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# Comparison of physical and mechanical properties of four rattan species grown in China

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## Abstract

Rattan cane is an important forest product only second to timber and bamboo, with higher economic value and ecological benefits. Physical and mechanical properties are more important quality performance indexes, which are highly correlated with the processing and utilization of rattan cane. The present paper describes a study of main physical and mechanical properties in different heights of rattan cane for four rattan species, and also makes a comparison of property for *Calamus simplicifolius* grown in different sites. The relationship between species, cane position, density and mechanical properties of the rattan in China is also discussed. The results show that the physical and mechanical properties differ among four rattan species, and they follow irregular variation pattern with height. The physical–mechanical properties have no significant difference among species except modulus of elasticity, and the same as the different geographical areas. The basic density and mechanical properties gave a more moderate correlation with quadric equation. This result will provide basic data support for property modification and commercial utilization of rattan resources.

**Keywords:** Rattan, Physical–mechanical properties, *Calamus*, Species

## Introduction

Rattan is a multi-purpose plant resource with long tough slender stems found mostly in the tropical rainforests, and has a high economic value which can be considered as a material with high potential in the construction industry [1]. Rattan cane is an important forest product only second to timber and bamboo, and is extensively used as an excellent natural material for furniture, ropes, decorative items, housing, craft products, and also as an innovative bone implant materials [2–4]. The physical–mechanical properties of rattan are the most important and most direct performance indicator to determine cane processing and utilization, while the most important factors that influence physical–mechanical properties are species, stem position, density and so on [5]. The density will directly affect the strength, hardness, natural

durability, and many other performance indicators of physical and mechanical properties.

From the 1860s, the study on physical and mechanical properties of some rattan species began to increase in the Southeast Asia region, including major effecting factor to mechanical strength, and cane grading based on mechanical strength [5–9]. Research on physical and mechanical properties of rattan in China is mainly focused on *Daemonorops margaritae*, *Calamus tetradactylus* and *C. simplicifolius*, including test methods, specific gravity, shrinkage, longitudinal compressive strength, tensile strength, hardness, wear resistance, bending strength, shear strength parallel to the grain and micromechanics [10–13]. However, the research on rattan property still lacks systematic basic data. There were no universal international standards to test, and the available results have been obtained by different techniques and methods. As yet, a complete picture of the quadruple interplay between species, cane position, density and mechanical properties of the rattan in China is missing.

*Calamus* consists of more species and grows over a large area with excellent properties and extensive

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commercial uses, while studies on it are now quite scarce [10–12]. The present paper describes a study of basic density, tensile property, bending property, compression strength and impact toughness in different heights of rattan cane for four rattan species distributed in Hainan and Yunnan province, and also makes a comparison of property for *C. simplicifolius* grown in different geographical areas of Guangxi and Hainan. The study of physical–mechanical properties of four rattan species, will reveal characteristics of mechanical behavior, provide reliable basic data and promote reasonable use for rattan industry development and standard’s establishment in China.

**Materials and methods**

**Sample preparation**

Four rattan species were obtained from Guangxi, Hainan and Yunnan province, the main rattan regions, and the species are listed in Table 1. Ten healthy rattans of each species with approximately same diameter in straight part were chosen in accordance with the standard sample collection and preparation for properties of rattan

cane—part 1: physical and mechanical properties [14]. The leaves and top young parts were removed, followed by subdividing the main culm into 2 m intervals. Thereafter, the canes were transported to the laboratory and stored in air-dry condition.

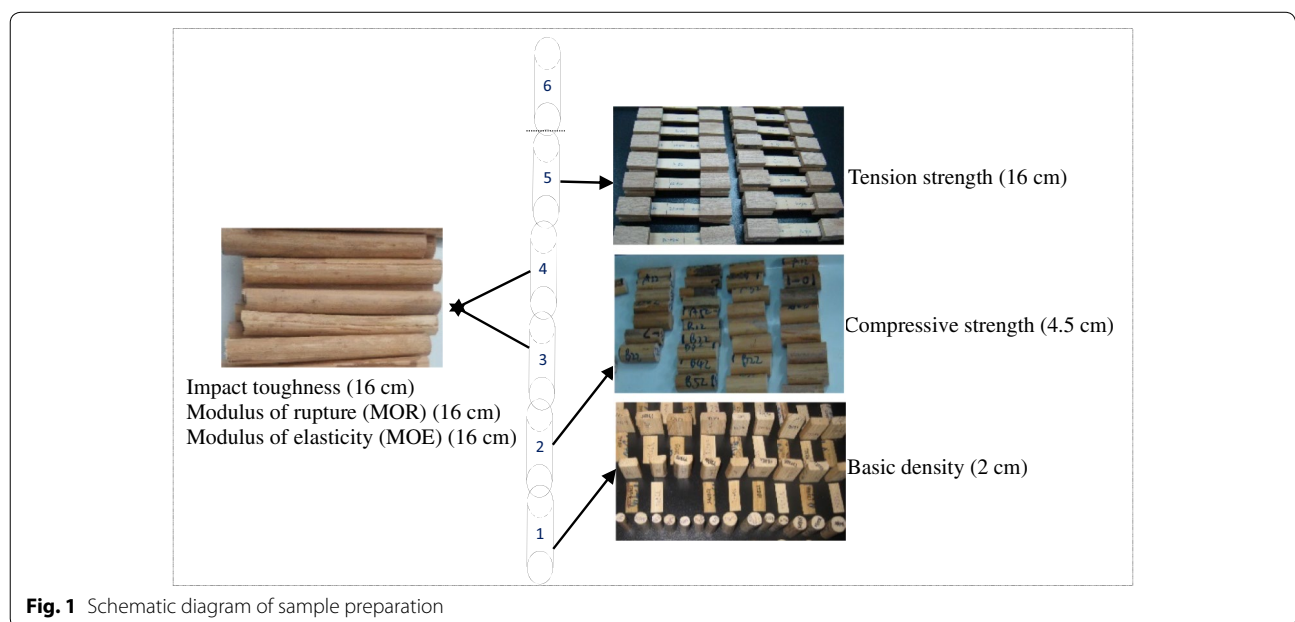
**Methods**

Five canes of each species with almost similar internode length and total internode number were prepared. To analyze longitudinal variations of the cane, each cane was divided into several height intervals, with 5 internodes in each height interval, numbered from the base. If there was a bend or damage in the internode, it will be replaced by a neighboring regular one. The key processes of sample preparation are shown in Fig. 1.

The prepared samples were placed in a temperature and humidity chamber with 20 °C, and relative humidity 65% for 40–60 days until samples moisture up to 9–15%. In each height interval, a 2-cm-long cane was cut for measuring the density from *C. yunnanensis* with small diameter, and the density specimens from other three

**Table 1 The materials of rattan species in the investigation**

Species	Latin name	Average length/diameter (cm)	Location
A	<i>Calamus simplicifolius</i> Wei	2420/1.76	Guangxi and Hainan
B	<i>C. nambariensis</i> Becc. var. <i>yingjiangensis</i> S. J. Pei et S. Y. Chen	1779/2.31	Yunnan
C	<i>C. nambariensis</i> Becc. var. <i>xishuang-bannaensis</i> S. J. Pei et S. Y. Chen	1314/1.49	
D	<i>C. yunnanensis</i> S. J. Pei et S. Y. Chen	1629/1.27	



**Fig. 1** Schematic diagram of sample preparation

species with larger diameter were dissected into cortex and core of cane. A 4.5-cm-long sample was prepared to measure compressive strength, and 16-cm-long sample for impact toughness and bending strength. As there is no published international standards to test the physical–mechanical properties of rattan cane, the tests of tension property (tension strength TS, tension modulus TM, MPa) and bending property (modulus of rupture MOR, modulus of elasticity MOE, MPa) through a 16-cm-long sample were carried out according to methods outlined by Lv et al. [10, 11], and other mechanical properties, including compressive strength (CS, MPa) and impact toughness (IT, MPa) were analyzed following the bamboo standards using Instron mechanical testing machine and impact testing machine [15]. Three-point bending strength and modulus were evaluated. The basic density was measured by the method of water content. Average values of 30 measurements were considered in the each portion analysis.

**Statistical analysis**

Statistical analysis was carried out using SPSS (version 20, IBM Company). Analysis of variance (ANOVA) at  $\alpha=5\%$  was performed to determine if there were significant differences in species and height at the different independent mechanical variables. Likewise, relationships between basic density and mechanical properties were analyzed with a simple linear and quadric equation regression.

**Results and discussion**

**The basic density**

The results showed that basic density range from 0.33 to 0.36 g/cm<sup>3</sup> in core, 0.52–0.60 g/cm<sup>3</sup> in cortex of cane for three rattan species with larger diameter, the density of cortex was larger than that in core (Table 2). The maximum of density in core and cortex are both present in *C. nambariensis* var. *yingjiangensis*. The basic density of

rattan cane is closely related to composition, structure and extracts of cell wall [5, 12, 16, 17]. Larger vascular bundle density, thicker fiber cell wall and smaller cell size in cortex tends to higher basic density than that in core. The variation of rattan’s density is not only determined by its own genetic characteristics, but also positively or negatively affected by some external factors, such as climate, soil and hydrology, etc. [18].

The average density of core and cortex is taken as the density of the cane for the above-mentioned three rattan species with larger diameter, compared with *C. yunnanensis*. Considering the overall basic density, it was observed that there is a great deal of irregular variation between the culm heights (Table 2), which is not similar to the findings by Tesoro [19]. The cane of different heights is formed within a certain rattan age, and a previous study indicates that the basic density is significantly higher as the canes mature [9]. In general, the age and height will affect the physical properties [20–22]. Bhat [5, 16] reported that rattan density along the stem (base to top) was highly affected by proportion of fibers, fiber wall thickness, the ratio of wall thickness to lumen diameter and metaxylem vessel diameter. Fiber wall thickness is the most important anatomical feature determining the physical properties of rattan cane [23]. The basic density tended to decrease with cane height from the basal towards the top portion, which the relationship is probably related to the numerous fiber cells with thicker wall thickness, smaller lumen diameter, and smaller metaxylem vessel element distributed in the basal cane compared to the upper portion. On the whole, it conforms to the research law of predecessors that the basic density decreases gradually from the base to top. But for the four rattan species, the variation between the culm heights diverged from each other.

Generally mean density differed among four species, and the differences were not statistically significant, only by 0.05 g/cm<sup>3</sup>. The rattan cane becomes fragile when its

**Table 2 The basic density in different cane height of four rattan species (g/cm<sup>3</sup>)**

Height	<i>C. simplicifolius</i>		<i>C. nambariensis</i> var. <i>xishuangbannaensis</i>		<i>C. nambariensis</i> var. <i>yingjiangensis</i>		<i>C. yunnanensis</i> Cane
	Cortex	Core	Cortex	Core	Cortex	Core	
1	0.57	0.36	0.52	0.33	0.67	0.37	0.39
2	0.55	0.36	0.5	0.36	0.52	0.33	0.59
3	0.52	0.32	0.54	0.35	0.53	0.32	0.48
4	0.5	0.32			0.64	0.41	0.43
5	0.49	0.3			0.64	0.37	0.43
Average 1	0.53	0.33	0.52	0.35	0.60	0.36	0.46
Average 2	0.43		0.43		0.48		0.46

basic density was lesser than 0.25 g/cm<sup>3</sup>. The above-mentioned four species have higher basic density and hence they can be used in reinforced part in furniture and decorations with better flexibility [24]. The ANOVA showed that there is no significant difference in the basic density among rattan species and cane height (Table 3).

**Mechanical properties**

Mean values of different mechanical properties for four rattan species are tabulated in Table 4. Comparing the mechanical properties of four rattan species, *C. yunnanensis* cane appeared to be the strongest as it displayed highest mean values of tensile properties (TS and TM) and bending properties (MOR and MOE) as well as relatively high CS. In contrast, *C. simplicifolius* had the lowest strength with exceptionally low values of TS and MOR. The rest of two species had no apparent difference in mechanical properties except the values of MOE and IT. The CS and MOR ranged from 24.93 to 27.75 MPa and 54.13 to 72.32 MPa, respectively, in which the former was less than half of the latter. IT of rattans ranged from 22.56 to 53.81 MPa. The IT in *C. nambariensis* var. *yingjiangensis* is the largest, more than twice that of the other three rattan species, suggested that *C. nambariensis* var. *yingjiangensis* will be more resistant to external impact loads.

The mechanical strength of rattan is closely related to its structure and chemical composition. Rattan is a natural fiber bio-composite, consisting of unidirectional fibers as a reinforcement, and parenchymatous ground tissue as a matrix. When rattan reaches the destruction, the total deformation is larger, but the ratio of limit deformation

to total deformation is smaller. The rattan has better plastic deformation and flexibility due to its higher proportion of parenchyma. The compression strength, tensile strength, tensile modulus is positively correlated with density and fiber proportion, and negatively correlated with parenchyma proportion [7]. The rattan with cortex presents strong bending characteristics, which may be due to large cellulose content in cortex [25].

Compared to commercial species *Calamus manna*, with 93.88, 2320 and 37.11 MPa for MOR, MOE and CS, respectively [12], the mechanical properties of four rattan species in this study is significantly lower than that in *Calamus manna* (Table 4). Therefore, four rattan species cannot be applied to a key load-bearing part of furniture only when any modification method used to improve the cane quality.

**Influence of species and geographical areas on mechanical properties**

The mechanical strength of rattan is affected by factors such as age, position, fiber ratio, density and water content. The ANOVA of the mechanical properties revealed that the species had a highly significant effect on the MOE (Table 3). The cane of *C. yunnanensis* has good mechanical property, but it is still limited in use due to its relatively small diameter.

The physical–mechanical properties of *C. simplicifolius* have no significant difference within species, and same as the different geographical areas (Table 5). Specimens collected from Guangxi and Hainan, which have a subtropical and tropical monsoon climate, respectively, representing different sunshine conditions, according to

**Table 3 ANOVA on mechanical properties of four rattan species at different heights**

Source of variation	df	Statistical significance						
		BD	TS	TM	CS	IT	MOR	MOE
Species	3	0.678	0.377	0.225	0.699	0.324	0.177	0.002**
Height	4	0.71	0.773	0.879	0.72	0.681	0.963	0.679

BD basic density, TS tensile strength, TM modulus of tension, CS compressive strength, IT impact toughness, MOR modulus of rupture, MOE modulus of elasticity

\*\* Significant at the 0.01 level

**Table 4 Comparison of physical–mechanical properties of four rattan species**

Species	TS (MPa)	TM (MPa)	CS (MPa)	IT (J/cm <sup>2</sup> )	MOR (MPa)	MOE (MPa)
<i>C. simplicifolius</i>	41.99 (a1)	1897.01 (a2)	24.93 (a3)	23.01 (a4)	54.13 (a5)	1303.36 (a6)
<i>C. nambariensis</i> var. <i>yingjiangensis</i>	44.74 (a1)	2315.46 (a2)	26.01 (a3)	53.81 (a4)	63.38 (a5)	1173.54 (a6)
<i>C. nambariensis</i> var. <i>xishuangbannaensis</i>	43.94 (a1)	2212.15 (a2)	25.07 (a3)	22.56 (a4)	67.64 (a5)	1816.34 (b6)
<i>C. yunnanensis</i>	57.21 (a1)	2514.2 (a2)	27.75 (a3)	23.82 (a4)	72.32 (a5)	2150.29 (b6)

1, 2, 3, 4, 5, 6 represents TS, TM, CS, IT, MOR, MOE. a, b means in the same rows followed by the same letter are not significantly different at the 0.05 probability level, different letters represent correlation is significant at the 0.05 level

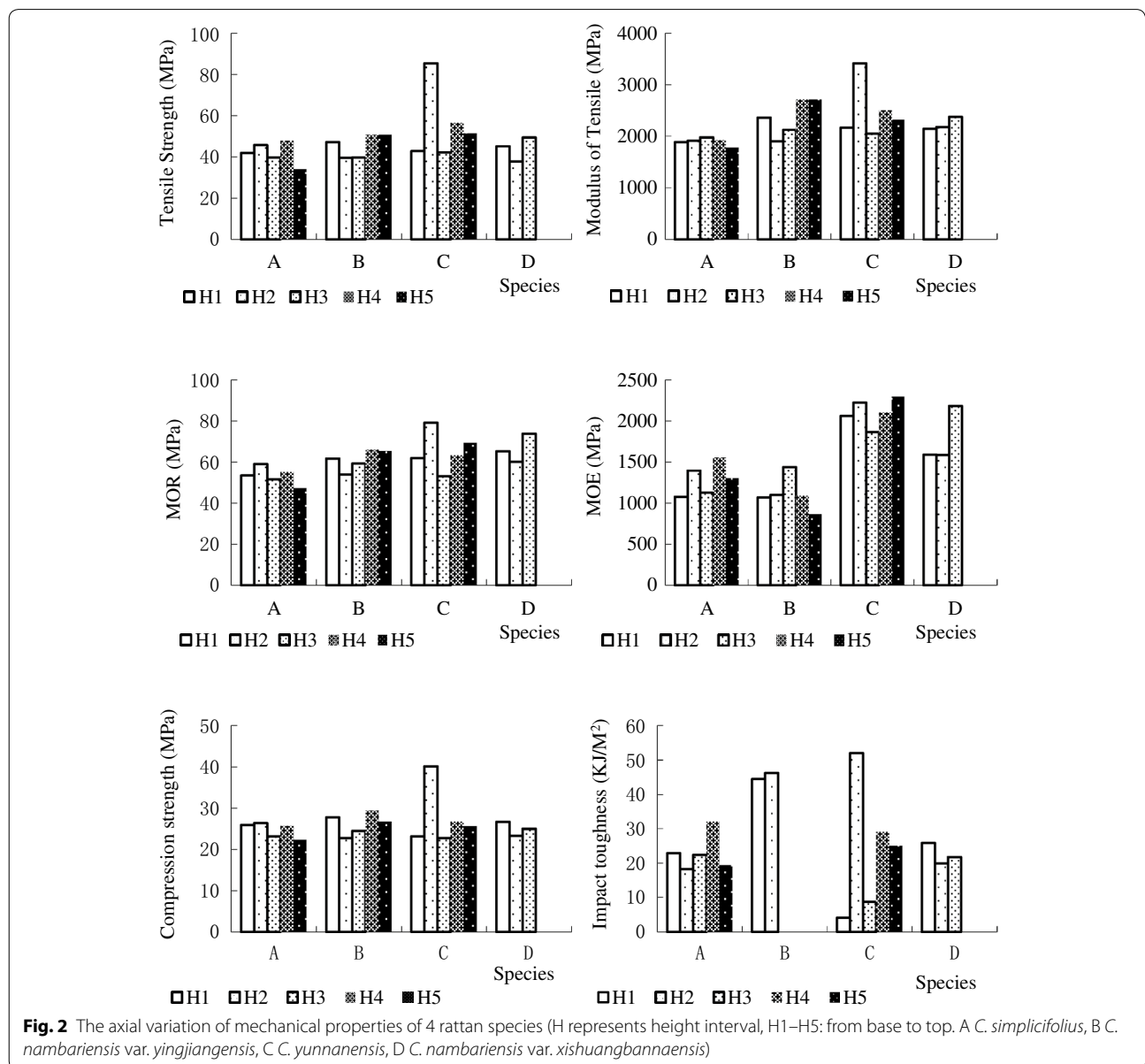
**Table 5 Comparison of physical–mechanical properties of *C. simplicifolius* in different locations**

Location	Basic density (g/cm <sup>3</sup> )		MOR (MPa)	MOE (MPa)	Tensile strength (MPa)	Compressive strength (MPa)
	Core	Cortex				
Hainan	0.332	0.524	54.13	1303.36	41.99	24.93
Guangxi	0.326	0.503	68.38	1888.36	41.97	24.11

what Abasolo and Lomboy [18] observed in their point of view palasan plants that are partially exposed to the sun produced the same type of cane as a fully exposed individual. *C. simplicifolius* grown in Guangxi province has larger MOR and MOE than that in Hainan province.

**Influence of cane position on mechanical properties**

The variation of mechanical strength presents irregular and indefinite pattern from the base towards apex (Fig. 2), which was not consistent with the findings by Bhat et al. [7] on India rattans where mechanical properties like



**Fig. 2** The axial variation of mechanical properties of 4 rattan species (H represents height interval, H1–H5: from base to top. A *C. simplicifolius*, B *C. nambariensis* var. *yingjiangensis*, C *C. yunnanensis*, D *C. nambariensis* var. *xishuangbannaensis*)

MOR and TS decrease from the base to the top within a stem. TS, CS, and MOR were unaltered by the pattern of longitudinal variation.

**Influence of basic density on mechanical properties**

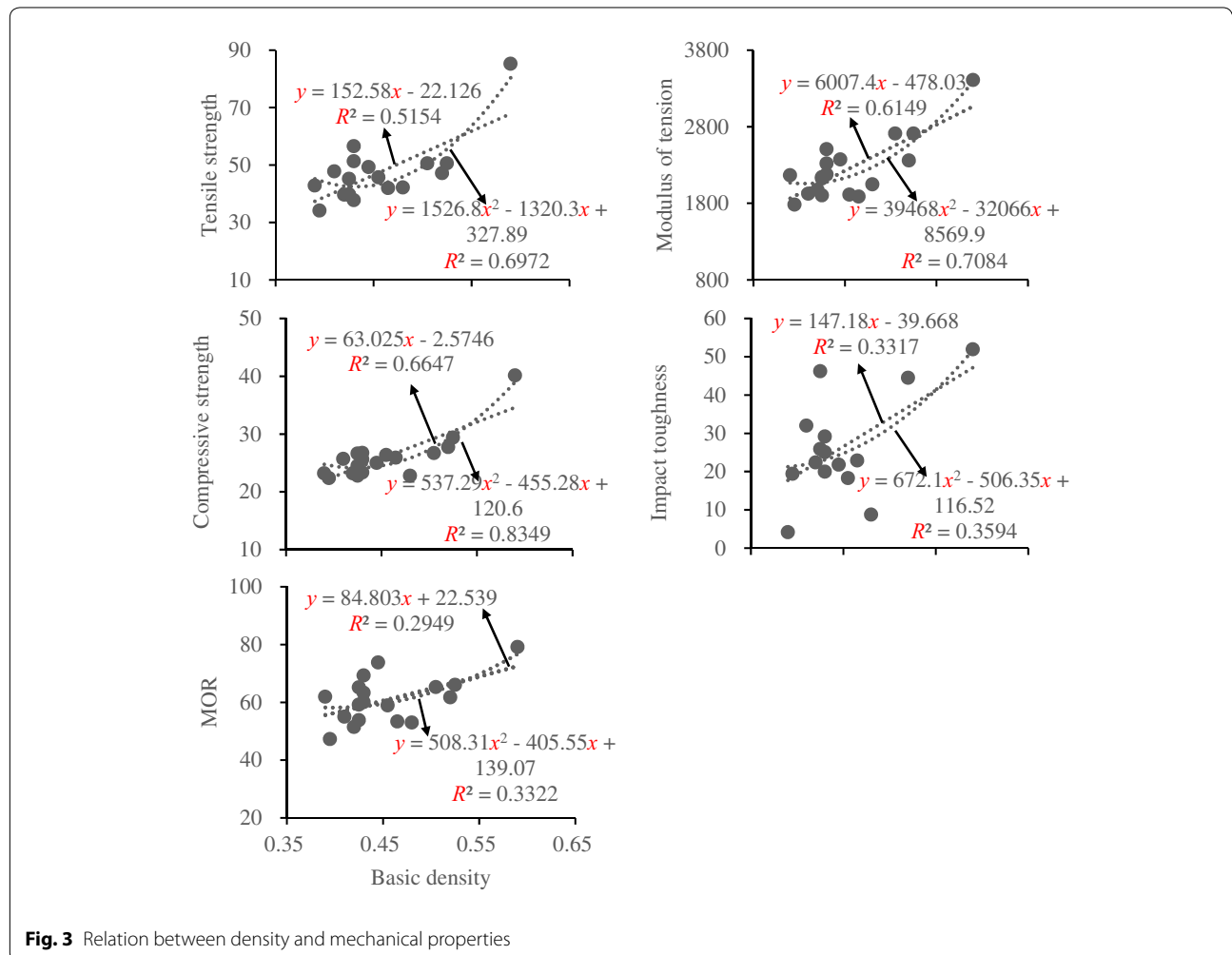
Usually, from the outside to the inside, from the base up, the strength of the rattan material is reduced, which is related to the change trend of fiber ratio and density

**Table 6 Correlations of the basic density and mechanical properties**

	BD	TS	TM	CS	IT	MOR	MOE
BD	1	0.718**	0.784**	0.815**	0.576*	0.543*	-0.076
TS	0.718**	1	0.882**	0.937**	0.559*	0.782**	0.460
TM	0.784**	0.882**	1	0.851**	0.506	0.840**	0.309
CS	0.815**	0.937**	0.851**	1	0.632*	0.710**	0.228
IT	0.576*	0.559*	0.506	0.632*	1	0.332	-0.161
MOR	0.543*	0.782**	0.840**	0.710**	0.332	1	0.543*
MOE	-0.076	0.460	0.309	0.228	-0.161	0.543*	1

\*Significant at the 0.05 level

\*\*Significant at the 0.01 level



**Fig. 3** Relation between density and mechanical properties



[7]. The correlations of the basic density and mechanical properties are summarized in Table 6. The basic density was significantly positive with each mechanical index, except MOE. Statistical analysis was then carried out to establish a linear and quadric equation regression between basic densities and mechanical properties (Fig. 3). Regression showed that basic density and mechanical properties gave a more moderate correlation with quadric equation, which had a higher correlation coefficient compared with linear. This is opposite to that of wood and bamboo where the linear model has a slightly larger correlation coefficient ( $R^2$ ) than the curve model [26, 27]. It also appeared that the moderate relationship of basic density to tensile strength ( $R^2=0.6972$ ), modulus of tension ( $R^2=0.7084$ ), and compression strength ( $R^2=0.8349$ ), the rest of the properties were minimally affected. Equations (1), (2) and (3) show a strong correlation with  $R^2$  values of 0.6972, 0.7084 and 0.8349, respectively.

$$y = 1526.8x^2 - 1320.3x + 327.89 \quad (1)$$

$$y = 39468x^2 - 32066x + 8569.9 \quad (2)$$

$$y = 537.29x^2 - 455.28x + 120.6 \quad (3)$$

## Conclusions

The measured physical and mechanical properties differ among four rattan species. Species do not significantly influence the mechanical properties except MOE. The basic density and mechanical properties follow irregular and indefinite variation pattern with height from the base to the top. In addition, basic density and mechanical properties gave a more moderate correlation with quadric equation.

Four rattan species have favorable mechanical properties and they can prove to be a good eco-friendly, sustainable material for green furniture. But the mechanical property is also clearly lower than that in commercial species *Calamus manna*, still limited to wide utilization for natural cane.

## Abbreviations

BD: basic density; TS: tension strength; TM: tension modulus; CS: compressive strength; IT: impact toughness; MOR: modulus of rupture; MOE: modulus of elasticity; ANOVA: analysis of variance.

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Not applicable.

## Authors' contributions

SY analyzed the data and was a major contributor in writing the manuscript. XL performed the experiment. LS was another major contributor in writing the

manuscript. XL participated in designing the experiment. GT and JM collected the samples. All authors read and approved the final manuscript.

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## Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no competing interests.

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