Int. j. adv. multidisc. res. stud. 2022; 2(5):443-449

Received: 15-08-2022
Accepted: 25-09-2022

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Characterization of the Powder of *Salicornia* sp. (AMARANTHACEAE)

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Abstract

The general objective of this research work is to contribute to the promotion of wild vegetables to fight against malnutrition. Its specific objective is to determine the physico-chemical, nutritional and functional properties as well as the polyphenol and flavonoid contents of *Salicornia* sp. The results of the analyzes show that the contents of proteins, lipids and total carbohydrates (in g/100g of dry matter) of this plant are respectively 10.63±0.41; 2.49±0.26 and 31.65±0.00. The amount of metabolizable energy of this plant is 159.77kcal per 100g of product. It contains 50.94±0.32% of raw ash containing mineral elements (in mg/100g), such as sodium (11584.10±1.22), magnesium (897.11±0.53), potassium (607.00±0.95), calcium (406.42±1.85), iron (142.20±0.03), phosphorus (52.34±0.06) and zinc (2.47±0.07). The Ca/P and Na/K ratios are 7.7650 and 19.0842 respectively. *Salicornia* sp is an alkalizing plant with a potential renal acid load – 12.94. The powder of this plant has important functional properties (in %), such as water retention capacity (149.73), oil retention capacity (94.71) and solubility (45.79±1.04). The hydrophilic-lipophilic ratio of the powder of this plant is 1.65. This powder contains 51.40 ± 0.12mg pyrogallol equivalent per 100g of dry matter of total polyphenols and 3.02± 0.58mg quercetin equivalent per 100g of dry matter of flavonoids. This study shows that this plant can contribute to the body's needs through its supply of mineral salts.

Keywords: Malnutrition, Vegetable, Physicochemical Property, Nutritional Property, Functional Property, Phytochemical Element

1. Introduction

Salicornia sp is a halophilic plant, from the AMARANTHACEAE family, which grows in salty environments. This plant grows naturally by the sea (On salty land). It is present in the temperate zone of all continents (Lahondère, 2004) [24]. It appears fleshy, quite thick, formed of articulated stems that end in a fertile red spike (Tela botanica, 2016) [51].

This plant is found on the coast of Madagascar, in the bay of Diego-Suarez, north of the Big Island, in Tulear. It comes into vegetation in June. It is in full development from August to January. It is abundant on the coast of the District of Morondava (Chevalier, 1922) [11].

The young branches of this plant are edible. They are eaten like vegetables in the village of Anamakia, District of Diégo I, Region of DIANA, Madagascar. They are preserved in vinegar, eaten as appetizers, or in omelet or in salads after desalination in boiling water. They can also be prepared like green beans. This plant has not been valued enough in the Malagasy diet, because it is not known everywhere in Madagascar. Apart from food use, it is also used for therapeutic use. The infusion of the plant restores the mineral salts lost following diarrhea. The plant also has diuretic properties (Chevalier, 1922) [11].

Madagascar is a country rich in edible plant biodiversity. Despite this, the populations suffer from acute malnutrition. Macronutrient, vitamin, fiber and mineral deficiencies promote birth defects, mental and physical retardation, weakened immune system, blindness and even death. Fruits and vegetables are essential sources of nutrients against these diseases.

The general objective of this research work is to contribute to the promotion of wild vegetables to fight against malnutrition. Its specific objective is to determine the physicochemical, nutritional and functional properties as well as the polyphenol and flavonoid contents of *Salicornia* sp. The results obtained will therefore make it possible to know the importance of this plant in the field of human nutrition.

2. Materials and methods
2.1. Biological materials
In this study, young stems with small opposite leaves reduced to scales of *Salicornia* sp were used as biological materials. They are therefore considered raw materials.

2.2. Harvesting and transformation of raw materials into powder
The raw materials were harvested at the seaside of Anamakia, District of Diégo I, in the DIANA Region (Madagascar), on March 02, 2019. The young stems of the plant with small leaves were harvested manually. They were then dried away from the sun according to the model of traditional therapists, in the open air, at room temperature, then in an oven at 40°C. The young dry stems were crushed using a blender. The powder thus obtained was kept in a tightly closed box while awaiting the analyses.

2.3. Determination of the physical, physico-chemical, nutritional and functional properties of the powder
Several parameters were determined to know the characteristics of the powder of *Salicornia* sp. The water, dry matter, crude ash, crude protein, crude fat and total carbohydrate contents were determined according to the method of AOAC (2005) [4]. The pH and total acidity were determined according to the method of Oyewole (1990) [30] and Vasconcelos *et al*. (1990) [53]. The reducing sugars were assayed according to the method of BIPEA (1978) [5]. The value of metabolizable energy was calculated according to the difference method used by AOAC (2005) [4]. The mineral elements were determined by atomic absorption spectrophotometry, except phosphorus which was determined by colorimetry. A simple calculation employed by Houndji *et al*. (2018) [19] was carried out to determine the Ca/P and Na/K ratios. The PRAL (Potential Renal Acid Load) index was calculated according to the formula proposed by Remer and Manz (1995) [45] and Pamplona-Roger (2016) [34]. Four parameters were measured to determine the functional properties of the powder produced. These are the water-holding capacity and the water solubility index, determined by the methods of Anderson *et al*. (1969) [3] and Philips *et al*. (1988) [35], the oil retention capacity, calculated according to the method of Sosulski (1962) [48] and the hydrophilic-lipophilic ratio, defined by Njintang *et al*. (2001) [28].

2.4. Dosages of polyphenols and total flavonoids contained in the powder
The dosage of total polyphenols of the ethanolic extract of the powder produced was carried out using the Folin-Ciocalteu reagent according to the method described by Singleton and Rossi (1965) [47]. Total flavonoids were determined according to the method described by Dehpour et al. (2009) [13].

3. Results
The physical, physico-chemical, nutritional, functional characteristics and the levels of polyphenols and total flavonoids of the powder of *Salicornia* sp. are presented in Table 1. These results indicate that the water, lipid and reducing sugar contents of this powder are very low. This powder has a pH of less than 7, low total acidity and high protein, total carbohydrate and raw ash contents. The amount of metabolizable energy of this plant is 159.77kcal per 100g of product. Its contents of sodium, magnesium, potassium, calcium and iron are high. On the other hand, those of phosphorus and zinc are weak. The Ca/P and Na/K ratios and the hydrophilic-lipophilic ratio of this powder are all greater than 1. Its PRAL index is negative (–12.94). Its water and oil retention capacities and its solubility are high. The levels of polyphenols and total flavonoids contained in this powder are respectively 51.40mg Eq Pyrogallol/100g of dry matter and 3.02mg Eq Quercetin/100g of dry matter.

Table 1: Physical, physico-chemical, nutritional, functional characteristics and total polyphenol and flavonoid levels of *Salicornia* sp. Powder

Parameters	Values
Water content (%)	4.27±0.13
Dry matter content (%)	95.73±0.13
pH	4.73±0.01
Total acidity (g of lactic acid /100 g of DM)	0.84±0.09
Protein (g/100 g of DM)	10.63±0.41
Lipid (g/100 g of DM)	2.49±0.26
Reducing sugar (g/100 g of DM)	0.93±0.01
Total carbohydrate (g/100 g of DM)	31.65±0.00
Metabolizable energy (kcal/100 g of product)	159.77
Raw ash (g/100 g of DM)	50.94±0.32
Sodium (mg/100 g of DM)	11 584.10±1.22
Magnesium (mg/100 g of DM)	897.11±0.53
Potassium (mg/100 g of DM)	607.00±0.95
Calcium (mg/100 g of DM)	406.42±1.85
Iron (mg/100 g of DM)	142.20±0.03
Phosphorus (mg/100 g of DM)	52.34±0.06
Zinc (mg/100 g of DM)	2.47±0.07
Ratio Ca/P	7.7650
Ratio Na/K	19.0842
PRAL (mEq/100 g of DM)	–12.94
Water retention capacity (%)	149.72±0.60
Oil retention capacity (%)	94.71±1.30
hydrophilic-lipophilic ratio	1.65
Solubility (%)	45.79±1.04
Total Polyphenols (mg Eq Pyrogallol/100 g of DM)	51.40±0.12
Total Flavonoids (mg Eq Quercetin/100 g of DM)	3.02±0.58

Each result represents the Mean ± Standard Deviation of 3 independent determinations (n = 3).
Eq: Equivalent; DM: Dry matter

4. Discussion
The water content of *Salicornia* sp. is very low (4.27%), which means that the dry matter content of this powder is very high (95.73%). The low water content of this powder is very important to allow its long-term storage in a dry place. It would thus be difficult for microorganisms to multiply there, because they need a water activity and, consequently, water content, high enough to proliferate (Cheftel and Cheftel, 1976) [10]. In addition, the chemical and enzymatic reactions of deterioration are greatly slowed down in foods with low water content (Cheftel and Cheftel, 1976; Randrianantoandro, 2004) [10, 41]. The powder thus produced can therefore be kept for a long time in jars, because its water content is less than 14%, the limit value reported by Soudy (2011) [49]. The water content of this powder is lower than that of the powder from the leaves of Moringa olifera (Family of MORINGACEAE) found by Yaméogo *et al*. (2011) [55] which is 5.90±1.80%. The difference in these results may be due to the inequality of species and drying methods.

Salicornia sp. is an acidic product because its pH (4.73±0.01) is less than 7. This pH is lower than that of green beans (*Phascolus vulgaris* L.) (FABACEAE family) which is 6.56±0.02 (Boulila and Chalal, 2017) [7]. *Salicornia* sp is therefore more acidic than green beans. The total acidity value of *Salicornia* sp powder (0.84±0.09) is greater than that of green beans (0.45g of total acidity per 100g of dry matter). The difference in these results can be explained by the inequality of the species studied and the environmental properties of the places where the samples were collected.

Salicornia sp powder is considered a source of protein and carbohydrates because its levels of these compounds are high. The protein (10.63±0.41%) and total carbohydrate (31.65±0.00%) contents of this powder are lower than those of *Lagenaria siceraria* (Family CUCURBITACEAE), a leafy vegetable which is widely used in Brazzaville (Congo). For this plant, the contents of these two compounds are respectively 24.50g and 63.22g/100g of dry matter (Itoua Okouango *et al*., 2019) [20]. This difference can be explained by the differences of the families and the environmental properties of the place of collection of the samples.

The fat content of *Salicornia* sp. is low (2.49±0.26% based on dry matter), but it is higher than that of *Lagenaria siceraria*, with a value of 1.93g per 100g of dry matter (Itoua Okouango *et al*., 2019) [20]. It should be noted that almost all vegetables are low in fat.

The level of reducing sugars in this plant (0.93±0.01%) is higher than the results obtained by Ocho-Anin Atchibri *et al*. (2012) [29] on *Celosia argentea* (Family AMARANTHACEAE), a vegetable harvested in three sites in Côte d'Ivoire, such as market gardener (Port-Bouet), Gouro market and Abodo station market. The levels of reducing sugars found by these authors on *Celosia argentea* in these three sample collection sites are respectively 0.67; 0.83 and 0.66g per 100g of dry matter (Ocho-Anin Atchibri *et al*., 2012) [29]. This difference may be due to the inequality of the species studied and the sample collection sites.

The amount of metabolizable energy provided by *Salicornia* sp. is not negligible (159.77kcal/100g). Compared to that provided by green beans, which is 120kcal/100g, published by Torres (2004) [52] and by Cauplan (1998) [9], this quantity is quite high. This difference can be explained by the fact that *Salicornia* sp. is richer in energy nutrients (proteins, carbohydrates and lipids) than green beans.

The raw ash content of *Salicornia* sp. (50.94±0.32%) is much higher than that of the *Cuervea isangiensis* powder (CELASTRACEAE family), which is 10.04% (Mbemba *et al*., 2012), than that of the powder of the leaves of *Stenochlaena tenuifolia* (BLECHNACEAE family) (10.35%) (Randrianantenaina *et al*., 2021b) [39] and those of the fruit powders of three Malagasy baobab species (MALVACEAE family), such as *Adansonia grandidieri* (4.42%), *Adansonia rubrostipa* (6.98%) and *Adansonia za* (6.71%), collected in Districts of Mahabo and Morondava, Region of Menabe (Razafimahefa *et al*., 2020) [44]. *Salicornia* sp. is therefore richer in mineral elements than *Cuervea isangiensis*, *Stenochlaena tenuifolia* and the three species of Malagasy baobab mentioned above. The ash content is thus variable according to the species; it can also vary depending on the age of the plant, the season and the place where the samples were collected.

By comparing with the contents of mineral elements (in mg per 100g) of green beans (*Phaseolus vulgaris* L.) (FABACEAE family) (Potassium: 208; Sodium: 6; Phosphorus: 38; Calcium: 37; Iron: 1 and Zinc: 0.10-0.20) (Torres, 2004; Cauplan, 1998) [52, 9], the values found, in mg per 100g of sample of *Salicornia* sp. powder, are much higher, especially for sodium (11 584.10mg/100g). However, when compared with the potassium (3140.59mg/100g) and phosphorus (540.90mg/100g) contents of the leaf powder of *Stenochlaena tenuifolia* (Randrianantenaina *et al*., 2021b) [39], the values found on *Salicornia* sp. are weak. The content of mineral elements therefore depends on the type of vegetable. It is also variable according to the species, the age of the plant, the environmental conditions, the place and the season of collection of the samples.

Also, are the Ca/P and Na/K ratios interesting? The calculations of these ratios would make it possible to show the role that food would play in improving cardiovascular functioning (He and Macgregor, 2008) [17] and in the mechanism of calcification and skeletal integrity (Kemi *et al*., 2006) [22]. For the *Salicornia* sp. powder, these two ratios are all greater than 1 (Table 1). These results indicate that the calcium and sodium contents are higher than those of phosphorus and potassium. The high sodium content of the powder of this plant (11584.10±1.22mg/100g) is due to the salinity of the harvesting medium. It should be remembered that this plant grows naturally at the seaside; it therefore always develops on salty ground. The powder of this plant may intervene in calcification during the formation of the skeleton (Kemi *et al*., 2006) [22], because the Ca/P ratio is greater than 1. However, it may promote an increase in blood pressure, because its sodium content is higher than that of potassium. It should be noted that sodium is an element that promotes high blood pressure (Pamplona-Roger, 2013b) [33]. Thus, the consumption of *Salicornia* sp. is not recommended for people with hypertension. But, consumed with other foods richer in potassium than sodium, this plant cannot pose a problem for these hypertensive people.

According to Pamplona-Roger (2013a) [32], the ideal Ca/P ratio is 1:1, indicating that calcium and phosphorus contents should be equal. However, according to Dany Cinq-Mars (2001) [12], the Ca/P ratio should be around 2:1. But, the important thing is never to have more phosphorus than calcium (Dany Cinq-Mars March, 2001) [12]. Moreover, ratios of calcium and phosphorus, which oscillate between 1:1 and 7:1, are considered very acceptable, provided that the phosphorus requirements are met (Dany Cinq-Mars, 2001) [12]. According to the results mentioned in Table 1, the Ca/P ratio for the powder of *Salicornia* sp. is greater than 7. This Ca/P ratio can therefore be corrected by adding foods richer in phosphorus than in calcium.

The PRAL (Potential Renal Acid Load) index reflects the acidifying or alkalizing power of a food (Piquet, 2012; Pamplona-Roger, 2016) [37, 34]. It depends on its nutritional composition and mainly on its composition in mineral elements and its protein content (Piquet, 2012) [37]. It is very essential, because it estimates the acid or alkaline load generated in the body by 100g of food (Piquet, 2007) [36]. Using the formula proposed by Remer and Manz (1995) [45] and Pamplona-Roger (2016) [34], the value of the PRAL index of *Salicornia* sp powder is negative (–12.94meq/100g). This plant therefore has an alkalizing power and generates more bases than acids. This indicates that, according to Piquet (2012) [37] and Pamplona-Roger (2016) [34], this plant helps to maintain the necessary balance between acid and alkaline in our body. Thus, it lightens the work of the kidneys to eliminate excess acids and promotes good human health.

Functional properties provide information on future applications of food formulations (Hermansson and Svegmark, 1996) [18]. During this study, the functional properties evaluated are the water retention capacity, the oil retention capacity, the hydrophilic/lipophilic ratio and the solubility (Table 1). Water retention capacity is one of the criteria that determines the sensory quality, in particular the texture of food products (Laignelet and Alary, 1984; Selmane, 2010) [25, 46]. Food products with a high water-holding capacity retain their friability during storage (Boye *et al*., 2010) [8]. Water retention is due to the presence of hygroscopic constituents with hydrophilic groups such as carbohydrates and proteins. By the presence of these hydrophilic groups, these compounds can therefore bind with water molecules via hydrogen bonds.

The water retention capacity found during this study is 149.72g per 100g of flour (Table 1). This value is higher than those of "*Mamoriaka mena*" rice flour (17.56g per 100g of flour) (Razafimahefa *et al*., 2021) [43], "*Telovolana*" cassava cultivar flour (136.39g per 100g of flour) (Ratolojanahary, 2018) [42] and flours of three cassava cultivars (*Menarevaka*, *Mena* and *Fotsy*), which are respectively 105.99, 103.81 and 116.42g per 100g of flour (Randrianantenaina, 2019) [40]. On the other hand, it is lower compared to the value found by Randrianantenaina *et al*. (2021a) [38] on *Typhonodorum madagascariense* (Family ARACEAE) seed flour (235.33g per 100g of flour) and that reported by Randrianantenaina *et al*. (2021b) [39] on the powder of the leaves of *Stenochlaena tenuifolia* (BLECHNACEAE family) (486.29 g per 100g of powder). *Salicornia* sp. is therefore capable of absorbing water and is richer in hygroscopic constituents than "*Mamoriaka mena*" rice flour and those of the four cassava cultivars mentioned above. On the other hand, it is poorer in these hygroscopic constituents than the flour of the seeds of *Typhonodorum madagascariense* and the powder of the leaves of *Stenochlaena tenuifolia*.

Concerning the oil retention capacity, the value found (94.71±1.30%) is higher than that found by Diallo *et al*. (2015) [14] on Voandzou flour (*Vigna subterranea* L. verdc) (FABACEAE family) (88.83±4.96%). It is, on the other hand, lower than those found by Randrianantenaina *et al*. (2021a) [38] on *Typhonodorum madagascariense* seed flour (97.35±0.69%), by Randrianantenaina *et al*. (2021b) [39] on *Stenochlaena tenuifolia* leaf powder (170.00±8.16%) and by Razafimahefa *et al*. (2021) [43] on "*Mamoriaka mena*" rice flour (127.52%). These data indicate that *Salicornia* sp. is able to absorb oil and is more lipophilic than Voandzou flour. On the other hand, it is less lipophilic than the flour of the seeds of *Typhonodorum madagascariense*, the powder of the leaves of *Stenochlaena tenuifolia* and the rice flour "*Mamoriaka mena*". *Salicornia* sp. therefore contains substances with non-polar chains such as lipids. Moreover, this powder contains lipids, although their content is low (2.49±0.26%). According to Medoua Nama (2005) [27], the variation in the oil absorption capacity of food products is linked to the presence of non-polar chains. Oil-holding capacity is an important property in feed formulation. Literature indicates that flours with very high oil retention capacity hold a flavor retention and mouthfeel enhancer feature in food products (Khattab and Arntfield, 2009; Kaushal *et al*., 2012; Yadahally *et al*., 2012) [23, 21, 54].

The hydrophilic-lipophilic ratio is a ratio which makes it possible to evaluate the comparative affinity of flours for water and for oil (Medoua Nama, 2005) [27]. During this study, the value found (1.65), which is greater than 1, indicates that the powder of *Salicornia* sp. has more affinity with water than with oil.

The solubility of *Saliconia* sp powder (45.79±1.04%) is lower than that of Voandzou flour (Vigna subterranea L. verdc) (FABACEAE family) (64.63±6.95%) (Diallo *et al*., 2015) [14]. On the other hand, it is higher than that of the flour of the seeds of *Typhonodorum madagascariense* (17.01±1.02%) (Randrianantenaina *et al*., 2021a) [38] and that of the powder of the leaves of *Stenochlaena tenuifolia* (20.36± 0.20%) (Randrianantenaina *et al*., 2021b) [39]. *Saliconia* sp. powder is therefore richer in water-soluble substances than *Typhonodorum madagascariense* seed flour and *Stenochlaena tenuifolia* leaf powder. On the other hand, it is less rich in these water-soluble substances than Voandzou flour.

Polyphenols are present in all higher plants (Hartmann, 2007) [16]. Each plant has their specific contents. These phytochemicals are natural antioxidants (Achat, 2013) [1]. Antioxidants are substances that have the ability to prevent the oxidation of various types of molecules in our body, such as free radicals (Pamplona Roger, 2010; Pamplona-Roger, 2013a) [31, 32]. These antioxidant compounds are characterized by their strong affinities with free radicals and can repair oxidative damage in the body, reducing the risk of chronic oxidative diseases (Dimitrios, 2006; Suganya *et al*., 2007) [15, 50]. The total polyphenol content of *Salicornia* sp. (51.40±0.12mg/100g of dry matter) is superior to that of eggplant (Solanum melongena) (Family of SOLANACEAE), which is equal to 26.61mg/100g of dry matter (Boulekbache-Makhlouf *et al*., 2013) [6]. According to Aganga and Mosase (2001) [2], the level of polyphenols depends a lot on extrinsic factors (such as geographical and climatic factors), genetic factors, the degree of maturation of the plant, the duration of storage and the varietal factor. Due to its polyphenol content, which is not negligible (51.40±0.12mg/100g of dry matter), the consumption of *Salicornia* sp. could therefore be recommended to consumers to reduce the risk of chronic oxidative diseases.

The total flavonoid content of *Salicornia* sp. (3.02±0.58mg quercetin eq/100g dry matter) is lower than that of eggplant (16.26mg quercetin equivalent per 100g dry matter) (Boulekbache-Makhlouf *et al*., 2013) [6]. Eggplant therefore contains more flavonoids than *Salicornia* sp. It is also lower than that of green beans, which is 71.35mg quercetin equivalent per 100g of dry matter (Boulila and Chalal, 2017) [7]. Green beans also contain more flavonoids than *Salicornia* sp. These differences may be due to the varietal difference.

5. Conclusion

The results of the analyzes show that *Salicornia* sp is very rich in mineral salts, in particular sodium, magnesium, potassium and calcium. Its protein content is not negligible. This plant can therefore be used to fight against deficiencies in mineral salts. It can be considered as a source of protein. It contains polyphenols and flavonoids, important phytochemicals to fight against oxidative damage caused by free radicals in the human body. By the presence of these antioxidants, the consumption of this plant is therefore highly recommended for consumers to avoid many diseases. *Salicornia* sp powder also has important functional properties such as water and oil retention capacities. These parameters make it possible to know the quantity of water and oil absorbed during the processes of preparing food products. This plant can therefore be used not only as a condiment pickled in vinegar, but, above all, in a cooked state prepared in very different ways.

6. Acknowledgements
We would like to thank all the staff of the National Center for Environmental Research, in Tsimbazaza, Antananarivo (Madagascar) who accepted our request for analysis of our samples in their laboratory.

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