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Phenotypic diversity of bamboo *Schizostachyum lima* (Blanco) Merr. population grown in several critical habitats on Lombok Island, Indonesia

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Abstract. *Aryanti E, Arumingtyas EL, Azrianingsih R, Arisoesilaningsih E. 2023. Phenotypic diversity of bamboo* Schizostachyum lima *(Blanco) Merr. population grown in several critical habitats on Lombok Island, Indonesia. Biodiversitas 24: 2788-2796.* This study aims to analyze the phenotypic diversity among populations of *Schizostachyum lima* (Blanco) Merr. grown in several critical habitats on Lombok Island. Sampling was conducted to record clump growth and habitat properties of 38 sites grouped based on the clump density using PAST 4.11 and ArcGIS 10.8.2 software. Sampling was conducted to record clump growth and habitat properties of 38 sites grouped based on the clump density using PAST 4.11 and ArcGIS 10.8.2 software. The results showed that habitat 1 was the most critical land and had the lowest fertility, but it provided a qualified bamboo as a raw material for the artisanal straw industry. The results showed that habitat 1 was the most critical land and had the lowest fertility, but it provided a qualified bamboo as a raw material for the artisanal straw industry. Bamboo density reached 46 culms per clump and had the smallest culms diameter of 13 mm. Bamboo density reached 46 culms per clump and had the smallest culms diameter of 13 mm. The soil comprised 90% sand, with SOC 0.9 $g.kg^{-1}$, total N 0.08 $g.kg^{-1}$, and CEC 8.3 me.100 g^{-1}. The soil comprised 90% sand, with SOC 0.9 $g.kg^{-1}$, total N 0.08 $g.kg^{-1}$, and CEC 8.3 me.100 g^{-1}. Meanwhile, habitat 6 and habitat 7 were lesser critical, consisted of 66% of sand, showed the best soil fertility, and mean SOC 4.98 $g.kg^{-1}$, total N 0.30 $g.kg^{-1}$, CEC 27.23 me.100 g^{-1}, density 151 culms, and biggest culms diameter 33 mm. Meanwhile, habitat 6 and habitat 7 were lesser critical, consisted of 66% of sand, showed the best soil fertility, and mean SOC 4.98 $g.kg^{-1}$, total N 0.30 $g.kg^{-1}$, CEC 27.23 me.100 g^{-1}, density 151 culms per clump, and biggest culms diameter 33 mm. The other habitats varied in soil quality and bamboo growth properties. It was revealed that the high culms density, diameter, height, and internodal length were significantly increased in the high soil CEC, SOC, and total N. Furthermore, the SOC and total N content significantly correlated with the wall thickness.

Keywords: Critical habitat, growth, Lombok Island, *Schizostachyum lima*

INTRODUCTION

Bamboo can grow optimally in soils with sandy loam and clay loam textures, open areas, good irrigation, and flat topography to moderate slopes (Durai and Long 2019). Bamboo can grow optimally in soils with sandy loam and clay loam textures, open areas, good irrigation, and flat topography to moderate slopes (Durai and Long 2019). However, bamboo is also found in dry and humid areas, rocky areas, and critical land (Mishra et al. 2014). However, bamboo is also found in dry and humid areas, rocky areas, and critical land (Mishra et al. 2014). Critical land has a low content of organic matter, nitrogen, and other elements. Therefore, critical land is considered unproductive and barren (Ivanina 2017). Previous studies show that improper tillage or land use is the most probable reason for the increasing number of critical lands yearly. Previous studies show that improper tillage or land use is the most probable reason for the increasing number of critical lands yearly. In Lombok Island, Indonesia, the number of critical lands in 2018 was 17,035 ha. This number increased to 35,736.84 ha in 2020 (Environment and Forestry Service of West Nusa Tenggara Province 2021). The increasing critical land becomes a big problem for land use and farming. However, several plants can adapt well to certain land conditions. However, several plants can adapt well to certain land conditions. Biologically, each plant can overcome environmental matter by modifying the morphological characteristics, physiology, and biochemical processes known as phenotypic plasticity. Phenotypic plasticity helps the plant to grow normally with habitat changes; it is also important in dealing with exotic species invasion. Phenotypic plasticity helps the plant to grow normally with habitat changes; it is also important in dealing with exotic species invasion. Apart from being influenced by genetic material, the morphological characteristics of most plants may also vary due to environmental factors such as temperature, humidity level, nutrients, and others (Laitinen et al. 2019). Apart from being influenced by genetic material, the morphological characteristics of most plants may also vary due to environmental factors such as temperature, humidity level, nutrients, and others (Laitinen et al. 2019).

Bamboo has a high adaptability level making it grow in various habitats. Bamboo has a high adaptability level, making it grow in various habitats. These characteristics have many benefits for bamboo usage for many purposes. These characteristics have many benefits for bamboo usage for many purposes. As explained above, bamboo can support cultivated plants, ropes, flutes, shortness of breath medicine, and house walls (Sinyo et al. 2017). Bamboo is also used to reduce plastic usage in life, such as a raw material for environmentally friendly straws. However, not all types of bamboo can be used for straw materials. Therefore, it is important to consider bamboo's diameter and thickness for straw materials. Therefore, it is important to consider bamboo's diameter and thickness for straw materials.

Schizostachyum lima (Blanco) Merr. is a bamboo species with a small diameter and thin wall thickness. For these reasons, *S. lima* can be used as raw straw material. A preliminary study indicates that *S. lima* is also found on Lombok Island, Indonesia. A preliminary study indicates that *S. lima* is also found on Lombok Island, Indonesia. This bamboo grows on unproductive lands, such as unmanaged yards around houses or abandoned land categorized as critical lands (Ivanina 2017). In Indonesia, such as on Lombok Island, *S. lima* is easily found at an altitude of 500 m asl (Damayanto et al. 2020). In Lombok Island, this species is generally used as raw material for eco-friendly straws and exported to many countries in Asia, Europe, Australia, and Africa (Aryanti et al. 2021).

According to the explanation above, *S. lima* bamboo grows on some critical lands in Lombok Island and is currently used as raw material for the straw industry. However, limited information about the relationship between critical land characteristics and population growth is shown by its phenotypic diversity. However, limited information about the relationship between critical land characteristics and population growth is shown by its phenotypic diversity. Thus, this study aims to analyze the relationship between the phenotypic diversity of the population of *S. lima*, which grows in several critical lands on Lombok Island. Thus, this study aims to analyze the relationship between the phenotypic diversity of the population of *S. lima*, which grows in several critical lands on Lombok Island. Furthermore, this study will be useful for determining the habitat preferences of *S. lima* populations and further support the bamboo-based straw industry. Furthermore, this study will be useful for determining the habitat preferences of *S. lima* populations and further support the bamboo-based straw industry.

MATERIALS AND METHODS

Sampling procedures

Sampling was conducted in 38 sites in four districts of Lombok Island, West Nusa Tenggara Province, Indonesia (Figure 1). These areas were selected based on the preliminary data from the literature and the community. This fieldwork recorded several parameters, such as coordinates, altitude (m asl), culm height (m), diameter (mm), intermodal length (cm), wall thickness (mm), clump density (culms per clump), number of old culms, number of young culms, and number of shoots of each clump.

Soil sampling

Soil rings were used to get the soil samples in-depth 0 to 20 cm, measured from the surface around the clumps. Soil rings were used to get the soil samples in-depth 0 to 20 cm, measured from the surface around the clumps. The soil samples of 500 g were analyzed in the West Nusa Tenggara Agricultural Technology Assessment Center (BPTP). The tested physical and chemical properties were: soil texture, pH, soil organic carbon (SOC), total N, and cation exchange capacity (CEC).

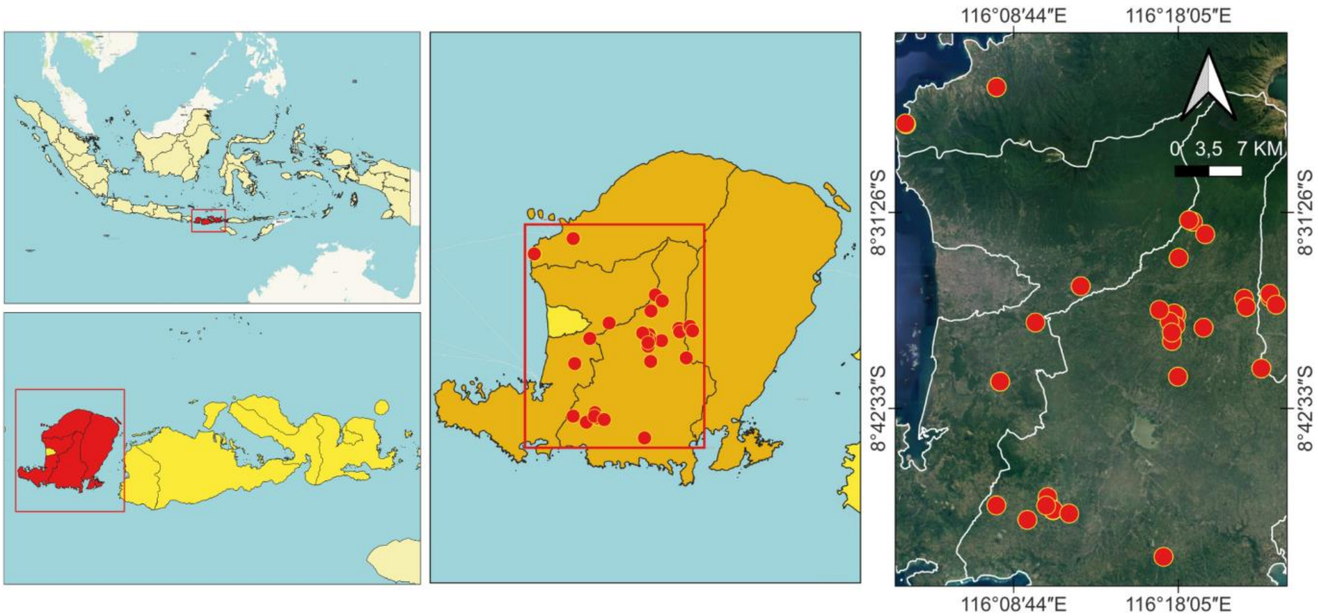


Figure 1. Sampling sites of *S. lima* distribution on Lombok Island, West Nusa Tenggara Province, Indonesia

Table 1. *Schizostachyum lima* population grouping based on clump density

Habitat group	Clump density (culms per clump)
Habitat 1	<50
Habitat 2	51-90
Habitat 3	91-105
Habitat 4	106-125
Habitat 5	126-140
Habitat 6	141-150
Habitat 7	>150

Statistical analysis

The sampling data were classified into seven groups based on the clump density (Table 1). The bamboo ecological character data and population growth were analyzed using univariate descriptive statistics, regression analysis, and biplot analysis (PAST Software, version 4.11). An ArcGIS Desktop (version 10.8.2) was used to analyze the distribution profile of the *S. lima* population and the soil texture of the habitat on Lombok Island. An ArcGIS Desktop (version 10.8.2) was used to analyze the distribution profile of the *S. lima* population and the soil texture of the habitat on Lombok Island, Indonesia.

RESULTS AND DISCUSSION

Spatial variation of abiotic factors of *S. lima* populations habitat

The soil texture of the habitat of the *S. lima* population found on Lombok Island is sandy, loamy sand, sandy loam, and loam. The soil texture of the habitat of the *S. lima* population found on Lombok Island is sandy, loamy sand, sandy loam, and loam. The soil texture of habitat-1 was sandy; in contrast, habitat-3, habitat-4, and habitat-5 showed loamy texture, sandy loam, and loamy sand (Figure 2.A). Besides, habitat-2 soil had sand, loam, sandy loam, and loamy sand texture. On the other side, habitat-6 and habitat-7 showed a loam-sandy loam texture and a loamy sand texture, respectively. In addition, the sampling sites varied in soil fraction (Figure 2.B). In line with this, the sand, silt, and clay fractions might affect the formed soil texture. In line with this, the sand, silt, and clay fractions might affect the formed soil texture. The highest fraction of sand in habitat-1 was 90%, while the other habitats ranged from 52 to 75%. Habitat-1 had the lowest fractions of silt and clay than other habitats, 10%, and 0%, respectively. Habitat-1 had the lowest fractions of silt and clay than other habitats, 10%, and 0%, respectively. The clay fraction from habitat-2 to 7 ranged from 16 to 35%, with 5% to 12%. The clay fraction from habitat-2 to 7 ranged from 16 to 35%, with 5% to 12%. However, all habitats' sand fraction was relatively higher than the silt and clay. However, all habitats' sand fraction was relatively higher than the silt and clay.

Figure 3 shows a spatial variation of the soil properties in all habitats. Figure 3 shows a spatial variation of the soil properties in all habitats. The highest SOC and total N contents were found in habitat-7: 5.7 $g.kg^{-1}$ and 0.43 $g.kg^{-1}$. Meanwhile, the lowest SOC and total N contents were found in habitat-1 and habitat-2, respectively, 0.9 $g.kg^{-1}$ and 0.06 $g.kg^{-1}$. The highest CEC was recorded in habitat-6, reaching 29.5 me.100 g^{-1}. Interestingly, the lowest CEC in habitat-1 was only 8.3 me.100 g^{-1}. The pH values in all habitats were classified as slightly acidic ranging from 6.1 to 6.6.

Spatial variations of *S. lima* population growth

The *S. lima* population was found in 38 sites spread across four districts on Lombok Island from an altitude of 60 m asl to 566 m asl. According to the observation, the bamboo populations were generally found in home gardens, bamboo plantations, rivers, paddy fields, shrubs, dry land, hills, and secondary forests (Table 2). Based on the local people's information, bamboo usually grows in critical lands, including unproductive, under-utilized, and abandoned lands. Based on the local people's information, bamboo usually grows in critical lands, including unproductive, under-utilized, and abandoned lands.

The lowest clump density was found in habitat-1 and only 46 culms per clump at Sanggar Sari 3. In contrast, habitat-7 had the highest clump density (161 culms per clump). Old and young culms were highly found at habitat-7 and habitat-5, respectively. There was no different density of bamboo shoots in all habitats, with approximately 1 to 5 shoots in each habitat (Figure 4).

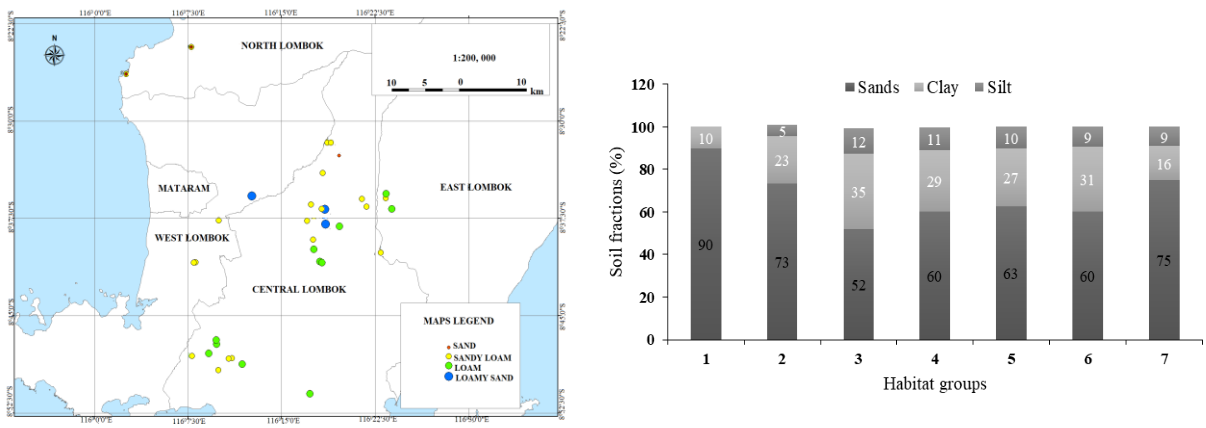
The data showed a spatial variation of bamboo's culm height-diameter, internodal length, and thickness (Figure 5). The culm height varied from 4 m to 10 m, and internode lengths ranged from 64 to 95 cm. The average diameters were also variable, ranging from 13 mm to 36 mm. Regarding the wall thickness, habitats 1-5 had similar thicknesses, around 0.2 mm. Interestingly, bamboo grown in habitats-6 and -7 had thicker walls that reached 0.3 mm. Interestingly, bamboo grown in habitats-6 and-7 had thicker walls that reached 0.3 mm.

A regression analysis identified the relation between SOC and total N on the culm height, diameter, and wall thickness. A regression analysis identified the relation between SOC and total N on the culm height, diameter, and wall thickness. This analysis showed that increases in soil SOC and total N significantly increased the culm height, diameter, and wall thickness. This analysis showed that increases in soil SOC and total N significantly increased the culm height, diameter, and wall thickness. Besides, the CEC content also significantly increased the number of culms per clump (Figure 6).

According to the biplot analysis, the observed habitat groups were classified into three clusters regarding the similarity of bamboo growth and habitat characteristics (Figure 7). The first cluster belongs to habitats-1 and -2 with a high sand fraction and a low clay and silt fractions, culm height, culms density, and soil CEC. The first cluster belongs to habitats-1 and -2 with a high sand fraction and a low clay and silt fractions, culm height, culms density, and soil CEC. The second cluster consisted of habitat-3, habitat-4, and habitat-5, showing a high density of young culm and a low culm diameter, mature culm density, wall thickness, SOC, and total N. The second cluster consisted of habitat-3, habitat-4, and habitat-5, showing a high density of young culm and a low culm diameter, mature culm density, wall thickness, SOC, and total N. Finally, the third cluster corresponds to habitats -6 and -7 where the high culm height, diameter, wall thickness, culm density, mature culms, and a high value of all environmental parameters except the sand fraction. Finally, the third cluster corresponds to habitats-6 and -7, where the high culm height, diameter, wall thickness, culm density, mature culms, and a high value of all environmental parameters except the sand fraction.

Table 2. *Schizostachyum lima*, population habitat grouping, based on clump density (culms per clump)

Habitat groups	Sampling sites	Coordinates	Main land use	Category habitats	Altitude (m asl.)	Clump density
1	Sanggar Sari 3	8°24’18.7”S, 116°07’45.9”E	Bamboo plantations	Unproductive land	116	46
2	Lendang Dode	8°62’70.7”S, 116°29’32.8”E	Home garden	Under-utilized land	330	82
	Kangas Lauk 2	8°47’34.7”S, 116°10’39.6”E	Home garden	Under-utilized land	108	83
	Sanggar Sari 2	8°24’18.7”S, 116°07’45.9”E	Bamboo plantations	Unproductive land	119	80
	Tunak	8°50’58.1”S, 116°17’14.9”E	Paddy field	Productive land	170	80
	Sedayu	8°37’40.1”S, 116°09’58.4”E	Dryland	Abandoned land	87	80
	Malimbu 2	8°26’22.4”S, 116°02’35.0”E	Hill near the beach	Unproductive land	60	75
	Lantan	8°32’39.6”S, 116°19’36.9”E	Hill near paddy field	Abandoned land	538	75
	Sanggar Sari 1	8°24’18.7”S, 116°07’45.9”E	River	Productive land	106	73
3	Pampang 2	8°48’03.6”S, 116°10’34.8”E	Bamboo plantations	Unproductive land	137	102
	Kangas Lauk 1	8°47’44.8”S, 116°10’40.1”E	Bamboo plantations	Unproductive land	123	104
	Karang Sidemen 2	8°34’00.1”S, 116°18’06.7”E	Home garden	Under-utilized land	407	93
	Narmada	8°35’36.4”S, 116°12’32.7”E	Home garden	Under-utilized land	129	90
	Presak Bat	8°36’39.6”S, 116°23’38.9”E	Home garden	Under-utilized land	408	95
	Tojak	8°38’14.3”S, 116°17’43.3”E	Bamboo plantations	Unproductive land	322	96
	Batu Jangkih	8°48’52.1”S, 116°09’30.8”E	Dryland	Abandoned land	284	96
	Montong Terep	8°38’43.1”S, 116°17’43.3”E	Bamboo plantations	Unproductive land	302	98
4	Panggongan	8°48’30.6”S, 116°11’53.3”E	River, paddy field	Productive land	139	122
	Jurit	8°36’18.8”S, 116°21’49.3”E	Bamboo plantations	Unproductive land	399	119
	Bebante 1	8°37’13.7”S, 116°17’58.9”E	Dryland	Abandoned land	384	115
	Lendang Kondak 2	8°40’44.6”S, 116°18’04.0”E	Home garden	Under-utilized land	255	115
	Kending Sampi 1	8°48’19.7”S, 116°10’58.6”E	Home garden	Under-utilized land	116	112
	Pampang 1	8°48’03.0”S, 116°07’45.1”E	Home garden	Under-utilized land	129	111
	Bebante 2	8°37’09.1”S, 116°17’50.8”E	Bamboo plantations	Unproductive land	379	109
5	Lando 1	8°48’18.0”S, 116°10’58.7”E	Home garden	Under-utilized land	491	132
	Kending Sampi 2	8°48’18.0”S, 116°10’58.7”E	Home garden	Under-utilized land	125	132
	Sape	8°37’57.8”S, 116°19’31.3”E	Home garden	Under-utilized land	363	130
	Lando 2	8°36’02.4”S, 116°23’17.4”E	Shurbs and dry land	Unproductive land	409	130
	Karang Lebah	8°36’47.2”S, 116°21’56.8”E	Home garden	Under-utilized land	345	128
	Gunung Sasak 1	8°41’01.4”S, 116°07’57.8”E	Home garden	Under-utilized land	72	128
	Gunung Ise	8°37’51.2”S, 116°17’55.9”E	Bamboo plantations	Unproductive land	347	128
	Beson	8°40’16.4”S, 116°22’48.3”E	Bamboo plantations	Unproductive land	369	136
	Malimbu 1	8°26’25.5”S, 116°02’37.7”E	Hill near the beach	Unproductive land	60	134
6	Lendang Tampel	8°36’56.9”S, 116°17’01.0”E	Paddy field	Productive land	294	144
	Gunung Sasak 2	8°41’01.4”S, 116°07’58.1”E	Hill near settlement	Unproductive land	70	143
	Lendang Kondak 1	8°40’44.6”S, 116°18’04.0”E	River	Productive land	251	146
7	Karang Sidemen 3	8°31’51.3”S, 116°18’41.6”E	Secondary forest	Productive land	564	157
	Karang Sidemen 1	8°31’56.7”S, 116°18’55.3”E	Secondary forest	Productive land	554	165



A B

Figure 2. Spatial variation of soil texture. A. Soil texture distribution, B. Spatial variations of soil fraction

According to the straw home industry, four sizes of bamboo straws are preferred by consumers and have been exported to several countries. According to the straw home industry, four sizes of bamboo straws are preferred by consumers and have been exported to several countries. These straws have different diameter classifications: thin, medium, large, and extra large (Figure 8). The most fitted diameter of bamboo culms grown in habitat-1 were thin, small, and large diameters; the *S. lima*-based straws for those three categories were produced from habitat-1. The most fitted diameter of bamboo culms grown in habitat-1 were thin, small, and large diameters; the *S. lima*-based straws for those three categories were produced from habitat-1. Bamboo grown in habitat-2 had medium, large, and extra-large straw sizes. Large and extra-large straw sizes were also provided by habitat-3. Habitat-6 and habitat-7 did not provide any bamboo straw classification (Table 3). Bamboo grown in habitat-2 had medium, large, and extra-large straw sizes. Large and extra-large straw sizes were also provided by habitat-3. Habitat-6 and habitat-7 did not provide any bamboo straw classification (Table 3).

Table 3. Various sizes of straws provided by some bamboo clumps diameters

Habitat groups	Culms diameter (mm)	Variation of bamboo straws size (mm)			
		Thin (5 to10)	Medium (11 to 15)	Large (16 to 20)	Extra large (21 to 25)
1	13.01±6.09	√	√	√	-
2	20.22±6.33	-	√	√	√
3	23.29±3.24	-	-	√	√
4	22.87±2.06	-	-	-	√
5	23.23±1.79	-	-	-	√
6	35.56±2.98	-	-	-	-
7	30.03±1.41	-	-	-	-

Note: Values indicate mean ±SD, -: not meet the standard),√: meet the standard

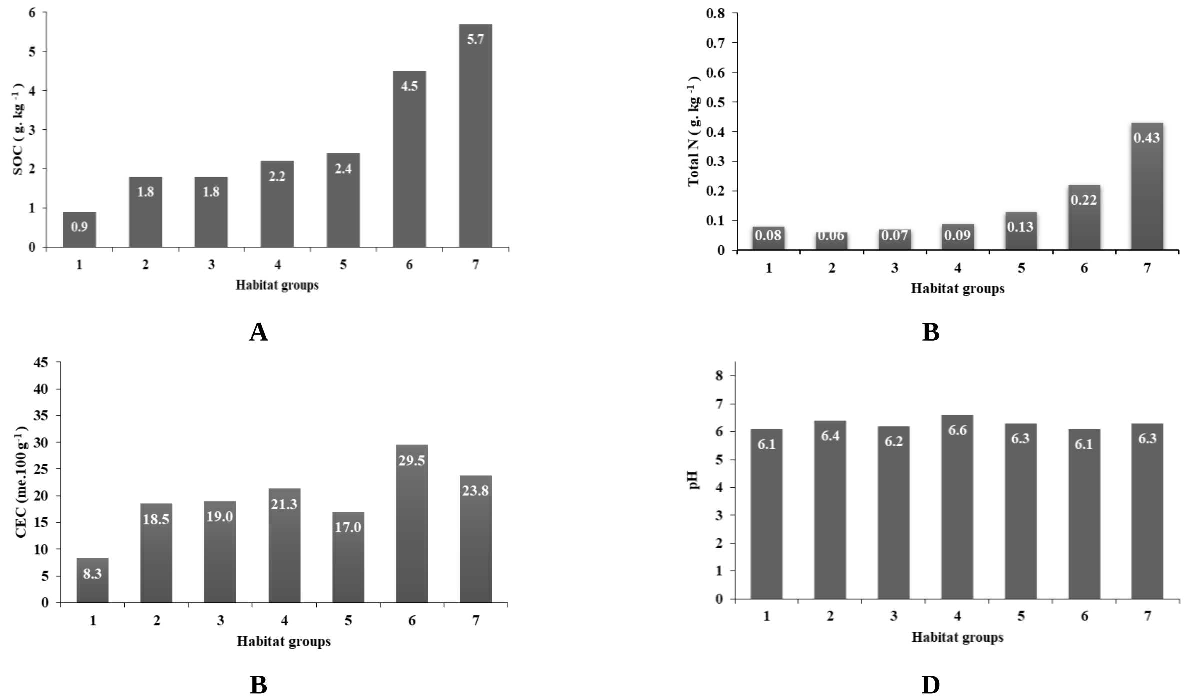


Figure 3. Variation of soil properties of *Schizostachyum lima* habitat. A. SOC, B. Total N, C. CEC, D. pH

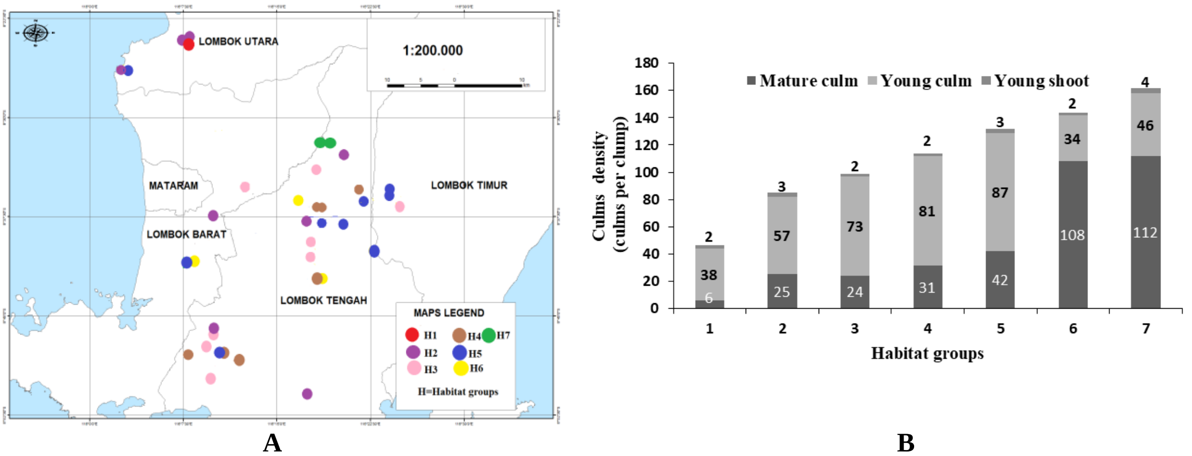


Figure 4. Spatial variation of *Schizostachyum lima* population. A. Distribution, B. Clump density (culms per clump)

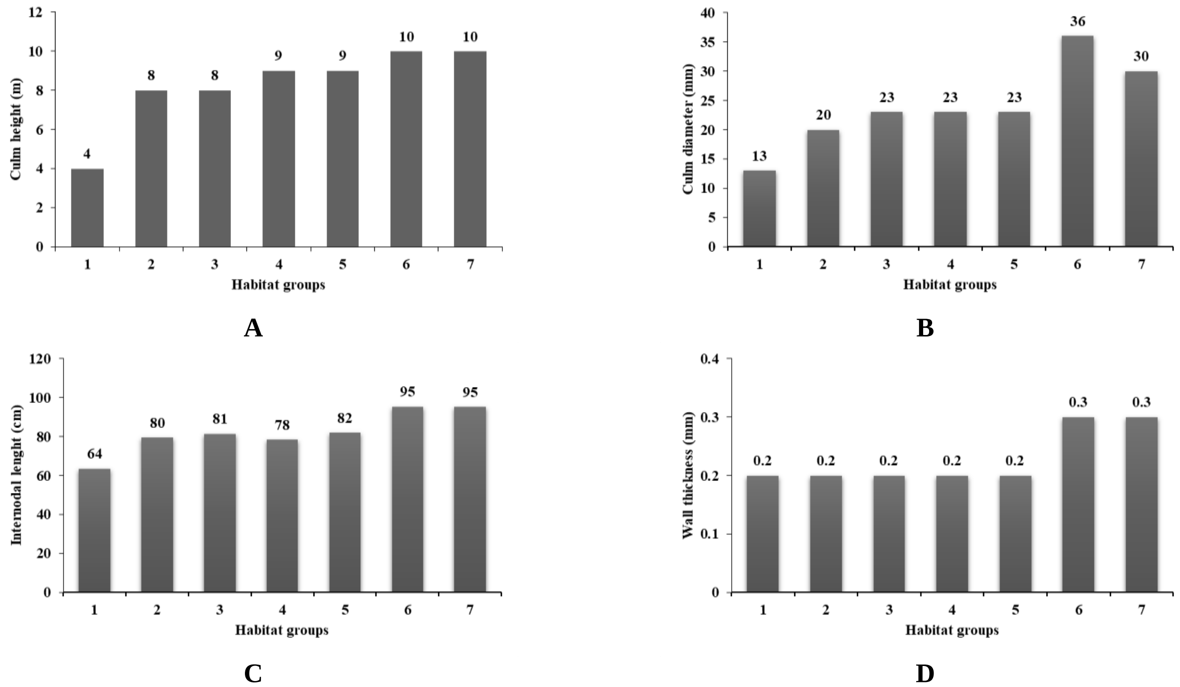


Figure 5. Variation of culm growth in populations of *Schizostachyum lima*. A. Height (m), B. Diameter (mm), C. Internodal length (cm), D. Wall thickness (mm)

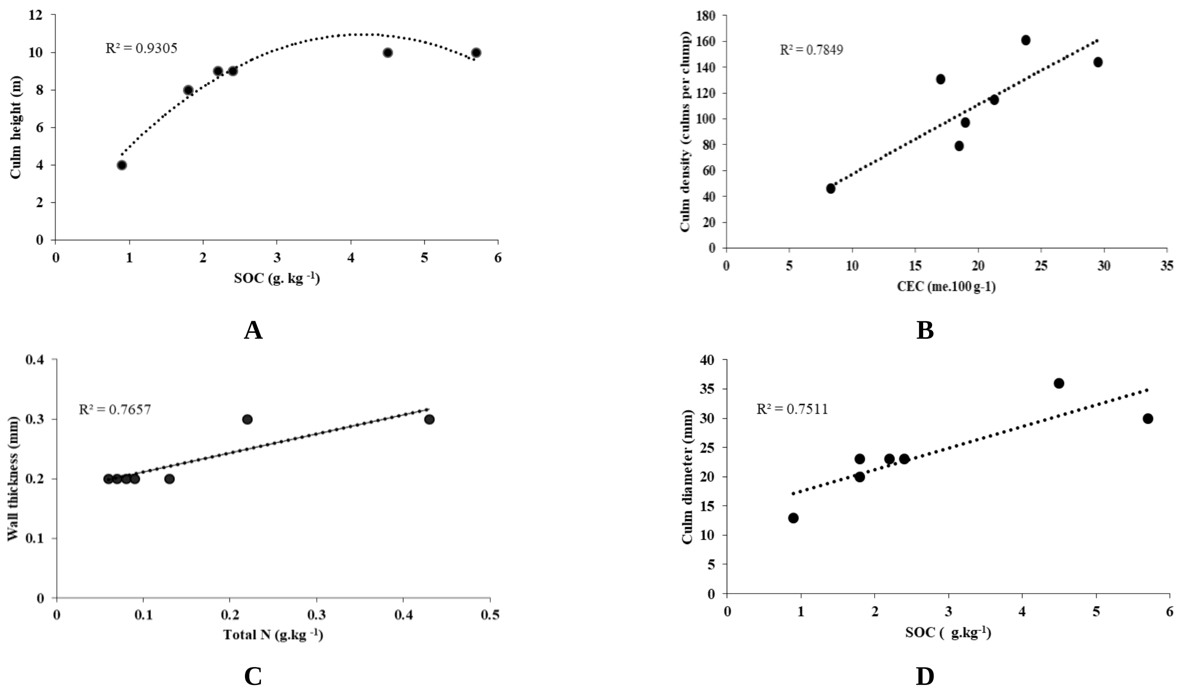


Figure 6. Significant relationships between growth and soil properties. A. Culm height with SOC, B. Culm diameter with SOC, C. Wall thickness with total N, D. Culm density with CEC

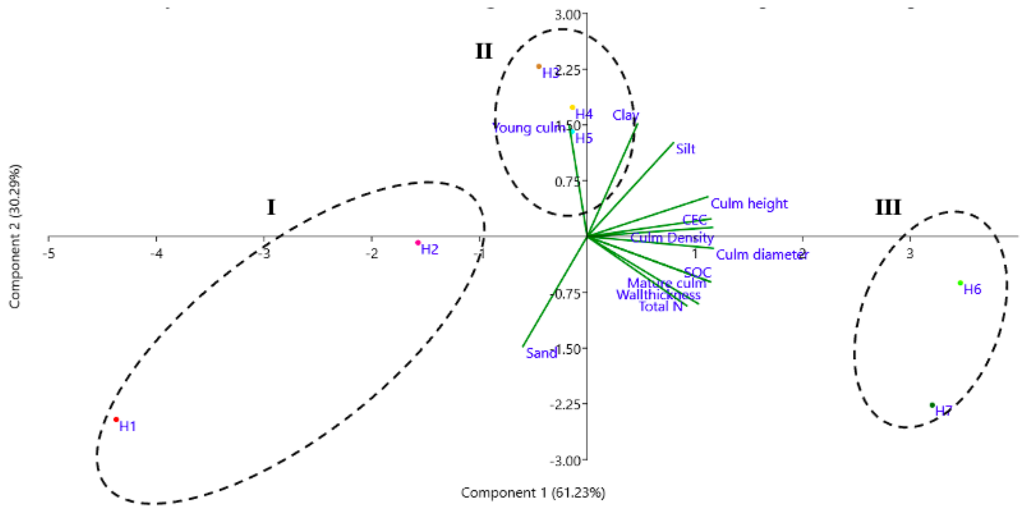


Figure 7. Interaction between habitat properties and growth of *Schizostachyum lima*

A B C D

Figure 8. Various sizes of bamboo straws of *Schizostachyum lima.* A. thin (5-10 mm), B. Medium (11-15 mm), C. Large (16-20 mm), D. Extra-large (21-25 mm). Scale bar: 2 cm

Discussion

The habitat conditions strongly influenced the population growth of *S. lima*. As confirmed by previous studies, the limiting factors for bamboo growth were altitude, climate, and soil type (Fitmawati et al. 2021). This study revealed that the *S. lima* populations in Lombok Island were found in 107 m asl to 456 m asl (Table 1). A previous study also supported these results, where *S. lima* was found at an altitude of 500 m asl in Central Lombok (Damayanto et al. 2020). A previous study also supported these results, where *S. lima* was found at an altitude of 500 m asl in Central Lombok (Damayanto et al. 2020). Furthermore, the population of *S. lima* on this island grew in the specific soil pH values from 6.23 to 6.53 (Figure 3), while the bamboo population grown in Gunung Baung Nature Park, Pasuruan, grew in pH 5.6 to 6.5 (Sofiah et al. 2018). Furthermore, the population of *S. lima* on this island grew in the specific soil pH values from 6.23 to 6.53 (Figure 3), while the bamboo population grown in Gunung Baung Nature Park, Pasuruan, grew in pH 5.6 to 6.5 (Sofiah et al. 2018). These data indicated that *S. lima* bamboo populations grew well in slightly acidic soil. However, some studies reported that bamboo could adapt well to non-optimum or harsh soil by modifying its morphological, physiological, or biochemical properties. However, some studies reported that bamboo could adapt well to non-optimum or harsh soil by modifying its morphological, physiological, or biochemical properties. These growth variations or phenotypic variability included culm height, diameter size, internodal length, and wall thickness (Gratani 2014; Granata et al. 2020; Zhang et al. 2022).

Three growth variations were found in Lombok Island's *S. lima* population: poor, good, and very good. Three growth variations were found in Lombok Island's S. lima population: poor, good, and very good. The population growth of *S. lima* in habitats-1 and -2 was categorized as poor due to the lowest growth parameters. The soil properties of these two habitats were categorized as poor based on the soil quality standards by the Indonesian Soil Research Center (2009), the SOC content ranged from 0.9-1.8 $g.kg^{-1}$, and total N ranged from 0.06-0.08 $g.kg^{-1}$. The population growth of *S. lima* in habitats -1 and -2 was categorized as poor due to the lowest growth parameters. The soil properties of these two habitats were categorized as poor based on the soil quality standards by the Indonesian Soil Research Center (2009), the SOC content ranged from 0.9-1.8 $g.kg^{-1}$, and total N ranged from 0.06-0.08 $g.kg^{-1}$. Meanwhile, the SOC and total N content in habitats -6 and -7 were relatively higher than in other habitats (ranging from 4.5-5.7 $g.kg^{-1}$ and 0.22-0.43 $g.kg^{-1}$, respectively, Figure 5). Meanwhile, the SOC and total N content in habitats -7 and -6 were relatively higher than in other habitats (ranging from 4.5-5.7 $g.kg^{-1}$ and 0.22-0.43 $g.kg^{-1}$, respectively, Figure 5). As stated in a previous study, organic SOC and total N content are essential nutrients in the soil for plant development and growth (Heuermann et al. 2021). The statistical regression analysis showed significant correlation between growth parameters, SOC, and total N content (Figure 6). The statistical regression analysis showed significant correlation between growth parameters, SOC, and total N content (Figure 6). The SOC determined soil quality, especially nutrient reserves and fertility (Gerke 2022).

In addition, nitrogen is a macronutrient for growth, categorized as an essential plant substance (Leghari et al. 2016). In addition, nitrogen is a macronutrient for growth, categorized as an essential plant substance (Leghari et al. 2016). Nitrogen is needed in most plants' metabolic and physiological processes more than other important nutrients (Kishorekumar et al. 2020). Nitrogen is needed for most plants' metabolic and physiological processes more than other important nutrients (Kishorekumar et al. 2020). As studied before, the different nitrogen levels correlated to the population of bamboo shoots and leaves of *Dendrocalamus latiflorus* Munro (Lili et al. 2021). As studied before, the different nitrogen levels correlated to the population of bamboo shoots and leaves of *Dendrocalamus latiflorus* Munro (Lili et al. 2021). Moreover, using nitrogen fertilizer on *Bambusa bambos* L. influenced the height, the number of culms, diameter, and growth rate of new culms daily (Waseem et al. 2019). Moreover, using nitrogen fertilizer on *Bambusa bambos* L. influenced the height, the number of culms, diameter, and growth rate of new culms daily (Waseem et al. 2019). Besides, SOC and total N content, and CEC also played an important role in plant growth and development. As previously studied, the CEC is an important soil property of fertility due to its ability to prevent nutrient loss from leaching (Zhao 2016). Therefore, a higher CEC value may provide more nutrients than a lower one (Räty et al. 2021). Therefore, a higher CEC value may provide more nutrients than a lower one (Räty et al. 2021). The CEC value found in all habitats was 8.3 to 29.5 me.100 g^{-1} and categorized as low to medium levels (Soil Research Center 2009). Then, the regression analysis showed that increasing CEC significantly increased the culm density (Figure 6). The CEC value was closely related to the soil fraction and pH (Tomašić et al. 2013). However, the soil CEC did not correlate with pH in this study due to no pH variation in all habitats. However, the soil CEC did not correlate with pH in this study due to no pH variation in all habitats. A previous study in Vojvodina, Serbia, indicated that CEC depended on the clay fraction and humic organic matter (Nešić et al. 2015). A previous study in Vojvodina, Serbia, indicated that CEC depended on the clay fraction and humic organic matter (Nešić et al. 2015). Another study also supported this result, where CEC showed a positive correlation with clay, silt, and organic matter but had a negative correlation with sand (Yunan et al. 2018).

Biplot analysis showed that the high sand fraction was the main character of cluster 1 (habitat-1 and habitat-2). This sand fraction was negatively correlated with the clay and silt fractions, culm height, culms density, and CEC (Figure 7. This sand fraction was negatively correlated with the clay and silt fractions, culm height, culms density, and CEC (Figure 7). The sand fraction in cluster 1 reached 90%, while the other habitats ranged from 52% to 75%. The sand fraction in cluster 1 reached 90%, while the other habitats ranged from 52% to 75%. Sandy soil has low water and nutrient content and weak particle binding capacity (Tsozué et al. 2016). Sandy soil has low water and nutrient content and weak particle binding capacity (Tsozué et al. 2016). A previous study confirmed that sandy soil is unsuitable for growing bamboo due to its high permeability (Durai and Long 2019) and nutrients leaching from the topsoil layer (Huang and Hartemink 2020).

In contrast, cluster 3, consisting of habitats-6 and -7, was found to have a high value for almost all soil parameters except sand fraction. In contrast, cluster 3, consisting of habitats-6 and -7, was found to have a high value for almost all soil parameters except sand fraction. The high CEC, SOC, and total N content promoted good growth parameters except for young culm. The high CEC, SOC, and total N content promoted good growth parameters except for young culm. It was revealed that a culm larger than 30 to 36 mm in diameter might prevent bamboo harvest in cluster 3 habitats. It was revealed that a culm larger than 30 to 36 mm in diameter might prevent bamboo harvest in cluster 3 habitats. Consequently, these habitats had a higher old culm density and litter biomass for better soil fertility, as shown by the high SOC, total-N, and CEC content. Consequently, these habitats had a higher old culm density and litter biomass for better soil fertility, as shown by the high SOC, total-N, and CEC content. This SOC increased the age of old clump density (Nath et al. 2015). The decomposition and nutrient release from bamboo in the Northeast India traditional agroforestry system increased the SOC and total N content. Hence, it might improve the soil microenvironment (Nath and Das 2011).

The soil textures in cluster 3 were loam, sandy loam, and loamy sand. The clay soils have greater total pore space than sandy soil (Firoozi et al. 2016). Besides, sandy loam and clay soils had a medium soil texture (Jaja 2016). Soil texture influences water content, nutrient availability, and retention (Silver et al. 2000). Generally, good soils have a fine and medium texture that makes it easier to bind nutrients, and water content and supply the available nutrients. Generally, good soils have a fine and medium texture that makes it easier to bind nutrients and water content and supply the available nutrients. This study recorded two soil classes, such as medium and coarse textures. This study recorded two soil classes, such as medium and coarse textures. The medium texture includes loam and sandy loam, while the coarse texture consists of sand and loamy sand (Jaja 2016).

Meanwhile, bamboo growth in cluster 2 was found in habitats -3, -4 and -5 and is considered a good category. Meanwhile, bamboo growth in cluster 2 was found in habitats -3, -4, and -5 and is considered a good category. The average culm height of this population was 8 to 9 m, with a diameter ranging from 22 to 23 mm. The soil textures were loam, sandy loam, and loamy sand; the SOC varied from 1.8 to 2.4 $g.kg^{-1}$, while the total N content varied from 0.06 to 0.13 $g.kg^{-1}$. The soil textures were loam, sandy loam, and loamy sand; the SOC varied from 1.8 to 2.4 $g.kg^{-1}$, while the total N content varied from 0.06 to 0.13 $g.kg^{-1}$. Although the culm diameter in clusters 1 and 2, including habitat-1 to habitat-5 ranged from 13 to 24 mm, it met the standard for medium to extralarge straw. Although the culm diameter in clusters 1 and 2, including habitat-1 to habitat-5 ranged from 13 to 24 mm, it met the standard for medium to extralarge straw. In contrast, the bamboo population in cluster 3, including habitat-6 and habitat-7 had higher diameters reaching 30 mm to 36 mm, and did not meet the straw standard (Table 3). In contrast, the bamboo population in cluster 3, including habitat-6 and habitat-7 had higher diameters reaching 30 mm to 36 mm, and did not meet the straw standard (Table 3).

Spatial variations in SOC, total N, CEC, and soil texture greatly influenced the growth of *S. lima* populations, shown by phenotypic variability in height, diameter, intermodal length, wall thickness, and clump density. The habitat properties of clusters 1 and 2 had low SOC, total N content, and CEC but a high sand fraction. These properties promoted low growth parameter levels, including bamboo height, diameter size, intermodal length, and wall thickness. These properties promoted low growth parameter levels, including bamboo height, diameter size, intermodal length, and wall thickness. Hence, clusters 1 and 2 should be used as the referenced habitats for the *S. lima* population, which provided a high qualification of straw industry materials. Hence, clusters 1 and 2 should be used as the referenced habitats for the *S. lima* population, which provided a high qualification of straw industry materials. Besides, a better bamboo growth of cluster 3, mostly grown in the less critical land, had a higher SOC, total N, and CEC content, but a low sand fraction. Besides, a better bamboo growth of cluster 3, mostly grown in the less critical land, had a higher SOC, total N, and CEC content but a low sand fraction.

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