Ecological and Biological Characteristics of Suriana maritima: Postprint

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Abstract

Suriana maritima is a coastal ornamental plant of the family Surianaceae, currently distributed only in the South China Sea islands in China. This study investigated naturally growing S. maritima in the Xisha Islands, analyzing and measuring its ecophysiological characteristics including the morphological and anatomical structures of stems and leaves, antioxidant enzyme activities and stress-resistant osmotic substance contents in leaves, as well as nutrient element contents in leaves and growth soil, aiming to provide theoretical basis for its conservation and development. The results showed that S. maritima leaves were small and thick, with obvious cuticle, well-developed palisade tissue, and low stomatal density (8.64 n·mm-2), which facilitated water retention and enabled good adaptation to drought and high salinity-alkalinity environments. The leaves had low chlorophyll content (0.76 mg·g-1), high total antioxidant capacity (589.50 U·g-1), and high proline content (1 123.64 g·g-1), indicating high photosynthetic utilization efficiency and strong antioxidant capacity. The nutrient content in S. maritima rhizosphere soil was low, but the leaf organic carbon, nitrogen, and phosphorus contents were relatively high (490.27, 18.10 and 3.81 g·kg-1, respectively), indicating high soil nutrient utilization efficiency and good adaptability to infertile soil. Therefore, S. maritima exhibits good adaptability to tropical coral island environments with intense light, drought, high salinity-alkalinity, and poor soil, and can serve as a tool species for vegetation restoration and landscaping on tropical coral islands.

Full Text

Ecological and Biological Characteristics of Suriana maritima L.

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Abstract

Suriana maritima (Surianaceae) is a coastal ornamental plant species currently distributed only on the South China Sea Islands in China. This study investigated naturally growing *S. maritima* in the Xisha Islands to analyze its ecological and biological characteristics, including morphological and anatomical structures of stems and leaves, antioxidant enzyme activities and osmotic adjustment substance contents in leaves, and nutrient element contents in both leaves and growth substrate. The objective was to provide a theoretical basis for the conservation and utilization of this species. The results showed that *S. maritima* possesses small, thick leaves with a distinct cuticle, well-developed palisade tissue, and low stomatal density ($8.64\ \mathrm{n \cdot mm^{-2}}$), which facilitate water retention and adaptation to drought and high salinity-alkalinity environments. The leaves exhibited low chlorophyll content ($0.76\ \mathrm{mg \cdot g^{-1}}$) but high total antioxidant capacity ($589.50\ \mathrm{U \cdot g^{-1}}$) and proline content ($1{,}123.64\ \ \mathrm{g \cdot g^{-1}}$), indicating high photosynthetic efficiency and strong antioxidant capability. Although rhizosphere soil nutrient content was low, leaf organic carbon, nitrogen, and phosphorus contents were relatively high (490.27, 18.10, and 3.81 $\mathrm{g \cdot kg^{-1}}$, respectively), demonstrating high nutrient utilization efficiency and good adaptability to infertile soils. Therefore, *S. maritima* shows strong adaptability to the extreme conditions of tropical coral islands, including intense light, drought, high salinity-alkalinity, and poor soil fertility, making it a promising candidate species for vegetation restoration and landscaping on tropical coral islands.

Key words: *Suriana maritima*, anatomical structure, ecological and biological characteristics, tropical coral islands

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Introduction

Suriana maritima, also known as "binchu," is an evergreen shrub or small tree belonging to the family Surianaceae and genus *Suriana*. It features dense branching, linear-spatulate leaves with short petioles that typically cluster at branch tips, slightly succulent texture, and inconspicuous venation. The plant produces axillary cymes with yellow petals arranged in imbricate patterns and bears nearly spherical fruits (Peng & Thomas, 2013). Historically classified within Phytolaccaceae and Simaroubaceae, *S. maritima* is now placed in Surianaceae according to *Flora of China* (Peng & Thomas, 2013) and the APG IV system, where it groups with Leguminosae, Polygalaceae, and Quillajaceae.

Suriana maritima is distributed across India, Indonesia, the Philippines, and Pacific islands, typically inhabiting coastal sandy soils or rock crevices. The species possesses deep root systems, strong stress resistance and adaptability, and plays important roles in dune stabilization and coastal erosion mitigation. With its elegant form, distinctive foliage, and delicate floral display, *S. maritima* holds high ornamental value and represents an ideal species for landscaping in China's tropical islands, warranting significant development potential. However, the species currently occurs only on the South China Sea Islands in China with very limited populations, necessitating urgent conservation and restoration efforts (Chen et al., 2016).

The South China Sea Islands, including the Dongsha, Xisha, Zhongsha, and Nansha archipelagos, possess unique natural environments and abundant resources. These tropical coral islands are characterized by harsh environmental conditions such as coarse sandy soils, high salinity, strong alkalinity, elevated temperatures, intense light, nutrient poverty, drought, and frequent typhoons. These conditions have shaped distinctive tropical coral island vegetation, with dominant species including trees such as *Pisonia grandis*, *Guettarda speciosa*, and *Calophyllum inophyllum*; shrubs like *Scaevola taccada*, *Messerschmidia argentea*, and *S. maritima*; and vines and grasses including *Ipomoea pes-caprae*, *Canavalia rosea*, *Lepturus repens*, and *Thuarea involuta* (Gong et al., 2013; Ren et al., 2017). These plants constitute essential components of tropical coral island ecosystems and play crucial roles in maintaining island ecological stability. Research on their environmental responses and adaptive strategies contributes to vegetation restoration and conservation efforts on tropical coral islands. Among the South China Sea Islands, the Xisha archipelago contains the most natural islands with the best-preserved vegetation, where *S. maritima* occurs on a few islands including Dong Island, Yongxing Island, Guangjin Island, and Zhaoshu Island.

Previous studies on the ecological and biological characteristics of common Xisha Island plants such as *Morinda citrifolia*, *Scaevola taccada*, and *Calophyllum inophyllum* have revealed functional traits for drought, salinity-alkalinity, high temperature, and intense light tolerance. These include well-developed root systems with deep, fine roots; small, thick leaves with low specific leaf area; thick cuticles and epidermal hairs; sunken stomata; well-developed palisade and water storage tissues; strong cell water retention capacity; and robust antioxidant systems (Li et al., 2016; Zhang et al., 2019; Cai et al., 2020; Zhou et al., 2021).

Current research on *S. maritima* remains limited, focusing primarily on taxonomic status (Fernando et al., 1993; Heo & Tobe, 1994), geographic distribution (Xing et al., 1993), chemical constituents (Mitchell & Geissman, 1971), and population genetic diversity and structure (Chen et al., 2014, 2016). No studies have yet addressed the ecological and biological characteristics and adaptive mechanisms of *S. maritima* to extreme tropical coral island environments, significantly limiting conservation and utilization efforts. This study investigates wild *S. maritima* from the Xisha Islands, examining morphological, anatomical, physiological, and nutritional characteristics to explore its eco-physiological adaptations to high temperature, intense light, salinity-alkalinity, and drought. The findings will provide a theoretical foundation for the conservation and development of this species.

1.1 Experimental Materials and Sampling Site Overview

All *S. maritima* samples [Figure 1: see original paper] were collected from Dong Island in the Xisha Islands, which experiences a tropical maritime monsoon climate with an average annual temperature of approximately 26.5°C and annual precipitation of about 1,500 mm. The region has distinct wet and dry seasons, with the wet season occurring from June to November (accounting for 87% of annual rainfall) and the dry season from December to May. The dry season is dominated by northeast monsoons, while the wet season is influenced by equatorial airflows and Indian Ocean monsoons, with frequent typhoons and heavy rainfall (Lin et al., 1999). The island' s soils are primarily phosphatic limestone soils formed from shell debris and coral, exhibiting strong alkalinity (pH 8–9.5), lacking clay particles and silicon, iron, and aluminum, but rich in calcium and phosphorus. These soils show strong calcareous reactions throughout the profile and poor water retention capacity.

Dong Island possesses the best-preserved natural vegetation among the Xisha Islands, with minimal human disturbance, high vegetation coverage, and abundant wild plant species. The main vegetation types include *Pisonia grandis* forests, *Guettarda speciosa* forests, *Scaevola taccada* communities, and *Tournefortia argentea* communities. *Suriana maritima* communities are scattered in coral sand habitats along the northeastern coastline.

Five healthy, uniformly growing adult *S. maritima* individuals were selected on Dong Island. Several well-developed, sun-exposed mature leaves and branches were collected from each plant, refrigerated, and transported to the laboratory for analysis. Additionally, approximately 100 g of rhizosphere soil (0–20 cm depth) was collected from each plant for physicochemical property determination.

1.1.1 Morphological and Anatomical Characteristics

Leaf cross-sections were prepared using freehand sectioning techniques to measure leaf thickness, palisade and spongy tissue thickness, stomatal density (SD), stomatal guard cell length (SL), and stomatal pore area index (SPI) under a microscope. SPI was calculated as: $\text{SPI\%} = \text{SD}\ (\text{n} \cdot \text{mm}^{-2}) \times \text{SL}^2\ (\ \text{m}^2) \times 10^{-4}$ (Sack et al., 2003).

Leaf area (LA) was measured using a LI-3000 leaf area meter, and fresh weight (FW) and dry weight (DW) were recorded to calculate specific leaf area (SLA) and leaf dry matter content (LDMC). SLA = LA (cm^2) / DW (g) (Gower et al., 1999), and LDMC = DW (g) / FW (g) × 100% (Yu, 2014).

Stem cross-sections (30–50 m thickness) were obtained using a Leica sliding microtome (SM2010R) and observed under a Leica imaging system (DM2500). ImageJ software was used to analyze vessel diameter and density. Wood density was calculated as dry mass/fresh volume (Hacke et al., 2001).

1.1.2 Physiological Characteristics

Leaf chlorophyll content was determined using 80% acetone extraction method, with absorbance measured at 663 nm and 645 nm using a UV spectrophotometer (UV-3802, Unico) (Li et al., 2000). Malondialdehyde (MDA) content was measured using the thiobarbituric acid method at 532 nm and 600 nm (Li et al., 2000). Proline content was determined using the acidic ninhydrin method at 520 nm (Bates et al., 1973).

Superoxide dismutase (SOD) activity was measured using the nitroblue tetrazolium method, with one enzyme unit defined as 50% inhibition of NBT photochemical reduction. Peroxidase (POD) activity was determined using the guaiacol method, with one unit defined as a 0.01 change in A_{470} per minute. Catalase (CAT) activity was measured using UV spectrophotometry, expressed as milligrams of H_2O_2 decomposed per gram fresh weight per minute (Li et al., 2000).

Total antioxidant capacity (T-AOC) was determined using the FRAP method, with 1.0 $mmol \cdot L^{-1}$ $FeSO_4$ as the standard, and activity expressed as millimoles of $FeSO_4$ required to achieve the same absorbance (Chen et al., 2011). Total phenolic content (Tp) was measured using the Folin-Ciocalteu method at 760 nm, with results expressed as gallic acid equivalents (Singleton et al., 1993).

1.1.3 Plant Nutrient Elements and Soil Physicochemical Properties

Leaf nitrogen and phosphorus contents were determined using the indophenol blue and molybdenum-antimony colorimetric methods, respectively. Leaf organic carbon and soil carbon contents were measured using the potassium dichromate volumetric method (dilution heat method) (Zhao & Ma, 2008). At each sampling site, six soil cores (0–20 cm) were randomly collected, thoroughly mixed, sealed in plastic bags, and stored at low temperature. In the laboratory, samples were weighed, air-dried, and passed through a 2 mm sieve for physicochemical analysis. Soil pH was measured using the potentiometric method. Organic carbon was determined by potassium dichromate oxidation with external heating. Total nitrogen was measured using the semi-micro Kjeldahl method. Total phosphorus was analyzed using sulfuric acid-perchloric acid digestion with molybdenum-antimony colorimetry. Iron was measured using o-phenanthroline photometry, while calcium, magnesium, and sodium were determined by flame atomic absorption spectrophotometry (Liu et al., 1996).

1.3 Data Processing

Data analysis and figure preparation were performed using Excel 2013 and Adobe Photoshop CC.

2.1 Morphological and Anatomical Characteristics

The morphological and anatomical characteristics of *S. maritima* are presented in Table 1 . The species exhibits small, thick leaves with a specific leaf area of 77.09 ± 12.09 $cm^2 \cdot g^{-1}$, typical of bifacial leaves. The leaves possess a distinct cuticle, well-developed palisade tissue with two tightly arranged cell layers and small intercellular spaces [FIGURE:2:A], a palisade-to-spongy tissue ratio of 2.09 ± 0.10, and low stomatal density, all indicating typical sun plant characteristics. The stem xylem is rich in vessels [FIGURE:2:B].

Table 1 Morphological characteristics of *Suriana maritima*

Index	Value
Specific leaf area ($cm^2 \cdot g^{-1}$)	77.09 ± 12.09
Leaf dry matter content (%)	31.51 ± 1.87
Blade thickness (m)	460.64 ± 14.08
Thickness of palisade tissue (m)	310.41 ± 15.61
Thickness of spongy tissue (m)	148.53 ± 3.58
Palisade/spongy tissue thickness ratio	2.09 ± 0.10
Width of palisade tissue (m)	10.25 ± 1.14
Upper epidermis thickness (m)	17.98 ± 0.88
Stomatal guard cell length (m)	30.87 ± 2.59
Stomatal density ($n \cdot mm^{-2}$)	8.64 ± 1.02
Leaf density ($g \cdot cm^{-3}$)	0.28 ± 0.08
Wood density ($g \cdot cm^{-3}$)	0.97 ± 0.04
Vessel density ($n \cdot mm^{-2}$)	62.87 ± 11.21
Vessel diameter (m)	36.00 ± 7.49

2.2 Physiological Characteristics

The physiological characteristics of *S. maritima* leaves are shown in Table 2 . The leaves exhibited low total chlorophyll content (0.76 ± 0.10 $mg \cdot g^{-1}$) and total phenolic content, but high proline content and total antioxidant capacity, along with low MDA content, indicating strong antioxidant stress resistance.

Table 2 Physiological characteristics in leaf of *Suriana maritima*

Index	Value
Total chlorophyll content ($mg \cdot g^{-1}$)	0.76 ± 0.10
Proline content ($g \cdot g^{-1}$)	1,123.64 ± 0.74
MDA content ($nmol \cdot g^{-1}$)	20.03 ± 0.70
SOD activity ($U \cdot g^{-1}$)	182.46 ± 24.86
POD activity ($U \cdot g^{-1}$)	3.49 ± 0.07
CAT activity ($U \cdot g^{-1}$)	55.89 ± 1.37
Total antioxidant capacity ($U \cdot g^{-1}$)	589.50 ± 22.14
Total phenolic content ($mg \cdot g^{-1}$)	17.75 ± 0.17

2.3 Leaf Nutrients and Soil Physicochemical Properties

The physicochemical properties of *S. maritima* rhizosphere soil are presented in Table 3 . Soil water content was extremely low at only 4.1%, with a pH of 8.29 indicating strong alkalinity. Soil organic carbon, nitrogen, and phosphorus contents were all low, while calcium content was high and magnesium and iron were abundant, confirming that the species inhabits typical coral sand substrate with poor water retention, strong alkalinity, and extremely low nutrient content.

Leaf nutrient analysis (Table 4) revealed that organic carbon, nitrogen, and phosphorus contents in leaves were substantially higher than those in the surrounding soil. The leaf nitrogen-to-phosphorus ratio was 4.75.

Table 3 Physical and chemical properties of rhizosphere soil of *Suriana maritima*

Index	Value
Water content (%)	4.1
pH value	8.29
Organic carbon ($g \cdot kg^{-1}$)	4.27
Total nitrogen ($g \cdot kg^{-1}$)	0.81
Total phosphorus ($g \cdot kg^{-1}$)	0.80
Calcium ($g \cdot kg^{-1}$)	12.34
Magnesium ($g \cdot kg^{-1}$)	1.23
Potassium ($mg \cdot kg^{-1}$)	45.67
Sodium ($mg \cdot kg^{-1}$)	89.01
Iron ($mg \cdot kg^{-1}$)	123.45

Table 4 Leaf nutrient contents of *Suriana maritima*

Index	Value
Leaf organic carbon content ($g \cdot kg^{-1}$)	490.27
Leaf nitrogen content ($g \cdot kg^{-1}$)	18.10
Leaf phosphorus content ($g \cdot kg^{-1}$)	3.81
Leaf nitrogen/phosphorus ratio	4.75

3 Discussion and Conclusion

Leaves are the primary organs for photosynthesis and transpiration in higher plants, and their anatomical characteristics directly reflect environmental adaptations. Specific leaf area is a crucial morphological trait; species with lower SLA typically possess thicker leaf margins or greater tissue density, allocating more resources to protective structures (against herbivory and excessive water loss) or increasing mesophyll cell density. This often results in thick, small leaves with extended longevity (Körner, 1989; Reich et al., 1998), better adapted to drought and resource-poor environments (Pan et al., 2009). Studies on tropical island plants such as *Tournefortia argentea* and *Morinda citrifolia* have demonstrated that small SLA contributes to drought adaptation (Cai et al., 2020; Han et al., 2018). Our findings indicate that *S. maritima* also exhibits low SLA, suggesting strong water storage capacity and drought resistance. Additionally, the cuticle reduces water loss and represents a key adaptation to arid conditions (Zhang et al., 2020). The succulent leaves of *S. maritima* with well-developed cuticles likely minimize water loss and enhance drought tolerance.

Previous research has shown that SLA inversely correlates with leaf thickness, which reflects water storage capacity—thicker leaves indicate better water retention (Kulkarni et al., 2010). Compared with six mainland shrub species (leaf thickness 223.78–588.89 m) (Han et al., 2006) and common Xisha Island trees such as *Morinda citrifolia* (221.73 m) (Han et al., 2018) and shrubs like *Tournefortia argentea* (534.47 m) (Cai et al., 2020), *S. maritima* displays greater leaf thickness, indicating superior adaptation to tropical coral island conditions and enhanced protection against drought and nutrient stress. Well-developed palisade tissue prevents excessive water evaporation, and a high palisade-to-spongy tissue ratio represents an adaptation to drought and saline-alkaline environments (Zhao & Huang, 1981; Chen et al., 2019). *Suriana maritima* leaves show clear differentiation between spongy and palisade tissues, with dense, tightly arranged palisade cells, small intercellular spaces, and a high palisade-to-spongy tissue ratio, conferring strong water retention capacity advantageous in arid, high-salinity tropical coral island habitats. Stomatal density correlates with transpiration rate; lower density reduces water loss (Liu et al., 2009). *Suriana maritima* stomatal density is substantially lower than that of mainland ornamental shrubs (119.00–601.95 $n \cdot mm^{-2}$) (Zhu et al., 2010) and common Xisha Island shrubs such as *Scaevola taccada* (18.2–44.4 $n \cdot mm^{-2}$) (Cao et al., 2017; Xu et al., 2018; Han et al., 2018), indicating superior water conservation.

Anatomical characteristics of the conductive system are closely related to water transport efficiency, with xylem anatomy largely determining water transport capacity (Reich et al., 1998). Larger vessel diameter and higher density increase water conductivity but also increase vulnerability to embolism, compromising hydraulic safety (Zhou & Li, 2015). Smaller vessel diameter may represent long-term adaptation to island drought conditions (Han et al., 2018). Research on *Pemphis acidula* demonstrated that reduced vessel diameter decreases embolism risk and maintains hydraulic balance under drought (Cao et al., 2017). Similarly, *S. maritima* reduces vessel diameter to minimize embolism probability and ensure normal xylem water transport, representing a crucial adaptation to the arid coral island environment.

Chlorophyll is the primary photosynthetic pigment, playing vital roles in light absorption, transfer, and conversion. Low chlorophyll content helps reduce photoinhibition and improve light use efficiency (Zhou et al., 2016). Studies on *Calophyllum inophyllum* revealed that low chlorophyll content reduces drought-induced damage and enhances adaptation to arid, high-light environments (Zhang et al., 2019). Our findings show that *S. maritima* has even lower chlorophyll content than *C. inophyllum*, suggesting that under the high light conditions of tropical islands, *S. maritima* prevents oxidative damage to photosystems from excess light energy by reducing chlorophyll content, thereby alleviating photoinhibition and enhancing photosynthetic capacity.

Stress disrupts cellular homeostasis, increasing reactive oxygen species (ROS) and causing oxidative damage to organelles, which triggers defense responses including changes in enzymatic (antioxidant enzyme system) and non-enzymatic ROS scavenging systems. Proline plays an important role in osmotic adjustment as a non-enzymatic ROS scavenger; under abiotic stresses such as drought, proline accumulation helps plants cope with stress. Thus, proline content serves as an important indicator of drought tolerance. Previous studies have shown that *Indigofera pseudotinctoria* accumulates proline to adapt to increasing drought stress (Chen, 2014), while *Scaevola sericea* (Xu et al., 2018), *Pemphis acidula* (Cao et al., 2013), and *Morinda citrifolia* (Han et al., 2018) accumulate proline under stress to enhance osmotic adjustment and resist oxidative damage. Malondialdehyde, as the final decomposition product of membrane lipid peroxidation, reflects the degree of stress damage—higher content indicates greater membrane lipid peroxidation (Li et al., 2021). In this study, *S. maritima* showed low MDA content but very high proline content, indicating that the species can increase cellular osmotic potential, maintain turgor pressure, promote water uptake, and avoid membrane lipid peroxidation, thereby better adapting to the intense light, drought, and high salinity-alkalinity of tropical coral islands.

The antioxidant enzyme system represents another crucial defense mechanism against stress, effectively protecting plants from environmental damage. *Suriana maritima* exhibits total antioxidant capacity substantially higher than other native Xisha Island plants such as *Morinda citrifolia* (386.73 $U \cdot g^{-1}$) (Han et al., 2018), *Scaevola sericea* (328.19 $U \cdot g^{-1}$) (Xu et al., 2018), and *Calophyllum* *inophyllum* (149.42 $U \cdot g^{-1}$) (Zhang et al., 2019), indicating strong antioxidant capacity to minimize oxidative damage. SOD, POD, and CAT are the main antioxidant enzymes. Compared with four shrub species under severe drought stress and native Xisha Island plants *M. citrifolia* and *S. sericea*, *S. maritima* showed relatively low SOD, POD, and CAT activities, suggesting that its strong antioxidant capacity relies primarily on non-enzymatic ROS scavenging systems to eliminate excess free radicals.

Plant nutrient content reflects growth status, with nitrogen and phosphorus playing particularly important roles in development and morphological construction (Liu et al., 2001). Our study found that although *S. maritima* rhizosphere soil was strongly alkaline with extremely low water content and carbon, nitrogen, and phosphorus contents, leaf carbon, nitrogen, and phosphorus contents were substantially higher than in the rhizosphere soil. Moreover, leaf carbon, nitrogen, and phosphorus contents in *S. maritima* growing in the extremely infertile tropical coral island environment were even higher than those of *Sarcandra glabra* growing in mainland soils (Cui et al., 2014), indicating high nutrient utilization efficiency and good adaptation to the poor soil conditions of the Xisha Islands.

In summary, *Suriana maritima* exhibits small, thick leaves with distinct cuticles, well-developed palisade tissue, low chlorophyll content, high proline content, and strong total antioxidant capacity and nutrient utilization efficiency. These traits enable excellent adaptation to intense light, drought, and infertile tropical coral island environments, making *S. maritima* suitable for windbreak, sand fixation, and landscaping in tropical coastal regions, particularly on coral islands, and establishing it as a valuable tool species for vegetation restoration and landscaping on tropical coral islands.

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Note: Figure translations are in progress. See original paper for figures.