BIODIVERSITAS
Volume 24, Number 8, August 2023
Pages: 4597-4608

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240842

Morphological diversity of Indian jujube (*Ziziphus mauritiana*) in Sumbawa Island, West Nusa Tenggara, Indonesia

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Manuscript received: 15 June 2023. Revision accepted: 28 August 2023.

Abstract. *Nikmatullah A, Nairfana I, Dewi SM, Sarjan M. 2023. Morphological diversity of Indian jujube (*Ziziphus mauritiana*) in Sumbawa Island, West Nusa Tenggara, Indonesia. Biodiversitas 24: 4597-4608. Ziziphus mauritiana* Lam. (Indian jujube or *Bidara*) is an evergreen shrub or small tree tolerant to drought, salinity, and high-temperature stress with various ethnobotanical and ecological values. However, minimal information is available on its diversity in Indonesia. The current study aims to assess the morphological diversity of *Z. mauritiana* accessions collected from 18 locations in Sumbawa Island, Indonesia. The plant's qualitative and quantitative morphological attributes were collected, including size, L/W ratio and color of leaf and fruit, length, and occurrence of spine and stem surface. The results revealed significant differences in some observed characters among the accessions. Petiole length varied from 0.6 to 1.4 cm, leaf length ranged from 2.9 to 5.0 cm, leaf width ranged from 2.6 to 4.2 cm, and leaf L/W ratio was 1.07 to 1.46. All samples of *Z. mauritiana* in Sumbawa Island had a spine that occurred evenly in every node, ranging from 0.1 to 1.0 cm. Most accessions had single spinal per node except two accessions, which had double horn-shaped spines in each node. The quantitative characters for fruits also varied, either orbicular or oblong. The fruit length ranged from 1.2 to 1.9 cm, the fruit width varied between 1.1 to 1.8 cm, and the fruit L/W ratio was between 1.0 and 1.2. There were also morphological differences in leaf color, fruit color, shape, and taste (sweet, sour, or bitter). The finding suggests some degree of morphological diversity of *Z. mauritiana* in Sumbawa, as shown by quantitative and qualitative attributes of the leaf, thorn, and fruit.

Keywords: *Bidara*, diversity, morphology, qualitative trait

INTRODUCTION

Bidara (*Ziziphus mauritiana* Lam.), or Indian jujube or ber, is one of the most economically important species of the *Ziziphus* genus of the Rhamnaceae family (Muhammad et al. 2022). The *Z. mauritiana* is an evergreen tree species found in many parts of the world, including Pakistan (Sharif et al. 2019; Muhammad et al. 2022), Africa (Stadlmayr et al. 2013), Australia and Fiji (Dhileepan 2017), India (Prakash et al. 2021), China (Uddin et al. 2021), Malaysia (Jaelani et al. 2020) and Indonesia (Soraya et al. 2022). In Indonesia, this species grows naturally in Sumatra (Askur and Ganning 2021), Java (Kurniawan et al. 2019), Bali (Soraya et al. 2022), Sumbawa of West Nusa Tenggara (Ani et al. 2018; Ardiansyah and Rita 2019; Zohriah et al. 2021), and in East Nusa Tenggara (Kurniawan and Pujiono 2018), mainly in the lowland including dry lands (Nairfana et al. 2022).

Ziziphus mauritiana has various ecological, ethnobotanical, medicinal, and food values. The plant can grow in various ecological conditions and provide ecosystem services, including preventing soil erosion (Gupta 2018) and mitigating global warming through carbon sequestration in the dryland (Muhammad et al. 2022). This plant's leaves, bark, root, and fruit are essential homeopathic medicine in many countries (Nyanga et al. 2013; Saqib et al. 2014; Ashraf et al. 2015; Delphine et al. 2017). The *Z. mauritiana* fruits are essential for the diet in many countries, such as Zimbabwe (Nyanga et al. 2013), India (Singh and Meghwal 2020), Bangladesh (Talukdar et al. 2014), Iran (Mirheidari et al. 2022) and Africa (Stadlmayr et al. 2013). The *Z. mauritiana*'s fruit is rich in nutrition and contains protein, lipid, crude fiber, ash, carbohydrate, vitamin C, potassium, calcium, sodium, magnesium, phosphorous, manganese, copper, iron, zinc (Rathore 2009; Nyanga et al. 2013, Stadlmayr et al. 2013; Talukdar et al. 2014; Mirheidari et al. 2022).

Despite such importance, only limited publications reported the morphological profiles, diversity, and distribution of *Z. mauritiana* in Indonesia. Investigations in other countries have shown that this species has a reasonably high diversity. In India, 119 genotypes of *Z. mauritiana* were reported (Mirheidari et al. 2022). In China, Talukdar et al. (2014) stated that there were 47 wild accessions of *Z. mauritiana*, while Sharif et al. (2019) found 60 accessions in Pakistan, and Talukdar et al. (2014) reported five accessions in Bangladesh, based on morphological and genetic analysis. Mirheidari et al. (2022) evaluated 44 morphological characters to study the diversity of 119 Indian genotypes of *Z. mauritiana*, including tree growth, branching habit, leaf size, leaf shape and color, fruit density, fruit shape and fruit color. They found substantial diversity among the 119 genotypes as shown by leaf shape, size and color, and fruit skin ground

color. Similarly, Ahmad et al. (2021) used fruit characters to assess the diversity of *Z. mauritiana* in Pakistan and found that 22 cultivars in Pakistan varied in fruit weight, fruit length, fruit diameter, seed weight, seed length, seed diameter, pulp weight and total soluble solid of pulp. In a different study, Razi et al. (2013) also reported variations in leaf and fruit characteristics of 13 cultivars of *Z. mauritiana* in Pakistan. They showed that all varieties had different leaf areas, petiole lengths, leaf shapes (elliptic, oblanceolate, oval, ovate or oblong), apex shapes (obtuse, acute, sub-acute, or cuspidate), leaf margin, leaf base (obtuse or cuneate), leaf margin (crenate, serrate or serrulate), leaf surface (smooth, papery, glaucous, glabrous), fruit shape (round, oval, oblong, ovate, chordate or elongated), and fruit skin (smooth, wrinkle, dotted or scratching). To study the diversity of *Z. mauritiana* in India, Vir et al. (2019) used growth habits, foliage, thorns, fruits, and the presence or absence of stones in the fruits as morphological markers.

The genetic diversity of *Z. mauritiana* in Indonesia has not been well characterized, but two species of *Ziziphus* were found in Sumbawa: *Z. mauritiana* and *Z. jujuba* Mill. (Wiriadinata et al. 2013). Sareen et al. (2023) stated that cross-pollination of intra and inter-species of the genus Ziziphus is possible. Therefore, it is hypothesized that there might be some degree of diversity of Z. *mauritiana* in Sumbawa Island, which might result from the hybridization of *Ziziphus* within the species of Z. *mauritiana* varieties or with *Z. jujuba.*

This study examines the morphological diversity of *Z. mauritiana* found in three districts in Sumbawa Island, namely West Sumbawa, Sumbawa, and Dompu, Indonesia, which grow either wild or domesticated. Information on the genetic variation is needed for conservation, plant breeding, cultivation, and standardization of raw material for medicinal and other purposes, and therefore, the outcome of this study is essential for further utilization of Z. *mauritiana* as a source of food, conservation, natural preservatives, medicine, and many other purposes.

MATERIALS AND METHODS

Study area and period

The current study was conducted in three districts in Sumbawa Island, Indonesia: West Sumbawa (SB), Sumbawa (KS), and Dompu (Figure 1). Data collection was carried out from June to October 2022.

These three districts were selected based on climate conditions (annual rainfall and temperature), representing different degrees of dryness. SB has the highest annual rainfall of 1250-1500 mm/year, followed by KS with an annual rainfall of 1000-1250 mm and DP with an annual rainfall of 750-1000 mm (Keputusan Menteri PUPR 2016). In each district, six villages located in lowland areas (i.e., three villages in the coastal or savannas areas and three villages near the residential areas) were sampled for data collection, resulting in 18 villages. The characteristic of each sampling location is presented in Table 1.

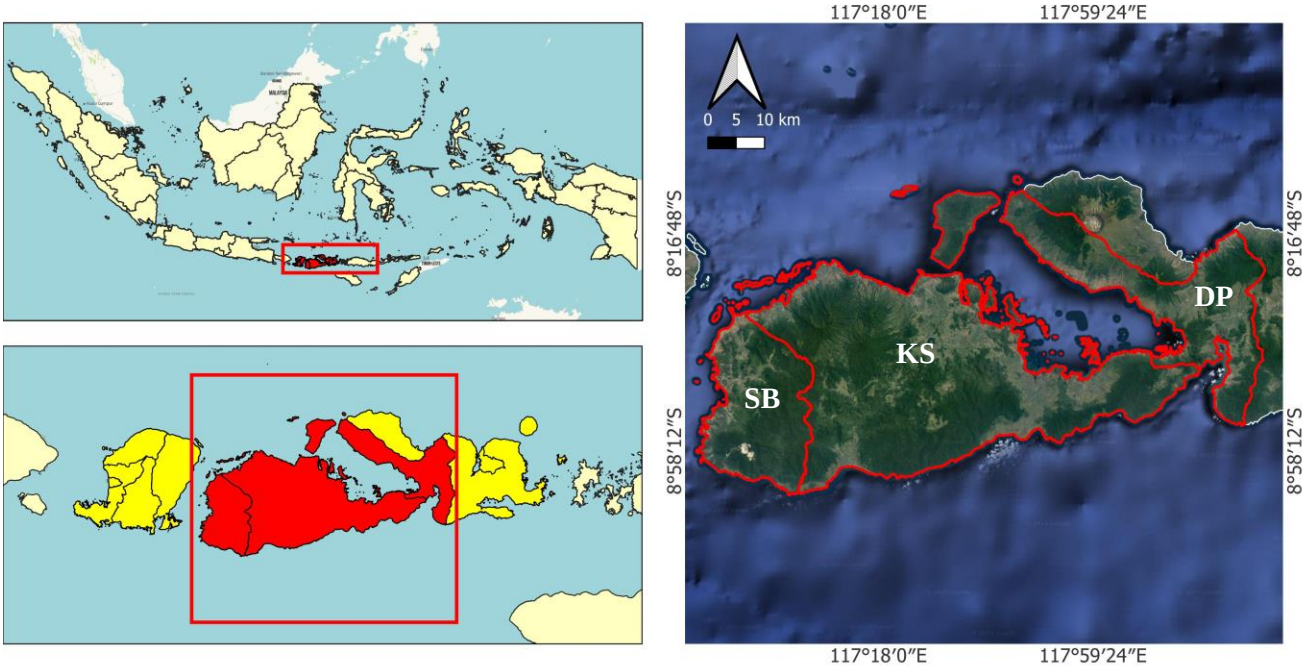

Figure 1. Location of Sumbawa Island in West Nusa Tenggara, Indonesia and the three districts of the study in Sumbawa Island: West Sumbawa (SB), Sumbawa (KS) and Dompu (DP). Map source: modified from the geoportal of the National Geospatial Agency (https://geoportal.big.go.id/#/viewer)

Table 1. Characteristics of each sampling site in this study

Location name	Location	Habitat	Date collected	Altitude (m a.s.l)	Latitude/ Longitude (GPS)	Plant Status
West Sumbawa District						
SB1L1	Poto Tano-1	Coastal	18/6/22	5	8°31'58.0"S 116°50'08.0"E to 8°32'12.3"S 116°50'12.3"E	Wild
SB1L2	Kertasari	Coastal	24/6/22	5	8°41'26.9"S 116°46'35.7"E to 8°41'30.8"S 116°46'37.3"E	Wild
SB1L3	Poto Tano-2	Coastal	24/6/22	10	8°33'20.9"S 116°50'28.5"E to 8°33'29.6"S 116°50'31.2"E	Wild
SB2L1	Taliwang-1	Garden/forest edge	23/6/22	72	8°44'15.9"S 116°49'39.1"E to 8°44'16.8"S 116°49'35.1"E	Wild
SB2L2	Taliwang-2	Garden/forest edge	23/6/22	84	8°44'35.0"S 116°49'15.6"E to 8°44'51.8"S 116°49'09.0"E	Wild
SB2L3	Jereweh	Garden/forest edge	28/7/22	93	8°51'58.3"S 116°49'41.2"E to 8°52'02.3"S 116°49'39.3"E	Wild
Sumbawa District						
KS1L1	Labuan Badas	Coastal	24/6/22	5	8°27'14.4"S 117°21'01.3"E to 8°27'15.0"S 117°21'02.2"E	Wild
KS1L2	Luk	Garden/forest edge	27/6/22	15	8°26'29.3"S 117°18'23.2"E 8°26'19.7"S 117°18'27.4"Eto	Wild
KS1L3	Rhee	Coastal	27/6/22	5	8°25'21.6"S 117°16'37.0"E to 8°25'28.9"S 117°16'50.6"E	Wild
KS2L1	Sebasang Moyo Hulu (Peruak Bagek)	Rice paddy field and garden	22/6/22	320	8°39'36.2"S 117°27'01.8"E to 8°39'38.5"S 117°27'19.0"E	Wild
KS2L2	Sebasang, Moyo Hulu	Garden	24/6/22	120	8°38'44.7"S 117°26'15.4"E to 8°38'47.4"S 117°26'14.2"E	Wild
KS2L3	Boak	Garden and near rice paddy field	28/6/22	115	8°33'54.4"S 117°26'14.5"E to 8°35'12.9"S 117°27'06.0"E	Wild
Dompu District						
DP1L1	Doropeti, Pekat	Coastal savanna	19/6/22	45	8°24'00.3"S 117°54'19.3"E to 8°24'49.2"S 117°55'57.9"E	Wild
DP1L2	Doro Nchanga	Coastal savanna	19/6/22	32	8°26'24.7"S 117°58'33.9"E to 8°26'31.4"S 117°58'44.9"E	Wild
DP1L3	Persiapan Sori Tonga Pekat	Coastal savanna	19/6/22	52	8°27'15.9"S 117°59'47.4"E to 8°27'17.2"S 117°59'52.6"E	Wild
DP2L1	Doromelo, Manggalewa, Dompu Village	Backyard	21/6/22	120	8°30'59.3"S 118°18'17.6"E to 8°30'59.4"S 118°18'18.1"E	Domesticated
DP2L2	Dompu Village	Backyard	22/6/22	110	8°32'22.3"S 118°26'57.2"E to 8°32'44.6"S 118°27'29.3"E	Domesticated
DP2L3	Dompu Village	Backyard	22/6/22	115	8°31'54.3"S 118°28'39.7"E to 8°32'01.3"S 118°28'45.4"E	Domesticated

Plant materials

Three plants per location were assigned and sampled, resulting in fifty-four plants. The individual plant was selected randomly by considering the size of the plant (at least 2 m height and 40 cm of basal stem girth and at the generative phase) with a minimal distance between plants of 50 m. The representation of the plant in each sampling site is shown in Figure 2.

Morphological characterization was undertaken by evaluating quantitative and qualitative plant characters (Table 2). To measure the phenotypic diversity of leaves and spine, three branches (of minimum 60 cm length) were harvested from each plant (taken from different sites of each thee), and one quarterly branch (typically branch number 3 from the top) was selected for characterization. Leaf size was measured in five to seven mature leaves in each branch (leaves number 3 to 10), while spine length was measured in the same branch at the corresponding nodes to leaf measurement. Fruit characters were measured by harvesting at least seven mature fruits in each plant, taken from different branches.

The qualitative traits observed were the color of a leaf (lamina of abaxial and adaxial sides), the color of the fruit (young and mature fruits), the color of the seed, the color of fruit flesh, and the taste of the fruit. The color was determined by matching leaf/fruit color with the Royal Horticulture Society (RHS) color chart, while quantitative value was measured by ruler or/and Vernier caliper, as appropriate.

Data analysis

The quantitative and qualitative data were analyzed to obtain the Confidence of Variation (CV). In addition, the quantitative data was analyzed according to the analysis of variance using SPSS Version 22.

Table 2. Measurement of quantitative and qualitative characteristics of *Ziziphus mauritania*

Characters	Measurement	Unit
Petiole length	Measure with vernier caliper (Sigmat Tricle Brand)	cm
Leaf blade length	Measure with a stainless steel ruler (Joyco)	cm
Leaf blade width	Measure with a stainless steel ruler (Joyco)	cm
The ratio of leaf length and wide	Calculating the ratio between leaf length and wide to determine the shape: orbicular (L/W ratio 1 or close to 1) or oval/elliptic (L/W ratio is higher than 1.2 and symmetrical about the middle)	
Spine length	Measure with vernier caliper (Sigmat Tricle Brand)	cm
Spine occurrence	Regular: The spine is present in every node Irregular: The spine is not present in every node	
Fruit length	Measure with vernier caliper (Sigmat Tricle Brand) at the longest part of the fruit	cm
Fruit wide	Measure with vernier caliper (Sigmat Tricle Brand) at the widest part of the fruit	cm
The ratio of fruit length and wide	Calculating the ratio between fruit length and wide to determine the shape: orbicular (L/W ratio 1) or oblong (L/W ratio is higher than 1, rounded at each end with roughly parallel side)	
Fruit color	Matching the color of mature fruit (fully mature) with the Royal Horticulture Society (RHS) color chart	Number in RHS color chart
Fruit flesh color	Matching the color of the flesh in the fully mature fruit with the Royal Horticulture Society (RHS) color chart	Number in RHS color chart
Fruit flesh thickness	Measure with vernier caliper (Sigmat Tricle Brand)	cm
Fruit taste	By tasting mature fruits (5 mature fruits per tree) and considering them as sour, bitter, sweet, or plain based on the most robust taste	
Seed color	Matching the color of the seed in the fully mature fruit with the Royal Horticulture Society (RHS) color chart	Number in RHS color chart
Seed surface	Smooth or uneven (serrated)	
Leaf color (Abaxial)	Matching the color of a mature leaf with the Royal Horticulture Society (RHS) color chart	Number in RHS color chart
Leaf color (Adaxial)	Matching the color of a mature leaf with the Royal Horticulture Society (RHS) color chart	Number in RHS color chart
Bark surface	Smooth, uneven, or crack	

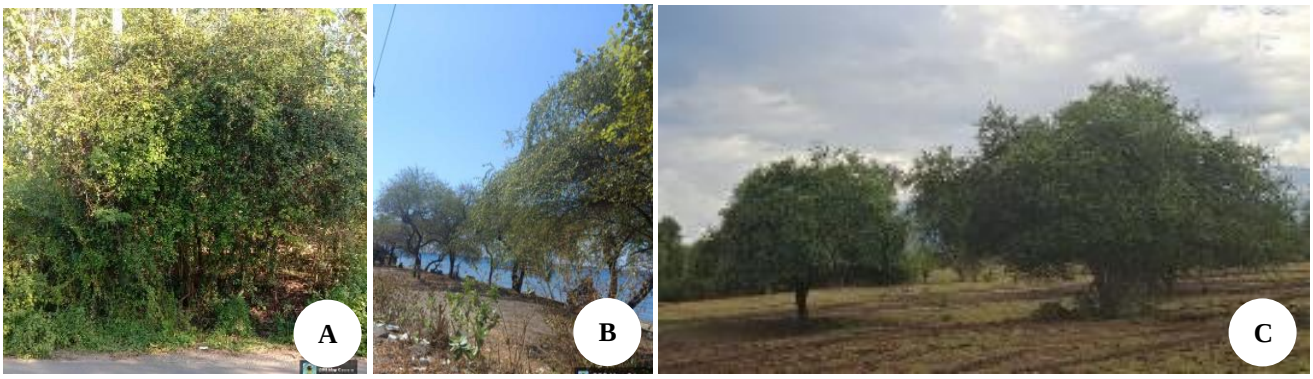

Figure 2. Representation of *Ziziphus mauritiana* trees in some sampling sites showing different ecosystems in each sampling site: A. Forest edge, B. Coastal area, and C. Savanna

RESULTS AND DISCUSSION

Variation in petiole and leaf of *Z. mauritania*

The *Z. mauritania* plants grow in different regions of Sumbawa Island showed a variation in the morphology of the leaves as shown by the length of the petiole, length of the leaf blade, wide of the leaf blade, the ratio between length and width of the leaf blade, and the color of the leaf (abaxial and adaxial sides). The length of the petiole of *Z. mauritania* leaf obtained in Sumbawa Island was between 0.6-1.4 cm. The accession obtained in Sumbawa District (KS) had a significant variation in the length of the petiole, with all accessions from KS2 (KS2L1, KS2L2, KS2L3) having a significantly shorter petiole (between 0.6 cm-0.7 cm) than those found in the coastal areas/KS1 (between 0.9-1.4 cm). Interestingly, less variation in the petiole length was observed among all accessions obtained in West Sumbawa (SB) and Dompu (DP) Districts. The length of the petiole in the SB accessions was between 0.6-0.9 cm, and in the DP accessions was between 0.9-1.1 cm. The shortest petiole of 0.6 cm was observed in *Z. mauritania* plants collected from KS2L1, SB1L1, and SB2L1, while the longest petiole of 1.4 cm was *Z. mauritania* plant collected from KS1L1.

Table 3 also shows the variation in the size of *Z. mauritania* leaf obtained from a different location on Sumbawa Island. *Z. mauritania* in Sumbawa Island had leaf blades with a length between 2.9-5.0 cm, width

between 2.6-4.2 cm, and leaf L/W ratio between 1.07-1.46. The plant with the longest leaf of 5.0 cm was the KS1L2 accession, and the shortest was the DP1L3. The SB2L2 had the widest leaf, and the DP1L3 had the narrowest one. The plant with the largest leaf was the KS1L2, and the smallest was D1L3. Most of the plants obtained in the KS and SB regions had a nearly orbicular leaf with an L/W ratio of 1.07 to 1.18, except for the KS1L2, KS2l1, and SB2L3 accessions, which were less orbicular in shape. Interestingly, the shape of the leaves of the *Z. mauritania* plant grown in the DP district was more varied, with the DP1 being nearly orbicular, while the DP2 plant had an oval-shaped (L/W ratio of 1.34 to 1.46).

The qualitative trait of leaf morphology, shown by the abaxial and adaxial leaf color, also varied. The *Z. mauritania* plants in Sumbawa Island had six different abaxial leaf colors: moderate olive green/RHS#137A (plants in nine sampling locations), greyish olive green/RHS#NN 137A (plants in five sampling locations), moderate yellow, green/RHS#137C (plants in one sampling location, KS1L1), strong yellow green/RHS#143A (plant in one location, KS2L2), strong yellow green/RHS #144A (plants in one sampling location, SB1L2), and moderate olive green/RHS#147A (plants in one sampling location, DP2L1). The adaxial leaf color of *Z. mauritania* leaf in Sumbawa Island was less varied, and there were four different colors: light greyish olive/RHS#195A (11 samples), greyish yellow green/RHS#195B (five samples), greyish yellow green/RHS#194A (one sample), and greyish yellow green/RHS#191A (one sample). The morphology of leaves of *Z. mauritania* plants found in Sumbawa Island is presented in Figures 3 to 5.

The variations in length, size, and color of the leaf varied across the sampling sites. Overall, the length and width of leaves of *Z. mauritania* found around the coastal area were greater than that located in the forest edge, savanna, and village. This can be seen from the overall leaf characters observed in the KS, SB, and DP sampling regions. The coastal area is an arid region with less water availability, and *Z. mauritania* plants are exposed directly to sunlight as they are mainly the only tree in the area. In addition, there was variation in the shape of *Z. mauritania* leaves taken from the Dompu District (DP), which was more orbicular than the leaves taken from Sumbawa (KS). Various factors, including environmental and genetic factors, may influence the phenotypic variations. Plant phenotypes are influenced by various abiotic factors such as water excess, temperature, soil type, nutrient availability, and light intensity (Shrivastava and Kumar 2015; Etesami and Maheshwari 2018). Previous findings suggested that the leaf size and shape variation correlate with climatic factors (Wright et al. 2017; Li et al. 2020). Further study is required to find out whether these differences were due to environmental factors or as a result of genetic factors as well. A clear understanding of *Z. mauritania* traits can help understand and predict whole plant performances under different climatic conditions, with applications in breeding improved varieties.

Variation in spine and bark of *Z. mauritania*

All *Z. mauritania* plants in Sumbawa Island are characterized by spines. The length of the spine in the tertiary branches was between 0.1-1.0 cm (Table 4). Most of the *Z. mauritania* plants reported in this study had an average spine length of 0.3 to 0.4 cm (11 accessions), and three accessions had spines of 0.5-0.7 cm (SB2L3, KS1L2, and DP1L2), only one accession had a very long spine of 1.0 cm (KS1L3), and three accessions had very short spines of 0.1-0.2 cm. The *Z. mauritiana* tree with very short spines was the DP2L1, DP2L2, and DP2L3 accessions (domesticated in the backyard). Zhao (2021) stated that the climate affected the agromorphological traits of ecotypes, such as spine length (Stoyanov 2015; Kim et al. 2019).

Table 3. The variation in the length of the petiole, length (L) and width (W) of the leaf blade, the ratio between the leaf blade length and width (L/W), and the color of the leaf of *Z. mauritania* plant found in Sumbawa Island, Indonesia

Location name	Petiole length (cm)	Leaf blade						
		Length (L) (cm)	Width (W) (cm)	L/W	Abaxial		Adaxial	
					Color	RHS no.	Color	RHS no.
SB1L1	0.6 a	3.9 c	3.3 cd	1.18 a (nearly orbicular)	Moderate olive green	137A	Light greyish olive	195A
SB1L2	0.8 b	3.4 b	3.0 sb	1.13 a (nearly orbicular)	Strong yellow green	144A	Greyish yellow green	195B
SB1L3	0.7 ab	3.3 b	2.8 ab	1.18 a (nearly orbicular)	Moderate olive green	137A	Light greyish olive	195A
SB2L1	0.6 a	3.9 c	3.3 cd	1.18 a (nearly orbicular)	Greyish olive green	NN 137A	Light greyish olive	195A
SB2L2	0.9 bc	4.5 e	4.2 e	1.07 a (nearly orbicular)	Greyish olive green	NN 137A	Light greyish olive	195A
SB2L3	0.7 ab	4.3 de	3.4 cd	1.26 ab (elliptic)	Greyish olive green	NN 137A	Light greyish olive	195A
KS1L1	1.4 e	3.9 c	3.4 cd	1.15 a (nearly orbicular)	Moderate yellow green	137C	Greyish yellow green	195B
KS1L2	1.1 d	5.0 f	4.0 e	1.25 ab (elliptic)	Moderate olive green	137A	Light greyish olive	195A
KS1L3	0.9 bc	4.2 d	3.9 e	1.08 a (nearly orbicular)	Moderate olive green	137A	Light greyish olive	195A
KS2L1	0.6 a	4.1 cd	3.2 c	1.28 ab (elliptic)	Greyish olive green	NN 137A	Light greyish olive	195A
KS2L2	0.7 ab	3.3 b	2.9 b	1.14 a (nearly orbicular)	Strong yellow green	143A	Greyish yellow green	191A
KS2L3	0.7 ab	3.6 bc	3.3 cd	1.09 a (nearly orbicular)	Moderate olive green	137A	Greyish yellow green	194A
DP1L1	0.9 bc	4.1cd	3.5 d	1.17 a (nearly orbicular)	Greyish olive green	NN 137	Greyish yellow green	195B
DP1L2	0.9 bc	4.1 cd	3.2 c	1.28 ab (elliptic)	Moderate olive green	137A	Greyish yellow green	195B
DP1L3	0.9 bc	2.9 a	2.6 a	1.12 a (nearly orbicular)	Moderate olive green	137A	Light greyish olive	195A
DP2L1	1.0 cd	4.3 de	3.1 bc	1.39 b (elliptic)	Moderate olive green	147A	Light greyish olive	195A
DP2L2	0.9 bc	4.1cd	2.8 ab	1.46 b (elliptic)	Moderate olive green	137A	Light greyish olive	195A
DP2L3	1.0 cd	4.3 de	3.2 c	1.34 b (elliptic)	Moderate olive green	137A	Greyish yellow green	195B

Note: Means followed by the same letter within a column are not significantly different according to Tukey's HSD (honestly significant different test), α: 0.05, n: 45

Figure 3. Variation in size and color of *Z. mauritania* leaves obtained in West Sumbawa District (SB), Sumbawa Island, Indonesia

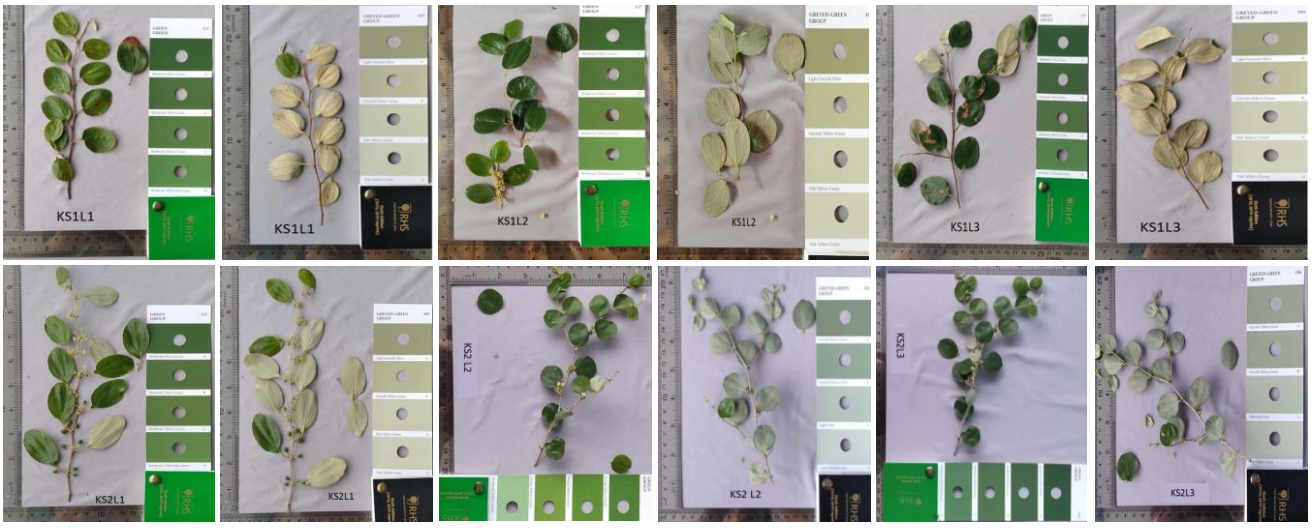

Figure 4. Variation in size and color of *Z. mauritania* leaves obtained in Sumbawa District (KS), Sumbawa Island, Indonesia

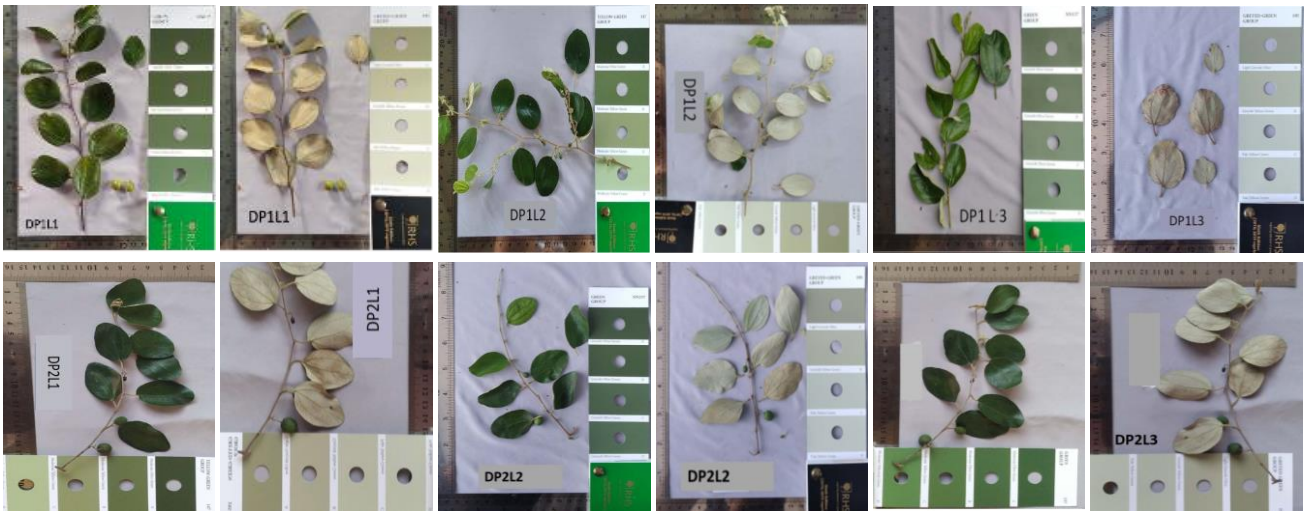

Figure 5. Variation in size and color of *Z. mauritania* leaves obtained in Dompu District (DP), Sumbawa Island, Indonesia

In this study, *Z. mauritania* that grow in the coastal area, garden edges, and savanna have longer, and some have double spines in each node, while the domesticated *Z. mauritania* (DP2L1, DP2L2, and DP2L3) have very short spines as shown in Figure 6. This difference is thought to be influenced by the environmental conditions where it grows or the growth habit of the *Z. mauritania*. Ecotypes in the yards of resident houses may get more frequent exposure to water spray from the daily activities of residents, while the plants growing in more arid coastal and forest edges were experiencing water deficit conditions due to the low frequency of rain in Sumbawa Island.

The *Z. mauritania* plants in Sumbawa Island characterized in this study were those with basal stem gird of 51.0 cm to 140.2 cm. The girth size may not be suitable for assessing the diversity of the *Z. mauritania* plant. However, the information is essential to show that the plants observed in this study were well adapted to the growing location and may reveal the importance of the plant for the community and environment. In Sumbawa Island, *Z. mauritania* can be the only tree species in several communal grazing areas such as Ndoro Ncanga (DP1L1 and DP1L2, in this study) and Gili Rakit savanna (Dilaga et al. 2017). In the communal grazing area of Sumbawa Island, locally designated as lar, the *Z. mauritania* trees provide shelter for livestock, particularly cow and buffalo, the primary livestock in Sumbawa (Shiddieqy et al. 2021). The presence of *Z. mauritania* trees in these semi-arid regions of Sumbawa confirms previous findings of the ecological importance of this plant in the marginal dry and hot region of the globe (Gupta 2018; Muhammad et al. 2022). In addition, its presence as the only tree in these areas may also show that it is essential for carbon sequestration in the dryland. Thus, preservation or cultivation of *Z. mauritania* in the semi-arid region may serve as an essential mitigation scenario for global warming (Muhammad et al. 2022).

Variation in fruits of *Z. mauritania*

In addition to leaf, bark, and spine morphology, the variation in fruit characteristics was also assessed in this study to identify the diversity of the *Z. mauritania* plant on Sumbawa Island. Variation in fruit phenotypes of the *Z. mauritania* plant in Sumbawa Island is presented in Table 5. As presented in Table 5, the length and width of *Z. mauritania* fruits taken from various sampling sites varied. The fruit length ranged from 1.1-1.9 cm, the wide range from 1.1-1.8, and the fruit L/W ratio was 1.0 (orbicular) to 1.2 (oblong). The fruits collected from trees domesticated in residential areas (DP2 and SB2) were larger, while the wild trees in the coastal and forest edges areas had smaller fruits. This shows that the grower has selected the Z. mauritania tree with desirable characteristics, such as larger fruit size. Previously, Huang et al. (2016) discovered that cultivated *Z. mauritania* was domesticated from their wild ancestors (*Z. jujuba* var. *spinosa* (Bunge) Hu ex H.F.Chow) through an artificial selection process for important agronomic traits. The domestication of wild *Z. mauritania* resulted in architectural and structural changes in the tree. These changes may include transitioning from bushes with more thorns to trees with fewer thorns and enlarged fruit sizes (Sharif et al. 2019). This investigation also observed that domesticated *Z. mauritania* plant has a shorter spine/thorn. It is interesting to explore further to confirm whether this difference is due to variation in the growing ecology or genetic variation of *Z. mauritania* in Sumbawa.

In addition to the quantitative character of the fruit, this study also examined the qualitative characters (shape and color) of the *Z. mauritania* fruits and seeds (Tables 5-6; Figures 7-12). The shape of *Z. mauritania* fruit on Sumbawa Island was orbicular or oblong. Most of *Z. mauritania* in the SB ecotype had orbicular fruits, while most in DP and KS ecotypes had oblong fruits. The color of immature *Z. mauritania* fruit skin was quite similar with small different intensity, corresponding to the RHS number 144A, 144B, or 144C (designated as strong yellow-green color). However, the mature fruit skin color varied from strong brown, strong reddish orange, moderate reddish orange, moderate orange, dark reddish-orange, greyish reddish brown, brownish orange, and moderate reddish brown. Figures 7-9 show the variation of *Z. mauritania* fruit color on different ripening stages collected from all sampling sites.

The thickness of mature fruits varied from 0.2-0.5 cm, and interestingly, the fruits collected from DP2L1, DP2L2, DP2L3, and KS2L1 regions had thicker fruit flesh than the others and had a sweet taste. Interestingly, the flesh color of the fruit collected from Dompu District (DP2L1m DP2L2, DP2L3, and DP1L2) also differed from other samples. The flesh of the fruits of these accessions was lighter in color, and it was described as pale yellow, while the fruits from other accessions had a darker flesh color (moderate orange and moderate orange-yellow).

Table 4. Characteristics of the spine and stem of *Z. mauritania* found in different locations in Sumbawa Island, Indonesia

Location name	Spine		Stem bark
	Length (cm)	Occurrence	
SB1L1	0.4 bc	Even	Crack
SB1L2	0.4 bc	Even	Crack
SB1L3	0.4 bc	Even	Crack
SB2L1	0.4 bc	Even	Crack
SB2L2	0.3 b	Even	Crack
SB2L3	0.7 d	Even, double spines in each node	Crack
KS1L1	0.3 b	Even	Crack
KS1L2	0.6 cd	Even, double spines in each node	Crack
KS1L3	1.0 e	Even	Crack
KS2L1	0.3 b	Even	Crack
KS2L2	0.4 bc	Even	Crack
KS2L3	0.4 bc	Even	Crack
DP1L1	0.3 b	Even	Crack
DP1L2	0.5 c	Even, double spines in each node	Crack
DP1L3	0.3 b	Even	Crack
DP2L1	0.2 ab	Even	Crack
DP2L2	0.1 a	Even	Crack
DP2L3	0.1 a	Even	Crack

Note: *Means followed by the same letter within a column are not significantly different according to Tukey's HSD (honestly significant different test), α: 0.05, n: 45

Table 5. Phenotypic variation of *Z. mauritania* fruits found in different locations on Sumbawa Island, Indonesia

Location name	Length (L) (cm)	Width (W) (cm)	L/W (shape)	Fruit			
				Immature		Mature	
				Color	RHS no.	Color	RHS no.
SB1L1	1.3 ab	1.3 ab	1.00 (orbicular)	Strong yellow green	144 A	Strong brown	172 A
SB1L2	1.3 ab	1.3 ab	1.00 (orbicular)	Strong yellow green	144 B	Strong reddish orange	169 A
SB1L3	1.3 ab	1.3 ab	1.00 (orbicular)	Strong yellow green	144 A	Dark reddish orange	175 B
SB2L1	1.2 a	1.2 a	1.00 (orbicular)	Strong yellow green	144 A	Moderate reddish orange	N 172 A
SB2L2	1.3 ab	1.2 a	1.08 (oblong)	Strong yellow green	144 A	Moderate orange	167 A
SB2L3	1.3 ab	1.2 a	1.08 (oblong)	Strong yellow green	144 A	Na	Na
KS1L1	1.5 b	1.4 b	1.07 (oblong)	Strong yellow green	144 A	Dark reddish orange	175 B
KS1L2	1.5 b	1.5 bc	1.00 (orbicular)	Strong yellow green	144 A	Moderate reddish orange	N 172 A
KS1L3	1.6 bc	1.5 bc	1.07 (oblong)	Strong yellow green	144 B	Moderate reddish orange	N 172 A
KS2L1	1.8 c	1.5 bc	1.20 (oblong)	Strong yellow green	144 A	Moderate reddish orange	N 172 B
KS2L2	1.6 bc	1.5 bc	1.08 (oblong)	Strong yellow green	144 C	Moderate orange	N 170 B
KS2L3	1.6 bc	1.6 c	1.00 (orbicular)	Strong yellow green	144 A	Dark reddish orange	175 B
DP1L1	1.4 b	1.3 ab	1.08 (oblong)	Strong yellow green	144 B	Dark reddish orange	175 B
DP1L2	1.1 a	1.1 a	1.00 (orbicular)	Strong yellow green	144 A	Greyish Reddish brown	200 B
DP1L3	1.5 b	1,4 b	1.07 (oblong)	Strong yellow green	144 B	Dark reddish orange	175 B
DP2L1	1.9 c	1.8 d	1.06 (oblong)	Strong yellow green	144 A	Moderate reddish brown	166 B
DP2L2	1.8 c	1.7 cd	1.06 (oblong)	Strong yellow green	144 A	Brownish orange	165 B
DP2L3	1.7 bc	1.6 c	1.06 (oblong)	Strong yellow green	144 A	Moderate reddish brown	166 B

Note: Means followed by the same letter within a column are not significantly different according to Tukey's HSD (honestly significant different test), α: 0.05, n: 21

Table 6. Variation in the morphology of fruit flesh, seed and taste of *Z. mauritania* grow in different locations on Sumbawa Island, Indonesia

Location Name	Mature fruit flesh				Mature seed		
	Thickness (cm)	Color	RHS	Taste	Color	RHS	Surface
SB1L1	0.3 ab	Moderate orange yellow	164 B	Sour	Moderate orange yellow	164 B	Serrated
SB1L2	0.3 ab	Moderate orange	167 C	Sour	Moderate orange	167 B	Serrated
SB1L3	0.2 a	Moderate orange yellow	164 B	Sour	Brownish orange	164 A	Serrated
SB2L1	0.2 a	Moderate orange	167C	Sour	Moderate orange	167B	Serrated
SB2L2	0.3 ab	Moderate orange yellow	164 B	Sweet	Brownish orange	164 A	Serrated
SB2L3	NA	NA	NA	Na	NA	NA	Na
KS1L1	0.3 ab	Brownish orange	N167 B	Sour	Grayed orange group	N167 B	Serrated
KS1L2	0.4 b	Moderate orange	167 C	Sour	Moderate orange	167 B	Serrated
KS1L3	0.4 b	Moderate orange	167 B	Sour	Grayed orange group	167B	Serrated
KS2L1	0.5 bc	Moderate orange	167 C	Sweet	Moderate orange	167 C	Serrated
KS2L2	0.2 a	Moderate orange yellow	165 C	Sour	Moderate orange yellow	165 C	Serrated
KS2L3	0.2 a	Moderate orange yellow	165 C	Sour	Moderate orange yellow	165 C	Serrated
DP1L1	0.3 ab	Moderate Orange yellow	165 C	Bitter	Brownish orange	165 B	Serrated
DP1L2	0.4 b	Pale yellow	164 D	Bitter	Moderate orange yellow	164 C	Serrated
DP1L3	0.4 b	Moderate orange yellow	165 C	Sour	Brownish orange	165 B	Serrated
DP2L1	0.5 bc	Pale yellow	165 D	Sweet	Moderate orange yellow	165 C	Serrated
DP2L2	0.5 bc	Pale yellow	165 D	Sweet	Moderate orange yellow	165 C	Serrated
DP2L3	0.5 bc	Pale yellow	165 D	Sweet	Moderate orange yellow	165 C	Serrated

Note: Means followed by the same letter within a column are not significantly different according to Tukey's HSD (honestly significant different test), α: 0.05, n: 21

Figure 6. Representation of *Z. mauritania* stem with double spines (left) and single spine (right) in each node

As with many agricultural crops, taste attributes of *Z. mauritania* fruits, such as sweetness and sourness, have been the subject of human selection (Huang et al. 2016). The findings from this study showed that the taste of fruits varied based on the ecology of the growing area. *Z. mauritania* fruits collected from household backyards (all DP2 samples), rice fields in the Sumbawa region (KS2 samples), and gardens belonging to a farmer in West Sumbawa (SB2L2) have a sweet taste. On the other hand, fruits collected from the coastal area (SB1 and DP1) have a sour taste, while *Z. mauritania* fruits from the coastal savanna have a bitter or sour taste. The domestication mechanism of fruit sweetness and acidity taste from their

wild relatives is still poorly characterized. Therefore, the characterization of *Z. mauritania* using molecular analyses would help elucidate the genomic mechanism underlying fruit sweetness and acidity taste improvement. In addition to fruit characters, the color and texture of *Z. mauritania* seeds were also examined in this study. Table 6 and Figures 10-12 show the variation in the color of *Z. mauritania* seeds obtained in different sampling sites, with seed color varied and well correlated with the fruit flesh color. However, all seeds had the same surface as serrated seeds.

Figure 7. Variation in size and color of *Z. mauritania* fruits obtained in West Sumbawa District (SB), Sumbawa Island, Indonesia

Figure 8. Variation in size and color of *Z. mauritania* fruits obtained in Sumbawa District (KS), Sumbawa Island, Indonesia

Figure 9. Variation in size and color of *Z. mauritania* fruits obtained in Dompu District (DP), Sumbawa Island, Indonesia

Figure 10. Variation in size and color of *Z. mauritania* seeds obtained in West Sumbawa District (SB), Sumbawa Island, Indonesia

Figure 11. Variation in size and color of *Z. mauritania* seeds obtained in Sumbawa District (KS), Sumbawa Island, Indonesia

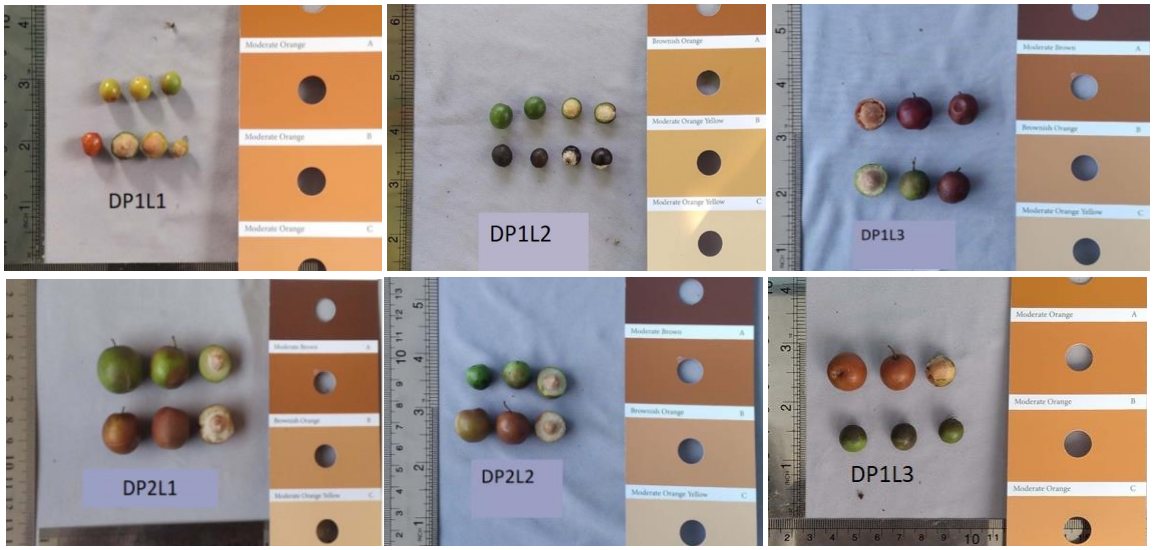

Figure 12. Variation in size and color of *Z. mauritania* seeds obtained in Dompu District (DP), Sumbawa Island, Indonesia

All data presented in this study confirm some morphological variations of *Z. mauritania* growing on Sumbawa Island, as shown by leaf, spine, fruit, and seed characters. Regardless of the region, the most visible difference between domesticated and wild plants was in the leaf, spine, and fruit characters. The domesticated *Z. mauritania* plants had larger leaves, shorter spina, and larger fruits with thicker flesh and a sweet taste. Another interesting difference was the variation in the fruit taste of wild *Z. mauritania* obtained in the Ndoro Ncanga savanna (DP1L1 and DP1L2) with a bitter taste compared to the other wild plants in other locations with a sour taste. The environment may influence this taste and variation in the secondary metabolites profile of the leaf, as previously shown by Nairfana et al. (2022). Further investigation is needed to understand the genetic basis of this phenotypic and biochemical variation in the fruits of *Z. mauritania.*

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Indonesian Ministry of Education, Culture, Research and Technology (*Pendidikan, Kebudayaan, Riset dan Teknologi*), which has funded this research through the National Competitive Basic Research scheme in 2023 with contract number 030/E5/PG.02.00.PL/2023.

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