

FIELD NOTE

Longitudinal and geographic variations in the green moisture content and basic density of bamboo culm in three species naturally grown in Lombok Island, Indonesia

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ABSTRACT Longitudinal and geographic variations in the green moisture content and basic density of bamboo culm were evaluated by using linear mixed-effect models for three bamboo species (*Bambusa vulgaris* Schrad. ex J.C., *Bambusa maculata* Widjaja, and *Gigantochloa atter* (Hassk) Kurz ex Munro) naturally grown in four locations in Lombok Island, Indonesia. The mean green moisture contents and basic densities were 74.2% and 0.69 g cm⁻³ for *B. vulgaris*, 78.5% and 0.65 g cm⁻³ for *B. maculata*, and 80.3% and 0.65 g cm⁻³ for *G. atter*, respectively. No significant differences in green moisture content and basic density were found among the species. A significant negative correlation between basic density and green moisture content was found in all three species. Based on the results of model selections for longitudinal variations, the green moisture content decreased with an increase in the culm height in all three species, and basic density tended to increase from the base to the top of the culm. Relatively large geographical variation was found in the green moisture content and basic density of *G. atter*, although the main reasons for variation of these properties were individual culm in three species.

Key words: *Bambusa vulgaris*, *Bambusa maculata*, *Gigantochloa atter*; longitudinal variation, mixed-effects model

INTRODUCTION

Lombok Island is located in central part of Indonesia and is belonging to West Nusa Tenggara. Because more than 80% of the forest area is classified as protected forest or conservation forest (Bae et al. 2014), utilization of wood from the forest are limited in this island. Thus, local people in Lombok Island needs to find substitute materials of wood for producing handicrafts, furniture, construction, and others.

Bamboo is a fast-growing plant (Kleinhenz and Midmore 2001, Liese and Kohl 2015, Wang et al. 2016) and is considered a substantial biomaterial (Peng and She 2014, Huang et al. 2015, Liese and Kohl 2015). Bamboo has traditionally been used for handicraft making, furniture and house construction (van Dam et al. 2018). Recently, bamboo has also been used in a wide range of engineering and civil construction applications (van der Lugt et al. 2006, Tan et al. 2011, Chaowana 2013, Sharma et al. 2015,

Liu et al. 2020, Aguinatan et al. 2019). To create the more value-added products such as modern civil construction materials, bamboo culm properties should be clarified. Up to date, bamboo culm properties have been investigated for some tropical bamboo species, such as *Dendrocalamus strictus*, *Dendrocalamus giganteus*, *Dendrocalamus asper*, *Bambusa blumeana*, *Bambusa vulgaris*, *Bambusa balcoa*, *Bambusa tulda*, *Gigantochloa scortechinii*, *Gigantochloa atter*, and *Gigantochloa levis* (Liese 1987, Mohmod et al. 1990, Hisham et al. 2006, Kamruzzaman et al. 2008, Wahab et al. 2010, Marsoem et al. 2015, Wang et al. 2016, Zakikhani et al. 2017, Aguinatan et al. 2019, Nordahlia et al. 2019). Unfortunately, no available information about bamboo culm properties was found in *B. vulgaris*, *B. maculata*, and *G. atter* which natively grown in Lombok Island and traditionally used for local products. To create the value-added new products based on bamboo instead of traditional local products such as handicrafts and others for developing local economy, detailed bamboo culm properties

should be clarified in these native bamboo species grown in Lombok Island.

It is known that bamboo properties varied along the longitudinal direction within the whole culm (Grosser and Liese 1971, Anokye et al. 2014, Marsoem et al. 2015, Vetter et al. 2015). For example, Anokye et al. (2014) reported that the moisture content decreased and the shrinkage increased along the culm from basal to the top section of *G. scortechinii* growing in Malaysia. In addition, bamboo culm properties have geographic variations (Yang et al. 2009, Wang et al. 2016). Wang et al. (2016) examined the fiber morphology and amounts of chemical components in *D. giganteus* collected from three different locations in China. They concluded significant differences in fiber morphologies among the three locations. Therefore, the longitudinal and geographical variations of bamboo culm properties should be clarified to effectively utilize bamboo culm resources.

The objective of this study was to investigate the longitudinal and geographic variations in the green moisture content and basic density of bamboo culm in three native species in Lombok Island, Indonesia.

MATERIALS AND METHODS

Experimental sites

Culms of three- to four-year-old *B. vulgaris*, *B. maculata*, and *G. atter* were collected from Tempos (Site I), Kabul (Site II), Keruak (Site III), and Genggelang (Site IV) in Lombok Island, Indonesia (Fig. 1). The climatic conditions of each site are shown in Fig. 1. All the bamboos used in this study were naturally grown in the four sites. No silvicultural treatments, such as fertilizing or watering, were applied at all sites before sampling. Ten individual culms in each species at each site were cut at 20 cm above the ground. Thus, a total of 120 culms were obtained from the three species at the four sites. Table 1 shows the culm diameter of 1.3 m above the ground, culm thickness, and culm height. After cutting the culm, approximately 3 cm-thick sample disks were obtained at 2-m intervals from 2 m to 8 m above the ground to determine the green moisture contents and basic densities.

Green moisture content and basic density

Four small specimens (2.5 [T] cm by 2.5 [L] cm with varied culm thicknesses in radial direction) were prepared

from various disk circumferences. Finally, 1,920 small specimens were obtained (four specimens \times four heights \times ten individuals \times three species \times four sites). The weight and volume in the green condition of the specimens were measured. Green volume was measured via a water displacement method (Barnett and Jeronimidis 2003). Then, the specimens were weighed after drying in an oven at $103 \pm 2^\circ\text{C}$ for 48 h.

Statistical analysis

Statistical analysis was conducted using R software ver. 4.0.3 (R Core Team 2020). The mean value in each culm was calculated by averaging the values obtained from 16 specimens (four specimens by four heights). Longitudinal variations in the green moisture content and basic density were evaluated by developing a linear mixed-effect model using the lme4 package in R software ver.4.0.2 (Bates et al. 2015). The full model is expressed as:

$$Y_{ijk} = (\beta_0 + Site_{0k} + Culm_{0jk})X_{ijk} + \beta_1 + Site_{1k} + Culm_{1jk} + e_{ijk} \quad (1)$$

where Y_{ijk} is the bamboo property (green moisture content or basic density) at the i th height position from the j th individual culm within the k th site, β_0 is the fixed slope, β_1 is the fixed intercept, X_{ijk} is the i th height position from the j th individual culm within the k th site. $Site_{0k}$ and $Site_{1k}$ are the random slope and intercept of the k th site, $Culm_{0jk}$ and $Culm_{1jk}$ are the random slope and intercept of the j th individual culm within the k th site, and e_{ijk} is the residual. Total 15 models were developed, and then the best model was determined based on the Akaike information criterion (AIC) (Akaike 1998); that is, the model with the minimum AIC is preferred. In addition, the differences in AIC (ΔAIC) ≤ 2 indicate no significant difference between models, and a simpler model with fewer parameters is preferred (Burnham and Anderson 2004). The significances of the fixed-effect parameters of the best model were determined using the lmerTest package (Bates et al. 2015).

Geographic variations in green moisture content and basic density were estimated by evaluating the variance component of sites as random effect by using the intercept-only linear mixed-effects model. The model is described as follows:

$$Y_{ijk} = \mu + Site_k + Culm_{jk} + e_{ijk} \quad (2)$$

where Y_{ijk} is the bamboo property at the i th height position of the j th individual culm within k th site, μ is the model intercept or grand mean, $Site_k$ is the random effect of the k th

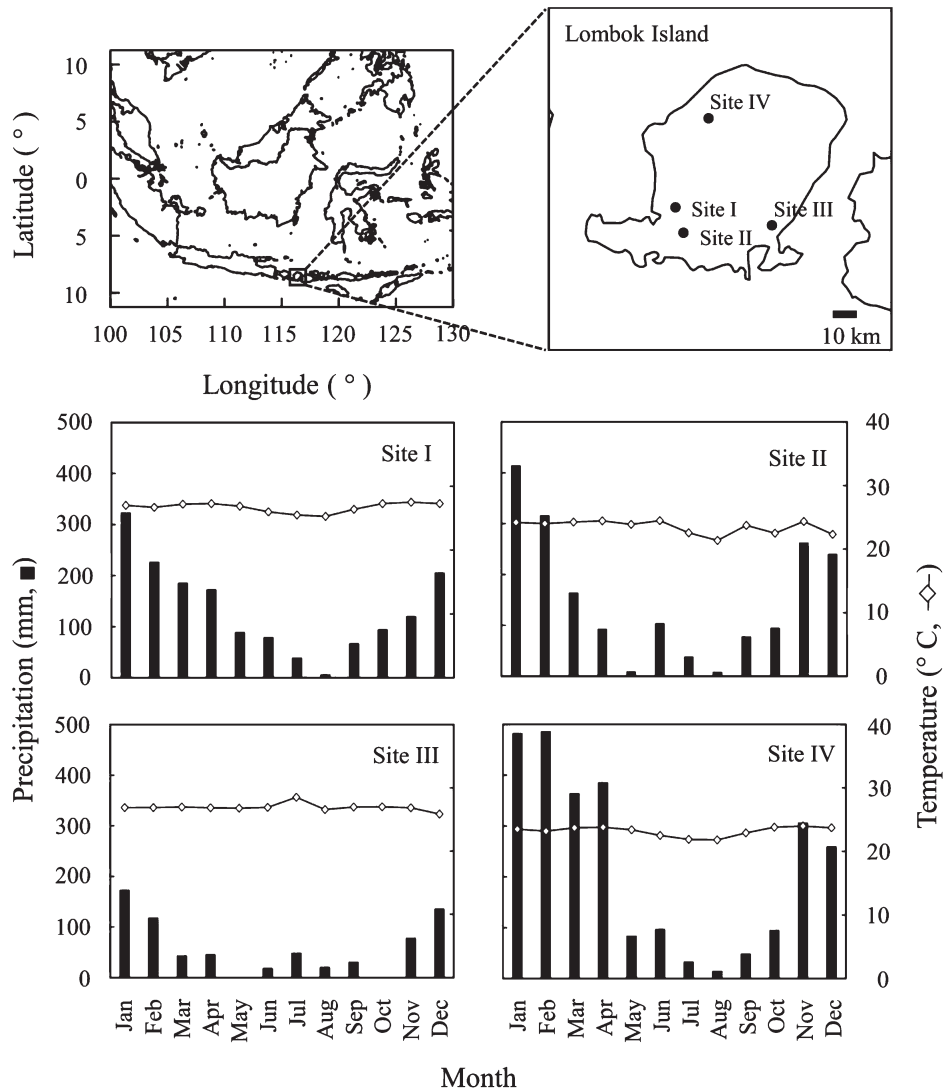


Fig. 1. Locations and climate conditions of sampling sites in the present study.

Note: Site I, Tempos ($8^{\circ}41'59''S$, $116^{\circ}8'40''E$); Site II, Kabul ($8^{\circ}47'21''S$, $116^{\circ}10'21''E$); Site III, Keruak ($8^{\circ}45'45''S$, $116^{\circ}28'54''E$); Site IV, Genggeling ($8^{\circ}23'16''S$, $116^{\circ}15'35''E$). Climate data were provided from Nusa Tenggara River Basin Management I, Indonesia. Mean monthly temperature and precipitation were calculated by averaging monthly values from 2016 to 2018. Diamonds indicate the mean values of temperature. Bars indicate the mean values of precipitation.

site, $Culm_{jk}$ is random effect of j th individual culm within k th site, and e_{ijk} is the residual. The contribution of each level of variation was calculated as a percentage of the total random variation in the best model (Wilhelmsson et al. 2002, Auty et al. 2013).

A Tukey-Kramer test was applied for detecting the among-species differences in growth characteristics, green moisture content, and basic density. The mean values of each individual culm were used for the Tukey-Kramer test.

RESULTS AND DISCUSSION

Growth characteristics

The growth characteristics of the three bamboo species at each site are presented in Table 1. The highest mean culm diameters were recorded in *G. atter* (ranged from 7.9 cm to 9.4 cm), followed by *B. vulgaris* (ranged from 6.8 cm to 8.0 cm) and *B. maculata* (ranged from 6.3 cm to 8.0 cm) (Table 1). The mean culm height and thickness values of *B. vulgaris*, *B. maculata*, and *G. atter* ranged from 13.59 m to 17.53 m and 0.66 cm to 0.90 cm, 14.77 m to 16.78 m and 0.56 cm to 0.81 cm, and 14.92 m to 18.10 m and 0.49 cm to

Table 1. Mean values of diameter, height, and culm thickness of three bamboo species.

Species	Site	n	CD (cm)		CH (m)		CT (cm)	
			Mean	SD	Mean	SD	Mean	SD
<i>Bambusa vulgaris</i>	I	10	8.0	0.2	17.53	1.38	0.90	0.12
	II	10	8.0	0.2	15.18	1.90	0.66	0.06
	III	10	6.8	0.4	15.92	1.78	0.76	0.05
	IV	10	7.1	0.2	13.59	1.56	0.85	0.12
	Mean	40	7.5 ^b	0.6	15.55 ^b	2.15	0.86 ^a	0.10
<i>Bambusa maculata</i>	I	10	8.0	0.2	16.78	1.63	0.61	0.09
	II	10	7.7	0.4	14.91	1.71	0.74	0.06
	III	10	6.3	0.3	14.77	1.45	0.81	0.06
	IV	10	7.0	0.6	16.41	1.49	0.56	0.05
	Mean	40	7.3 ^b	0.8	15.72 ^{ab}	1.76	0.58 ^c	0.09
<i>Gigantochloa atter</i>	I	10	9.3	0.4	18.10	1.39	0.68	0.06
	II	10	9.4	0.3	16.42	2.01	0.87	0.08
	III	10	7.9	0.4	14.92	1.44	0.49	0.04
	IV	10	8.4	0.2	17.05	2.03	0.77	0.06
	Mean	40	8.7 ^a	0.7	16.62 ^a	2.04	0.74 ^b	0.07

Note: n, number of individual culms; CD, culm diameter at 1.3 m above the ground; CH, culm height; CT, mean value of culm thickness from those at four height positions; SD, standard deviation. The same alphabet letters after mean values of each species indicate no significant differences at $p < 0.05$ among three species by Tukey-Kramer test.

0.87 cm, respectively (Table 1). Bamboo has various growth characteristics among its species (Akinlabi et al. 2017, Nordahlia et al. 2019). Each bamboo species has distinct absolute characteristics, such as its culm height, internode length, and culm thickness (Nordahlia et al. 2019). Based on the results, the growth characteristics of the three bamboo species could be summarized as follows: 1) the two *Bambusa* species had similar culm sizes (diameter and height) but differing culm thicknesses, 2) *B. vulgaris* had the thickest culm among the three species, and 3) *G. atter* had the largest culm size among the three species but had thinner culm compared with *B. vulgaris*.

Green moisture content and basic density

Table 2 shows the mean green moisture content and basic density values of the three bamboo species at each site. The mean green moisture content values of *B. vulgaris*, *B. maculata*, and *G. atter* ranged from 65.7% to 79.4%, 72.5% to 88.9%, and 69.0% to 95.7%, respectively. The mean basic density values of *B. vulgaris*, *B. maculata*, and *G. atter* ranged from 0.66 g cm⁻³ to 0.74 g cm⁻³, 0.62 g cm⁻³ to 0.68 g cm⁻³, and 0.59 g cm⁻³ to 0.71 g cm⁻³, respectively (Table 2). No significant differences in the mean values of both properties were found among the three species (Table

2). With a few exceptions, the mean green moisture content and basic density values in the present study were within the range of those reported in previous studies (Table 3; Hisham et al. 2006, Wahab et al. 2010, Anokye et al. 2014, Marsoem et al. 2015, Ogunsanwo et al. 2015, Nordahlia et al. 2019).

Relationships found between green moisture content and basic density are shown in Fig. 2. Green moisture content was negatively correlated with basic density in all three species. Similar results were obtained in many bamboo species (Hisham et al. 2006, Wahab et al. 2010, 2012, Sharma et al. 2017).

Longitudinal variations

Tables 4 and 5 show the rank of linear mixed-effects models of longitudinal variations in the three bamboo species of green moisture content and basic density in relation to AIC values. For the longitudinal variation of green moisture content and basic density, the model with random slope and intercept of individual culm was selected as the best model in all species with few exceptions (Tables 4 and 5). In addition, the best model also included the site of random intercept for both properties in *G. atter*, whereas the site was neither random slope nor intercept of the best

Table 2. Mean values of green moisture content and basic density of three bamboo species.

Species	Site	n	Green moisture content (%)		Basic density (g cm ⁻³)	
			Mean	SD	Mean	SD
<i>Bambusa vulgaris</i>	I	10	74.1	9.5	0.67	0.05
	II	10	77.6	23.7	0.69	0.10
	III	10	79.4	17.4	0.66	0.07
	IV	10	65.7	17.6	0.74	0.08
	Mean	40	74.2 ^a	17.9	0.69 ^a	0.08
<i>Bambusa maculata</i>	I	10	88.9	17.3	0.62	0.07
	II	10	77.6	17.9	0.66	0.08
	III	10	72.5	18.1	0.67	0.09
	IV	10	74.9	14.1	0.68	0.06
	Mean	40	78.5 ^a	17.5	0.65 ^a	0.08
<i>Gigantochloa atter</i>	I	10	79.4	17.6	0.66	0.07
	II	10	77.3	22.1	0.66	0.08
	III	10	95.7	16.9	0.59	0.06
	IV	10	69.0	10.4	0.71	0.05
	Mean	40	80.3 ^a	19.3	0.65 ^a	0.08

Note: n, number of individual culms; SD, standard deviation. The same alphabet letters after mean values of each species indicate no significances at $p < 0.05$ among three species by Tukey-Kramer test.

Table 3. Comparisons of green moisture content and basic density of *Bambusa* and *Gigantochloa* species in previous studies.

Genus	Species	Age (year)	MC (%)	BD (g cm ⁻³)	References
<i>Bambusa</i>	<i>B. vulgaris</i>	4	88.9	0.66	Wahab et al. (2010)
		4	ND	0.61	Nordahlia et al. (2019)
		5-6	ND	0.72	Ogunsanwo et al. (2015)
		4	96.0	ND	Anokye et al. (2014)
	<i>G. atter</i>	3	112.3	0.59	Marsoem et al. (2015)
<i>Gigantochloa</i>	<i>G. scortechinii</i>	3.5	65.4	0.61	Hisham et al. (2006)
		4	89.1	ND	Anokye et al. (2014)
		4	ND	0.64	Nordahlia et al. (2019)

Note: MC, green moisture content; BD, basic density; ND, no available data.

models in *B. maculata* (Tables 4 and 5). These results indicate that 1) the longitudinal variations of all species were dependent on the individual culm with few exceptions, and 2) the sites were affected on longitudinal variation in *G. atter*, but not in *B. maculata*.

Table 6 shows the fixed-effect parameters for the selected model. The fixed-effect parameters were significant for all parameters, except for the fixed slope of basic density in *B. vulgaris*. Fig. 3 shows the longitudinal variations in the green moisture content and basic density of the three bamboo species used in the present study. A

regression formula was obtained using a linear mixed-effects model with minimum AIC values among developed models (Tables 4 and 5). Green moisture content decreased with an increase in the culm height for all three species. The same longitudinal patterns of green moisture contents were also found in *B. vulgaris* grown in Malaysia (Wahab et al. 2010, Anokye et al. 2014); *B. balcooa*, *B. tulda*, and *B. salarkhanii* grown in Bangladesh (Kamruzzaman et al. 2008); and *G. atter* grown in Indonesia (Marsoem et al. 2015). On the other hand, basic densities tended to increase from the base to the top of the culm. Variations in the basic

Table 4. A comparison of linear mixed-effects models in the green moisture content of three bamboo species with sites and, or individual culms as random effects.

Species	Model ranking	Random slope		Random intercept		AIC	Δ AIC	R^2
		Site	Culm	Site	Culm			
<i>Bambusa vulgaris</i>	1st		+		+	1220.131	0	0.944
	2nd	+	+		+	1220.828	0.697	0.852
	3rd		+	+	+	1220.894	0.763	0.944
	4th	+	+	+	+	1221.209	1.078	0.944
	5th	+		+	+	1250.837	30.706	0.830
	6th	+			+	1251.119	30.988	0.608
	7th				+	1252.119	31.988	0.847
	8th			+	+	1254.086	33.955	0.944
	9th		+	+		1335.442	115.311	0.830
	10th		+			1343.221	123.090	0.470
<i>Bambusa maculata</i>	1st		+		+	1174.238	0	0.930
	2nd		+	+	+	1174.933	0.695	0.931
	3rd	+	+		+	1176.231	1.993	0.931
	4th	+	+	+	+	1176.795	2.557	0.931
	5th				+	1182.903	8.665	0.891
	6th			+	+	1184.297	10.059	0.892
	7th	+			+	1184.693	10.455	0.893
	8th	+		+	+	1185.567	11.329	0.895
	9th		+	+		1287.056	112.818	0.706
	10th		+			1298.697	124.459	0.592
<i>Gigantochloa atter</i>	1st	+		+	+	1189.973	0	0.928
	2nd	+	+	+	+	1191.030	1.057	0.937
	3rd	+			+	1202.631	12.658	0.927
	4th	+	+		+	1202.781	12.808	0.939
	5th		+	+	+	1207.716	17.743	0.939
	6th		+		+	1214.290	24.317	0.936
	7th			+	+	1215.625	25.652	0.899
	8th				+	1217.999	28.026	0.899
	9th		+	+		1314.135	124.162	0.765
	10th	+	+	+		1315.426	125.453	0.774

Note: AIC, Akaike information criterion; Δ AIC, change in AIC compared to the model with minimum AIC (1st place in 'Model ranking'); R^2 , model-based coefficient of determination. The symbol of '+' indicates the parameters included in the model. The Δ AIC ≤ 2 indicate no significant differences between models and a simpler model with fewer parameters is preferred. Bold model ranking represents the best model.

densities in the present study were also the same as those reported in *B. vulgaris* (Wahab et al. 2010), *B. vulgaris* 'Vittata' (Vetter et al. 2015), *B. rigida* (Huang et al. 2014), and *G. atter* (Marsoem et al. 2015).

Geographic variations

Fig. 4 shows the variance component ratio of the random-effect parameters estimated by the intercept-only linear mixed-effects model for the fixed mean values of

green moisture content and basic density in the three bamboo species. Among three species, the variance component ratio of the site was accounted for around or below 10% for the green moisture content and basic density in *B. vulgaris* and *B. maculata*. In contrast, the site variance component ratio in *G. atter* was larger than the other two species: 18.6% and 26.5% for green moisture content and basic density. Relatively higher variance component ratio of site in *G. atter* might be related to the model selection of longitudinal variations for two properties (Tables 4 and 5). These results suggested that main reasons for variation of

Table 5. A comparison of linear mixed-effects models in the basic density of three bamboo species with sites and, or individual culms as random effects.

Species	Model ranking	Random slope		Random intercept		AIC	Δ AIC	R^2
		Site	Culm	Site	Culm			
<i>Bambusa vulgaris</i>	1st	+	+	+	+	-500.819	0	0.936
	2nd		+	+	+	-498.733	2.086	0.936
	3rd	+	+		+	-497.336	3.483	0.936
	4th		+		+	-496.328	4.491	0.935
	5th	+		+	+	-472.977	27.842	0.860
	6th	+			+	-469.518	31.300	0.855
	7th				+	-464.289	36.531	0.828
	8th			+	+	-463.389	37.430	0.829
	9th		+	+		-405.674	95.145	0.712
	10th	+	+	+		-403.856	96.963	0.719
<i>Bambusa maculata</i>	1st		+		+	-499.322	0	0.873
	2nd				+	-498.647	0.675	0.849
	3rd		+	+	+	-497.517	1.805	0.874
	4th			+	+	-497.181	2.141	0.849
	5th	+			+	-497.181	2.140	0.853
	6th	+	+		+	-496.693	2.629	0.873
	7th	+	+	+	+	-495.827	3.495	0.875
	8th	+		+	+	-495.402	3.920	0.854
	9th		+	+		-414.244	85.078	0.643
	10th		+			-409.462	89.860	0.561
<i>Gigantochloa atter</i>	1st	+	+	+	+	-545.660	0	0.933
	2nd		+	+	+	-545.384	0.276	0.932
	3rd	+		+	+	-541.455	4.205	0.920
	4th			+	+	-538.500	7.160	0.912
	5th		+		+	-536.036	9.624	0.928
	6th	+	+		+	-535.003	10.657	0.930
	7th	+			+	-533.368	12.292	0.917
	8th				+	-533.139	12.521	0.911
	9th		+	+		-477.450	68.210	0.853
	10th	+	+			-426.766	118.894	0.695

Note: AIC, Akaike information criterion; Δ AIC, change in AIC compared to the model with minimum AIC (1st place in 'Model ranking'); R^2 , model-based coefficient of determination.

The symbol of '+' indicates the parameters included in the model. The Δ AIC ≤ 2 indicate no significant differences between models and simpler model with fewer parameters is preferred. Bold model ranking represents the best model.

green moisture content and basic density were individual culm rather than site for three native bamboo species naturally grown in Lombok Island. However, *G. atter* had relatively large geographic variations for green moisture content and basic density compared to remained two species.

CONCLUSIONS

Longitudinal and geographic variations in the green moisture content and basic density of bamboo culm were

evaluated by a linear mixed-effects model in three bamboo species (*B. vulgaris*, *B. maculata*, and *G. atter*) naturally grown in four locations in Lombok Island, Indonesia. The characteristics of the three bamboo species can be summarized as follows: 1) the two *Bambusa* species have similar culm sizes (diameter and height) but differing culm thicknesses, 2) *B. vulgaris* has the thickest culm among the three species, and 3) *G. atter* has the largest culm size among the three species but has thinner culm compared with *B. vulgaris*. The mean green moisture contents and

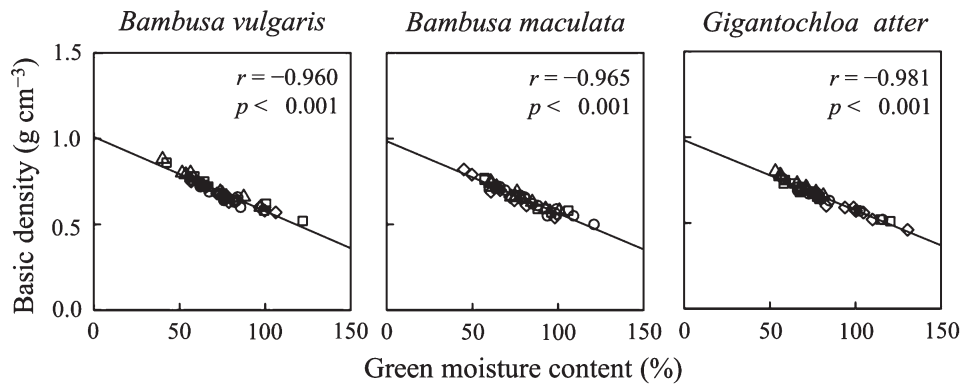


Fig. 2. Relationships between green moisture content and basic density of three bamboo species.

Note: Number of samples = 40 individual culms; r , correlation coefficient; p , p -value. The symbol circles, squares, diamonds, and triangles indicate the data at Site I, II, III, and IV, respectively.

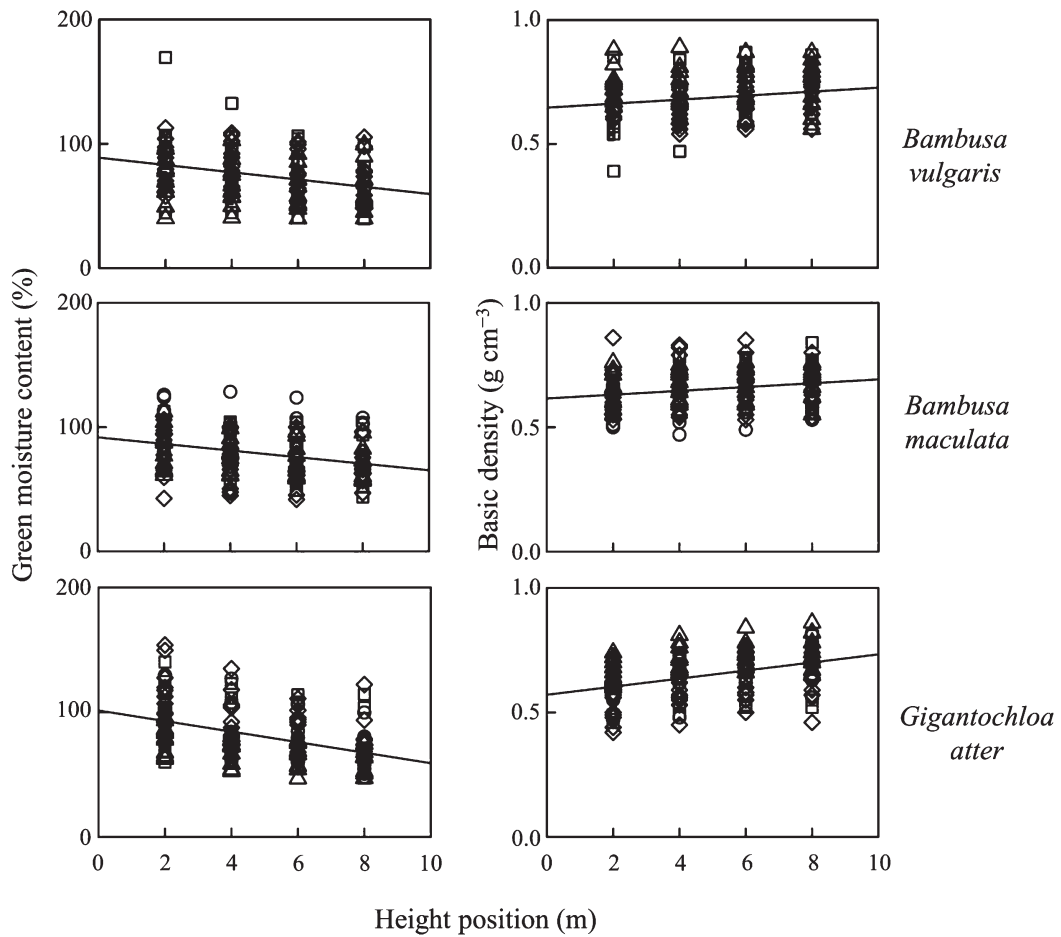


Fig. 3. Longitudinal variations of green moisture content and basic density of three bamboo species.

Note: Number of samples = 40 individual culms. Each solid line indicates the regression line based on the linear mixed-effects model with first ranked model listed in Tables 4 and 5. The symbols of circles, squares, diamonds, and triangles in each figure indicate the data at Site I, II, III, and IV, respectively.

Table 6. Parameter estimates, standard errors, *t*-values, and *p*-values of the fixed-effect parameters obtained from the best model for longitudinal variation of green moisture content and basic density.

Properties	Species	Fixed-effect parameters	Estimate	S.E.	<i>t</i> -value	<i>p</i> -value
Green moisture content	<i>B. vulgaris</i>	β_0	-2.923	0.430	-6.798	<0.001
		β_1	88.790	3.863	22.986	<0.001
	<i>B. maculata</i>	β_0	-2.642	0.278	-9.494	<0.001
		β_1	91.688	3.061	29.950	<0.001
	<i>G. atter</i>	β_0	-4.237	0.835	-5.077	0.015
		β_1	101.441	9.336	10.866	0.002
Basic density	<i>B. vulgaris</i>	β_0	0.008	0.003	2.393	0.097
		β_1	0.647	0.030	21.235	<0.001
	<i>B. maculata</i>	β_0	0.008	0.001	6.751	<0.001
		β_1	0.616	0.013	46.336	<0.001
	<i>G. atter</i>	β_0	0.016	0.001	13.780	<0.001
		β_1	0.571	0.030	19.100	<0.001

Note: β_0 , the fixed slope; β_1 , the fixed intercept; S.E., standard error.

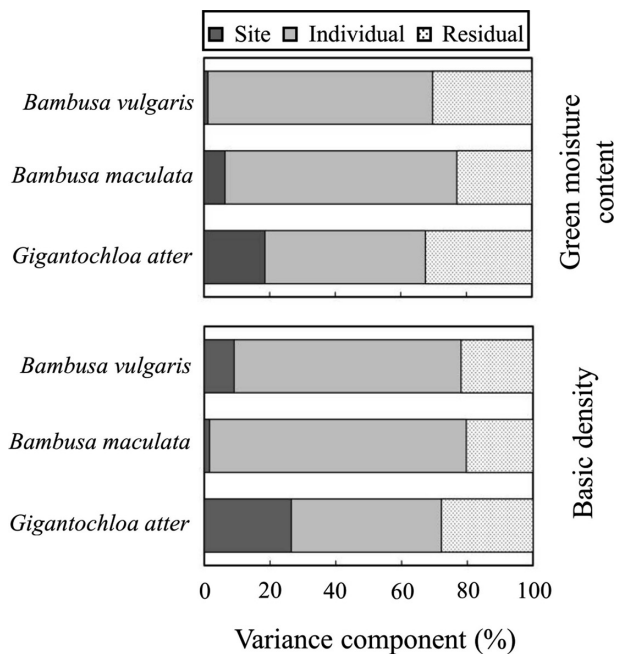


Fig. 4. Variance component ratio of site and individual culm as the random effects in the intercept-only linear mixed-effect model of green moisture content and basic density of three bamboo species.

basic densities of *B. vulgaris*, *B. maculata*, and *G. atter* were 74.2% and 0.69 g cm^{-3} , 78.5% and 0.65 g cm^{-3} , and 80.3% and 0.65 g cm^{-3} , respectively. No significant differences in the mean values of both properties among the three species were found. Significant negative correlations between the green moisture content and basic density of the three tested species were found. The green moisture content decreased with an increase in culm height, whereas the

basic density tended to increase from the base to the top of the culm for all three species. The results of the variance component ratio estimated by the intercept-only linear mixed-effects models indicated that the main reasons for variations of the green moisture content and basic density of bamboo culm in three bamboo species naturally grown in Lombok Island, Indonesia were variabilities among the individual culm. However, *G. atter* had relatively large geographic variations in these properties compared to remained two species.

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