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REVIEW PAPER

Evaluation of Nipa perennial seed-forage plant (*Distichlis palmeri*) in order to develop agricultural sustainability of coastal saline ecosystems

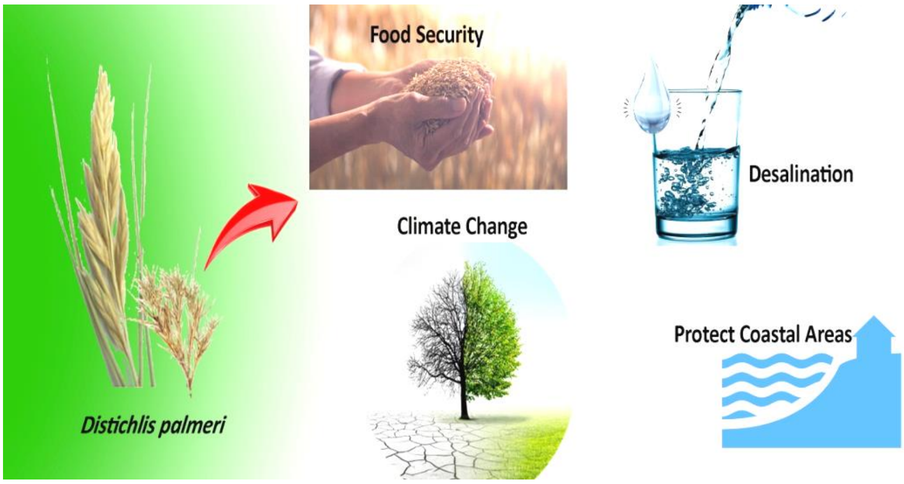
Mohammad Reza Zargaran Khouzani

Department of Agrotechnology, Majoring in Ecological Plants of Khuzestan University of Agricultural, Ahvaz, Iran

Highlights

- Nipa is now considered one of the most important species for centuries, a plant suitable for saline tropical regions and beyond.
- So far, few articles have been published on the Nipa plant in order to introduce this plant as a new crop and perennial tolerant to saline water.
- Nipa development should be a high priority for institutions and officials related to food security, desalination and climate change.

Graphical Abstract



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Abstract

Nipa with the scientific name Distichlis palmeri is a perennial plant of the Poaceae family that tolerates irrigation with salt water. It is a drought-tolerant plant native to the northern shores of the Gulf of California in Mexico, growing in salt marshes influenced by ocean tides. This plant is a wild type and produces grains like wheat. Nipa seeds provide most of the food needed by Cocopah natives in the Rio Colorado Delta. Researchers have studied the physiological, anatomical, genetic and agronomic potential of this valuable plant as a potential food crop. The researchers found that nipa seeds would germinate in a salinity range of 0-30 grams per liter of water and between 60 and 93%. The relative growth rate of the nipa plant in two types of flooded and non-flooded soils affected by salinity (30 grams of salt per liter) reaches about 50% of the plant's relative growth in freshwater. This perennial seed, now considered one of the most important species for centuries, is a plant suitable for saline tropical regions and beyond. Nipa development should be a high priority for institutions and officials concerned with food security, desalination, and climate change. It also provides an opportunity for entrepreneurship and agricultural development to develop, rehabilitate, and protect coastal areas from severe weather events.

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*Corresponding author: mr.zargarankh@gmail.com (M.R. Zargaran Khouzani)

1. Introduction

While sabkhas are usually associated with North Africa and the Middle East, they occur on all continents except Antarctica (Yechieli and Wood, 2002). An extensive set of coastal salt flats occurs in the Northern Gulf of California, where they are called esteros or negative estuaries (Briere 2000; Brusca et al., 2006; Glenn et al., 2006). In this extreme desert environment (less than 100 mm year−1 of rainfall) and with a tidal range of up to 7-9 m, esteros typically form at the mouths of rivers that are no longer connected to the sea. They are flooded and drained twice a day with hypersaline seawater (36-42 g/L) through a network of tidal creeks bringing seawater as much as 10 km^2 inland at high tide and exposing vast mudflats and salt flats at low tide. Occurring mainly along the Sonoran (eastern) coastline above 28° N, esteros extend from the city of Guaymas to the mouth of the Colorado River and occupy over 114,000 ha. Unlike normal estuaries with active river systems, these esteros often contain extensive salt flats and are saltier at their heads than at their mouths, with vegetation confined to the margins of the tidal creeks. The southernmost esteros, below 29° N, contain mangroves (Avicennia germinans, Rhizophora mangle, Laguncularia racemosa, and Conocarpus erectus) as well as 17 low-growing, halophytic shrubs, succulent forbs, and grasses (Glenn et al., 2006). Above 29° N, 14 halophytes are commonly found in the esteros, four of which are endemic to the Sonoran Desert. The dominant species in the low zone of these esteros is an endemic grass, Distichlis palmeri (Palmer's salt grass) known only from the northern Gulf of California (Felger, 2000; 2007). It was named nipa (nee-pah) by the indigenous Cocopah people, who harvested its grain as a major food staple in summer (Glover et al., 2010; Van Tassel and DeHaan, 2013).

Nipa is a unique saltgrass (*Distichlis palmeri* (Vasey) Fassett ex I.M. Johnston) endemic to the shores of the northern Gulf of California, Mexico (Felger, 2000). It is distinguished from *D. spicata* (L.) Greene and other Distichlis species by morphological, anatomical, ecological, and molecular characteristics, and in particular by the large size of its grain (caryopsis), larger than any of the other 10 species of the genus (Bell, 2010; Bell and Columbus, 2008; Felger, 2000). The name nipa ("nee-pah") derives from the indigenous Cocopah name (nypa) for *D. palmeri* (Felger, 2000; 2007) and we propose nipa as the internationally recognized vernacular name for this species. Nipa is one of only a few species of grasses (*Poaceae*) entirely endemic to the Sonoran Desert (Felger, 2000). The greatest stands are on tidal mud flats at the delta of the Río Colorado, especially Islas Gore and Montague and the opposite delta shores of Baja California and Sonora (Felger, 2000; Glenn et al., 2006). In these places nipa forms extensive monospecific stands, often with 100% coverage. It also extends several kilometers inland in a patchy distribution on salt flats and into brackish water influenced by occasional seawater tidal flow, and in some of the stands it occurs with other halophytes. Elsewhere, farther south along the shores of the northern Gulf of California, *D. palmeri* generally occurs intermixed with other halophytes in disjunct tidal marshes, but these populations are much reduced in areal extent compared to those of the immediate Río Colorado delta region. This distributional pattern resembles that of a meta-population with the large Río Colorado delta stands forming the most significant or core population. Ethnographic and historical accounts indicate that the Río Colorado delta population probably has become reduced since construction of the large upriver dams, diversions, and re-filling of the Salton Sea in the 20th century (Felger, 2000), yet there is no indication that *D. palmeri* has been appreciably diminished since the latter part of the 20th century. The core population has conservation protection since it is within the Zona Nucleo of the Reserva de la Biósfera Alto Golfo y Delta del Río Colorado of the Mexican federal government (Dixit, 2020; Felger, 2007).

However, other populations are vulnerable to coastal development (Glenn et al., 2006, Shahba and Qian, 2008). Nipa, scientifically named *Distichlis Palmeri*, is a halophyte weed local to the northern shores of the Gulf of California in Mexico. Compared to other species of the genus *Distichlis*, especially *D. spicata*, it is completely different in terms of morphology, anatomy, ecology, molecular properties and grain size. The word Nipa is pronounced nee-pah and nypa from the local name of the plant in the native language of Cocopah and has been chosen as an international name for different species of this genus (Bersdin and Glenn, 2016). Nipa is one of the few species of the family *Poaceae* or Grasses that is local to Sonoran Desert. Sonoran Desert is a desert in North America on both sides of the US-Mexico border. The desert covers large parts of the US states of Arizona and

California and the Mexican state of Sonoran. With an area of 311,000 Km², Sonoran is one of the largest and warmest deserts in the northern part of the Americas. This wilderness is home to many species of rare plants and animals, including the Saguaro cactus. This wilderness is home to many species of rare plants and animals, including the Saguaro cactus. Nipa's largest habitats are on the sedimentary plains of the Rio Colorado River, especially Slasgore, Montagu, the coasts of the Baja California Delta, and Sonora. Many of these delta lands, which are among the places where Nipa plants grow, are usually exposed to flooding twice a day in brackish sea water in a desert environment with an annual rainfall of 76 mm and a tidal range of more than 7 meters.

Nipa has spread to the above-mentioned areas as a plant with 100% or monospecific species dominance. The development of Nipa continues towards the inland lands of the coastal areas, especially in the areas where most of the saline water flows from the tides. In such a way that it sometimes shares with some other halophyte plants in their ecosystem and biomass. In addition, in the more southern coastal areas of the Gulf of California, we encounter scattered assemblages of Nipa along with other halophyte plants. They have grown in tidal wetlands, but their population density is much lower than that of the Nipa population in the delta. This pattern of Meta Population distribution, formed in the Rio Colorado Delta, is seen as a net central population. Historical and ethnographic studies show that the Nipa population in the Rio Colorado River Delta may have declined over time, possibly due to massive structures such as dams built on the river during the twentieth century, and an increase in salt deposits. Today, pure central populations called the Zona Nucleo Reserva Biosfera near the Rio Colorado Delta are protected by the Mexican government. However, other populations of the Nipa plant have developed in other parts of the Rio Colorado Delta coast that are prone to serious damage (Pearlstein et al., 2012; Bresdin and Glenn, 2016).

Cocopah natives used Nipa as a nutritious seed plant. They lived in the lower reaches of the Rio Colorado River and used Nipa seeds as their dominant force until modern dams were built upstream. But after the construction of water structures and the subsequent decrease in Nipa population, they were forced to move from their area of residence and suffer from socio-cultural splashes (Pearlstein et al., 2012). In mid-May to early July, large quantities of spikelets containing seeds fall from coastal shrubs and accumulate in the area due to tides. The stems with the inflorescence, while the seeds are still immature, are picked by the natives and collected in baskets, after drying, they are threshed to obtain the seeds. The resulting grains are ground into flour and eaten as porridge. Of course, the resulting flour is also used to make bread. The interest in the Nipa plant as a grain began in the early 1970s when the idea of producing halophyte crops by breeding wild halophyte plants was seriously discussed and pursued (Pearlstein et al., 2012). The 2006 United Nations environmental report on Nipa reads: Nipa is an important option for providing human food in the future, so much so that it can be considered as the greatest gift of the dry and salty deserts of the world. Today, the use of some cultivars of the Nipa plant is patented in the United States (Fedoroff et al., 2010). Table 1 compares the nutritional value and compounds present in the stems and seeds of Nipa and Alfalfa dry forage. Nipa stems are relatively low in ash and sodium and are comparable to alfalfa in terms of protein, digestible carbohydrates and energy production.

2. Nipa morphology

Nipa is a perennial grass of the *Gramineae* family with the scientific name *Distichlis palmeri*, which grows in swamps full of salt water affected by the daily tides of the sea. The scientific name of Nipa plant means Palmer`s grass or Nipa grass. Plants of the genus *Distichlis* have the following morphological features:

- Perennial
- Dioecious
- Kranz anatomy

The leaves have a Bicellular Microhair that secretes excess salt, so that salts are usually seen dramatically on the surface of the leaves (Pearlstein et al., 2012; Bresdin and Glenn, 2016). It is shown the scientific morphology classification of Nipa plant (Table 2).

Table 1. Comparing the nutritional value and compounds in the stems and seeds of Nipa and dry Alfalfa forage (Pearlstein et al., 2012).

Compounds (%)	Stem of Nipa	Seed of Nipa	Dry Alfalfa forage
Crude protein	16.26	8.7	12.9
Digestible fiber	31.86	---	44.0
Raw fiber	24.49	8.4	37.7
Digestible non-fibrous carbohydrates	24.39	71.1	37.4
Sugars	---	5.5	---
Ash	9.45	1.6	7.5
Fat	0.01	0.5	1.3
Total digestible material	49.47	79.9	50
Digestible energy	2.18	3.11	2.21
Phosphorus	0.21	0.22	0.25
Calcium	0.21	0.06	1.40
potassium	1.38	0.51	4.45
Sodium	1.69	0.21	0.25
Manganese	0.19	0.05	0.14

Table 2. Scientific classification of NIPA plant (Pearlstein et al., 2012; Bresdin and Glenn, 2016; Fedoroff et al., 2010).

Kingdom	Plantae
Division	Magnoliophyta
Phylum	Angiosperms
Class	Monocots
Order	Poales
Family	Poaceae
Genus	Distichlis
Species	Palmeri
Similar names	Palmer`s grass /Nipa grass/ Salt grass

Nipa yields in the Colorado River Delta produce an average of 1.5 tons of grain per hectare. Nipa can be grown as a perennial seed-forage plant, especially in saline and flooded lands. The stems of the plant produce the inflorescence of Nipa, compound, Terminal Panicle, female panicles are usually 5 to 13.5 cm long. The spikelets separate from the top of the glume and between the florets and each contains 6 to 9 flowers, but in general, the terminal flower is sterile from the beginning (Fig. 1). Scientific observations indicate that Nipa plants are maturing simultaneously and reaching the reproductive stage at the same time. Nipa flowering begins in mid-March to mid-April and the seeds arrive in mid-May to mid-June (Pearlstein et al., 2012). Nipa seeds are of the Caryopses type, and contain 7 to 9% protein, 8% sugar, 70 to 75% digestible carbohydrates, mainly starch, 2% ash, and 8% fiber (Table 1). Which is able to be equal to conventional grains in terms of nutritional value (Pearlstein et al., 2012; Brown et al., 2014). Researchers have found that Nipa has a very close relationship in terms of cellular characteristics and morphology of the leaves with salt grass, which has a wider geographical area (Flowers, 2004), which are compared in Table 3.

Table 3. Comparison of Salt grass species (*D. Spicata*) and Nipa (*D. palmeri*) characteristics (Flowers, 2004).

Species	Staminatelemma (mm)	Pistillatelemma (mm)	Anther (mm)	Habitats
Nipa	7-9	12-16	3.8-4.9	Tidal impact zone
Salt grass	3-6	3-6	1.8-2.6	Outside the tidal impact zone

Although these two species grow in the Rio Colorado Delta and are adjacent to each other, an intermediate species between the two species is not yet known. Some researchers have acknowledged that Nipa and South American local salt grass differ from other members of the genus in leaf anatomy (Pearlstein et al., 2012).

3. Ecology

All common cereals today are annuals, so the use of perennial grain crops such as Nipa, which do not require plowing and planting every year, and the use of no-till systems can save energy and reduce production costs. Among conventional grain crops, only rice is able to grow under anaerobic conditions in paddy systems, but other crops require well-drained soils and aerobic conditions (Qayyum et al., 2020).

Figure 1. Nipa plant components: panicle; male flower; female flower; spikelets of panicle; caryopses from panicle; Photos by Cylphine Bresdin.

Nipa plant is able to absorb the required water from the salt water of the sea, so this plant is classified as Halophyte plant. The salts that enter the body of the Nipa plant while absorbing seawater are excreted through special cells because the plant lacks Stomata on the surface of its leaves (Brown et al., 2014). A study examining the ability of Nipa to grow under the stress of hypoxic conditions and salinity-affected soils found that the plant grows well in heavy, poorly drained soil, similar to its natural habitat. Researchers believe that Nipa has several desirable characteristics in line with the goals of large-scale food production in saline lands. So far, many attempts have been made to commercialize Nipa, the forage potential of this plant has been reported to be favorable, but the seed production potential of this plant has not been reported to be favorable during field experiments in Australia, which needs further investigation (Pearlstein et al., 2012; Sarker et al., 2020).

4. Scientific and research records

So far, few articles have been published on the evaluation of growth rate, salinity tolerance, flood tolerance, physiological adaptation, grain yield and nutritional needs of Nipa plant in order to introduce this plant as a new crop and perennial tolerant to saline water. Many halophyte plants have a slow growth process, so they have not been developed to become crop plants and to promote them for seed production. Salt grass, for example, usually grows sparsely and with low density and has very fine grains that reduce the value of the economic investment. To date, no ecological reports have been observed regarding the dietary use of seeds of plants of the genus *Distichlis* except Nipa (Bersdin et al., 2016; Mahboub Khomami et al., 2021).

The results of the research are summarized as follows: The male and female plants of this dicotyledonous plant grow separately and their development through asexual due to rhizomes is much more than the sexual reproduction of this plant due to seed dispersal. Most plants focus on producing terminal panicles, but many mature seeds are separated from the plant in the form of spikelets due to tides. The density of female rootstocks was about 700 to 1000 plants m^2 and the plants did not reach the flowering stage at the end of the first year after planting in the greenhouse, but some of them entered the flowering stage at the end of the second year. Male flowers appeared from late December and female flowers several weeks later. The seeds entered the final ripening stage in late April. Many florets are seedless and have wrinkled Palea. The percentage of florets in this plant is 50% and florets and seeds without embryos often fall off. On average, each cluster has about 12 fully mature seeds. The average dry weight of each stem is 3.02 g and the total weight of the seeds of each stem is 0.139 g. Harvest index is the ratio of grain to total biomass per plant was equal to 44%. In this way, the yield value considering 900 stems m^2 is equal to 2.72 kg/m^2. Each plant was reported to have an average production potential of about 5 fertile stems with 95 seeds. The weight of each grain is reported to be about 11.2 mg with a diameter of 1.68 to 6.38 mm and a length of 7.6 to 8.5 mm (Pearlstein et al., 2012; Bersdin et al., 2016).

Increasing salinity from 0-30 g/L in Nipa seeds did not prevent germination. The germination percentage of Nipa seeds in salinity is zero g/L 93%, in salinity 20 g/L 70%, and in salinity 30 g/L 60%. Relative Growth Rate (RGR) has been reported in different salinity values under different flood and non-flood conditions. So that the highest growth rate led to the first harvest was related to salinity of 5 g/l and the relative growth rate at a salinity of 30 g/L decreased by 4.5% (Asadi and Jalilian, 2021). The greatest decrease in relative growth rate was reported at a salinity of 35 g/L and above. Post-harvest regeneration of Nipa plants in submerged conditions due to lower salinity has been reported to be slightly faster than non-submerged conditions. The salts first penetrated into the Aerenchyma tissue cells of the rhizomes but were prevented from entering the stems by the suberized epidermal layer around the stele. The amount of sulfate, potassium, calcium and magnesium in the stems and rhizomes was less measured than in the roots (Brown et al., 2014).

Nipa grains had less fiber than wheat and rice grains, but higher amounts of carbohydrates were digestible. Also, the amount of ash and sodium is less. Nipa grains with an average length of 6.8 mm and an average weight of 11 mg are similar to short-grain rice. Nipa is able to produce a yield of 1.25 tons/hectare in wild and perennial conditions. Nipa forage compounds are of great value due to their high protein and low sodium content. The biomass yield and forage quality of Nipa are similar to the value of Alfalfa. Nipa produces woody stems that make it difficult for livestock to digest, but with frequent harvesting, Nipa forage quality can be managed. Nipa growth capability in flooded lands can lead to the rehabilitation of wetland wetlands for crop production, but crops such as rice that do not have this capability and are sensitive to salinity and tolerate only fresh water up to maximum brackish (Pearlstein et al., 2012; Saffariha et al., 2021).

5. Conclusion

Successful research conducted to maintain and improve the Nipa plant worldwide has increased the yield of this plant from about 500 kg/hectare to 2 tons/hectare. Nipa is currently undergoing research for economic production in some countries, including Australia. This perennial seed, which is now considered one of the most important species for centuries, is a plant suitable for saline tropical regions and beyond. Nipa development should be a high priority for institutions and officials related to food security, desalination and climate change, and while providing a platform for entrepreneurship and agricultural development, it should be a good opportunity to develop, rehabilitate and protect coastal areas.

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