fish supplied by the consumption of dried shoots of *S. neei* BTH1-F4. The amounts of dry shoot biomass of *S. neei* considered for estimation of man, sheep and fish PIs were 20, 200 and 5 g, respectively, and their salt content should not adversely affect growth and feed efficiency of these organisms.

Diet	Macrominerals ($g.kg^{-1}$)					Microminerals ($mg.kg^{-1}$)			
	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
Man [1]	9.74*	0.70	4.70	1.20	0.42	8.00	2.30	0.90	11.00
PI (%)	(4)	(9)	(8)	(14)	(33)	(48)	(106)	(7)	(3)
Sheep [2]	16.52*	2.70	6.50	5.10	1.50	40.00	30.00	9.00	26.50
PI (%)	(23)	(22)	(60)	(34)	(92)	(97)	(82)	(7)	(14)
Fish [3,4]	1.75*	0.17	0.18	0.21	0.02	4.50	0.39	0.09	0.75
PI (%)	(6)	(9)	(55)	(20)	(208)	(22)	(157)	(18)	(13)

PI = Percentage of recommended mineral intake supplied. * A protein-to-nitrogen conversion factor of 5.75 for plant foods was applied (ANVISA, 2003). [1] Daily mineral requirement standards for an adult man (over 51 years old) (IOM, 2005). [2] Daily mineral requirement standards for an adult sheep (50 kg; consumption of 2% body weight of dry matter per day) (NRC, 1985; LEE, 2014). [3] Daily mineral requirement standards for a commercial-sized fish (1 kg; consumption of 3% body weight of dry matter per day) (NRC, 1993). [4] Combined values for carp and tilapia, except K (chinook salmon).

DW) (LU et al., 2010), *A. officinalis* (Cu = 18.0 mg.kg^{-1} DW and Zn = 77.3 mg.kg^{-1} DW) (MAKUS, 1994) and *S. oleracea* (Cu = 9.9 mg.kg^{-1} DW and Zn = 108.6 mg.kg^{-1} DW) (SHEIKHI; RONAGHI, 2012).

The daily consumption of 20 g of dried shoots of the BTH1-F4 progeny would partially supply the recommended daily intake of P (9%), K (8%), Ca (14%), Mg (33%), Fe (48%) and Mn (100%) for an adult man (over 51 years old) (IOM, 2005) (Table 1). Moreover, this amount of shoot mass would not exceed the recommended daily intake of salt for humans (less than 2 g.day^{-1}) (WHO, 2012), since Na content in *S. neei* shoots ranges between 87-139 g.kg^{-1} DW (BERTIN et al., 2014). Young sheep (≈ 35 kg) would be able to consume 74-90 g Na per day (MASTERS et al., 2005) and these amounts do not adversely affect the growth and feeding efficiency of salt tolerant varieties of carp and tilapia (NRC, 1993).

The recommended daily Fe and Mn intakes for an adult human are 8.0 mg and 2.3 mg (IOM, 2005), and half of Fe and the full amount of Mn can be reached by ingesting approximately 20 g DW of BTH1-F4 shoots. Deficiency in iron is probably the most common nutritional deficiency disorder in humans, causing anemia (MCDOWELL, 2003; FAO; WHO, 2004). Mn is an element that has low toxicity (oral ingestion) to humans (WHO, 1996), but its deficiency in domestic animals causes reduced appetite and growth, impairs the iron metabolism and alters brain function. Due to the Zn levels in BTH1-F4 tissues, high intakes of plant biomass would be necessary to meet the daily requirements of humans (11 mg) (IOM, 2005), but its use as a supplement in animal feed is possible. Zn deficiency in humans and animals results in reduced appetite, lethargic growth, skin abnormalities and impaired reproduction (WHO, 1996; MCDOWELL, 2003; FAO; WHO, 2004). In humans, Cu is needed in very small amounts (daily intake of 0.9 mg), according to IOM (2005), and its deficiency is associated with anemia and hematologic abnormalities (WILLIAMS, 1983; WHO, 1996). Excess Cu is toxic (WHO, 1996) and, according to the Brazilian Ministry of Health (BRASIL, 1998), the Cu concentration level in vegetables for sale corresponds to 10 mg.kg^{-1} FW; the World Health Organization defines a maximum Cu daily intake of 10 mg (WHO, 1996). Thus, *S. neei* BTH1-F4 had an average content several times lower than the limit for the Brazilian market of fruits, vegetables and oilseeds *in natura* and in industry.

Since adult sheep could intake a large amount of salt enriched *S. neei* BTH1-F4 biomass, 200 g of dried BTH1-F4 shoots can meet approximately 60% of its K maintenance requirement, while 5 g of dried BTH1-F4 shoots can meet half of K requirement for fish (Table 1). Potassium is the third most abundant mineral in the human body and often needs to be supplemented in some ruminant diets (MCDOWELL, 2003; MASTERS et al., 2005). Regarding Ca, P is one of the largest mineral constituents of bones, and its deficiency in vertebrate animals and young people results in rickets and in adults causes osteomalacia (WHO, 1998; MCDOWELL, 2003). For all organisms, P is used in the construction of genetic material (DNA and RNA) and in energy storage (ATP), and the daily consumption of dried *S. neei* BTH1-F4 shoots for a sheep (200 g DW) and a commercial-sized fish (5 g DW) can meet 22% and 9% of their P requirement, respectively. In monogastric animals and humans, Mg deficiencies are rare, but in ruminants this nutritional deficiency is related to hypomagnesemia (MCDOWELL, 2003). The high Ca and Mg content in *S. neei* BTH1-F4 means a daily consumption of 200 g of BTH1-F4 dry matter would supply 34% of the Ca and 92% of the Mg required for an adult sheep, as well as 20% and 200% for fish, respectively. Concerning microminerals, these amounts of dried BTH1-F4 shoots would supply roughly the daily needs of Fe and Mn for an adult sheep and exceed the Mn requirement for a commercial-sized fish. Overall, the novel *S. neei* BTH1-F4 has a rich mineral profile that could have great potential for feeding both humans and farm animals, particularly sheep.

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