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Research article

Study of the physical and mechanical characteristics of patchouli plants

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Abstract: Patchouli plant characteristics are the basis that must be ascertain to design a patchouli harvester machine. The objective of this study was to determine the physical and mechanical characteristics of patchouli plants that can be used in the design of patchouli harvester machines. The data were collected by doing observation and measurement in the field and laboratory. Patchouli plants used with water content from 30 to 40% at the age of harvest 8 months after planting. Various physical characteristics of patchouli indicated the average value of plant height 112.7 cm, clump circumference 1.67 m, main stem diameter 9.88 mm, the clump diameter at a height of 20 cm from the surface of the land 16.5 cm, mass/clump 1.48 kg, and bulk density 0.11 kg/L. Physical characteristics play an important role in choosing equipment and the main dimension in designing a harvester machine. Determination of mechanical characteristics showed that the tensile strength value of patchouli was from 5.7 to 17.15 MPa with a modulus of elasticity from 0.12 to 0.5 GPa. The forces required for the design of the harvester machine such as the laying force, the retraction force and patchouli's cutting resistance achieved an average value of 6.19 N, 68.89 N, 108.47 N, respectively. The mean angle of repose was 48° at 32 % moisture content and friction coefficient was 0.71. The results obtained about the physical and mechanical characteristics of patchouli plants can be useful in providing information that helps in designing patchouli harvesting machines.

Keywords: clump diameter; cutting resistance; modulus of elasticity; patchouli; tensile strenght

1. Introduction

Patchouli plant is one of the main essential oil plants in Indonesia, which has an important role in the food, perfume and pharmaceutical industries. This essential oil was known as Patchouli oil in international trade [1]. According to Swamy [2], which stated that of all important essential oil producing plants, patchouli (*Pogostemon cablin* Benth.) had been very good business potential. Lubbe [3] also stated that the trade value of patchouli oil provided higher income for farmers even though this industrial crop produced relatively lower products. Lisma [4] stated that the quality of patchouli oil from Indonesia ranked third after China and France. One of the factors that can improve the quality of patchouli oil was reduce the size of the patchouli before destilation process [5].

In general, at the level of patchouli farmers, the reduction in the size of patchouli is still done using machetes. The use of tools such as machetes, in addition to reducing the size, is also used for harvesting.

An effort to reduce mechanical damage due to harvest and post-harvest requires a research on the physical and mechanical properties of patchouli plants to design a patchouli harvester machine. Li [6] reported the physical properties of tomato plants, i.e., height, diameter, surface area, volume, pericarp mass, pericarp density, curvature radius of the fruit and various other physical properties to design a harvester robot. Research related to mechanical properties of plants such as coefficient of friction, rupture force [6,7], angle of repose [7] and compressibility [6] have been done by researchers. The physical and mechanical characteristics of plants are useful for designing a reed harvester [8], manufacturing and controlling robotic harvesters for tomato plants [6] and making harvesting equipment for corn and soybean plants [7].

Research on the physical properties of patchouli has been conducted by Haryudin [9] including plant height, length of stem segment, length of branch segment, width of crown, number of primary and secondary branches and stem diameter, but not much is known about the mechanical properties of patchouli plants and physical properties related to the circumference of a clump, clump diameter at a height of 20 cm from the soil surface, mass per clump and bulk density of patchouli plants. The purpose of this study was to determine the physical and mechanical characteristics of patchouli plants. The benefits of this study were to design patchouli harvester machines consisting of cutting, chopper, and conveyor units.

2. Materials and method

2.1. Time and location of research

The research was conducted from January to August 2019. The measurement of mechanical characteristics was carried out at the Design and Building Engineering Laboratory, Faculty of Forestry, Institut Pertanian Bogor (IPB) University. The research on plant physical characteristics was carried out in the patchouli garden of Sinar Sari Village, Dramaga District, Bogor Regency. The results of soil analysis used in the experiment showed the type of latosol soil, soil pH (H_2O) 6.48, sandy clay texture, low organic content C 2.41%, P_2O_5 content 8.6 ppm, CEC (Cation Exchange Capacity) 25.82 me/100 g, water content 36.6% and specific gravity 2.16 g/cc. Fertile soil conditions and a good growing environment are supporting growth media for the growth and development of patchouli plants.

2.2. Materials

The plant material for patchouli in this study was taken 10 samples randomly with three repetitions so that the total of sample used 30 samples. Plant seeds were originated from the Indonesian Spice and Medicinal Crops Research Institute, Bogor. Observations were made on plants of 8 months after planting (MAP).

2.3. Equipment

The equipment used in this study were (1) Nankai digital calipers / calipers with an accuracy level of 0.01 mm, (2) HWH digital scales with an accuracy level of 0.01 g, (3) Microcomputer Controlled Electronic Universal Testing Machine (Chung Yen) with a maximum load capacity 3 tons.

2.4. Determination of physical characteristics

Physical characteristics include plant height, circumference of the clump, main stem diameter, clump diameter at a height of 20 cm from the soil surface, mass/clump and bulk density. The method used in measuring the physical characteristics of this patchouli plant was by measuring directly with several measuring instruments, including a ruler, calipers, and meters. Plant height was measured starting from the base of the main stem near the soil surface to the topmost leaf tip. Stem diameter was measured from the base of the main stem on the first segment near the ground or measuring the diameter of the stem at a height of 10–20 cm from the ground because in the design of the harvest machine, harvesting was done at that height. Clump mass was measured by directly weighing the weight per plant. The determination of bulk density was done by filling the sample into a 3 liters volume container from a height of 150 mm at a constant rate, then the contents of the container were weighed. Bulk density was known to take into account the friction pressure on the patchouli stem, calculated from the sample mass and volume of the container Singh [10] using Eq 1 as follows:

$$\rho = \frac{m}{V} \tag{1}$$

note: $\boldsymbol{\rho}$ = bulk density (g/cm^3), m = patchouli weight (g), V = the volume filled by the patchouli (cm^3).

2.5. Determination of mechanical characteristics

Mechanical characteristics observed were tensile strength, modulus elasticity, stem retraction force, laying force, cutting resistance, angle of repose and friction coefficient. Measurement of the mechanical characteristics of patchouli plants is needed to design a harvesting machine to be an appropriate technology that can help in shortening the time of harvest.

2.6. Tensile strength

The measurement of tensile strength was performed by pulling the patchouli stem so that deformation occurred, i.e., the patchouli stem was broken or cracks occurred. The data obtained in the form of changes in length and load changes were then displayed in the form of a stress-strain graph.

Measuring instruments used in testing the main stem tensile strength of patchouli plants were calipers, tensile testing instruments (Instron Universal Testing Machine brand), and a meter. Loading speed was set at 10 mm/minute. Patchouli stem samples with a diameter of 6.62–10.71 mm and a length of 100 mm were prepared.

Measurement of the diameter in the sample was performed for the purposes of calculating the maximum tensile strength of patchouli plant stems. Force deformation was displayed on a monitor connected to UTM (Figure 1). To calculate the maximum tensile strength of patchouli (σmax), the following formula was used Chattopadhyay [11] :

$$\sigma_{maks} = \frac{F}{A} \quad (2)$$

note: σ_{max} is the maximum tensile strength (N/m^2), F is the tensile force (N) and A is the cross-sectional area of patchouli (m^2).

Figure 1. UTM and monitor screen.

2.7. Measurement of modulus of elasticity

The modulus of elasticity depends only on the material type of an object, not depending on the size or shape of the object. The modulus of elasticity (E) of the stress-strain curve was defined as the change in stress divided by the change in strain, with the formula:

$$E = \frac{\sigma}{\epsilon} \quad (3)$$

The modulus value was calculated as the linear slope of the stress-strain curve on the basis of the regression method.

2.8. Laying force

Measurement of patchouli plant laying force requirements was by pulling or laying down plants with a digital scale in a position perpendicular to the plant. Position of pulling height performed of 20 cm from the soil surface. The tools used include straighteners which equipped a ruler, scales to measure force, and wires used to tie patchouli stems to the scales. Patchouli clumps were laid down or pulled by 3, 5 and 7 cm intersections. Laying force (F) was recorded for each deviation.

This measurement was performed by taking a few random samples in the field and was useful to determine the maximum slope of the patchouli plant so that it does not collapse/break when the plant starts to be pushed by the harvester machine. Figure 2 shows a scheme of measuring the retraction force of patchouli plants by being laid down.

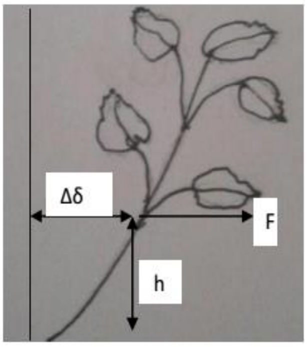

Figure 2. Schematic measurement of the laying force. Note: h = Measurement height from the soil (m); F = Laying force (N); Δδ = Deflection or laying distance (mm).

2.9. Retraction force

The retraction force was obtained by multiplying the mass (kg) of the measurement results with the gravity acceleration (m/s^2). Patchouli clumps that were sampled for the plant extraction force were taken randomly. Measurement of the retraction force in the field was carried out by pulling the plants in an upright position parallel to the plants and tie a digital scale to the patchouli stem to be pulled. The revocation load will be read on the digital scale at the time of withdrawal. The pulling height was 15 cm from the soil surface. Before pulling, the main stem diameter measurements were taken. The diameter of the main stem was measured 15–20 cm from the ground. After the plants were uprooted, patchouli clump was weighed using a digital scale, which was useful to determine the clump's weight.

2.10. Cutting resistance

Cutting resistance was obtained by using the shearing cutting method. The devices were used harvesting scissors, mini vise and digital scales. Cutting speed and cutting angle were ignored. Measurement of cutting resistance was carried out using harvesting shears attached to digital scales and clipped to the vise (Figure 3). The cutting force works when the digital scales are pulled downwards vertically, the weight of the cutting load will be read. The read value is converted into units of force (N) by multiplying the force of gravity. Cutting resistance is needed to design a cutting knife with an efficient mechanism referring to the maximum cutting resistance of cutting patchouli stems. Cutting resistance was calculated using the following equation:

$$F_c = \frac{F\left(L_{TP} + \frac{\theta_{BN}}{2}\right)}{L_F} \quad (4)$$

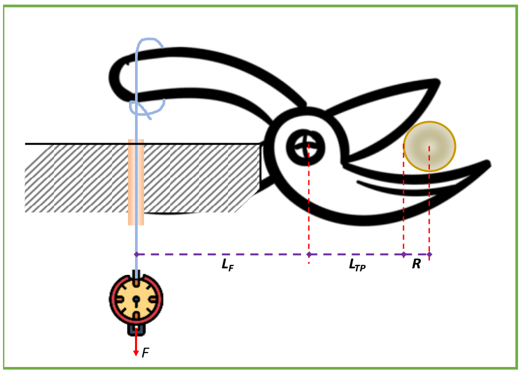

Figure 3. Patchouli shearing method. Note: F_c: Cutting resistance of patchouli stems (N); F: Measured force on the arm (N); L_{TP}: Cutting resistance arm (m); Θ_{BN}: Patchouli stem diameter (2R) (m); L_F: Force arm (m).

2.11. The angle of repose

The angle of repose is the angle formed between the flat surface and the sloping side if a number of patchouli is poured quickly and flows in gravity over the flat surface. The angle of repose was calculated using Eq 5 [12]:

$$tan\theta = \frac{t}{r}; \ \theta = arctan\theta \tag{5}$$

note: t = height (cm), r = radius (cm).

2.12. Friction coefficient

The coefficient of friction between the plant and the steel plate was measured by placing a vertical load on the patchouli plant and then the load was pulled horizontally using a scale while the patchouli plant was in a static state. The load used was a steel plate weighing 3 kg with dimensions of 25 × 10 × 5 cm. The purpose of this measurement was to determine the friction coefficient of plant for crop distribution applications after the plants are harvested in the harvest section to the enumeration process on the machine. The friction coefficient of plant was obtained from the relationship between normal force and friction according to the formula:

$$F = \mu \text{ x } N_f \tag{6}$$

note: F = friction force (N); μ = coefficient of friction; N_f = normal force (N).

3. Results and discussion

3.1. Physical characteristics of patchouli plants

The determination of the physical properties of plants is an important criterion for designing a harvesting machine such as those applied to vegetable [13], carrot harvesters [14] and tomato harvesters [15]. The results of the physical properties analysis of patchouli plants in this study are presented in Table 1.

Table 1. Physical characteristics of patchouli plants.

Physical properties	Unit	Max	Min	x	SD	CV
Height	Cm	150.00	75.50	112.70	20.19	17.92
Main stem diameter	Cm	12.79	7.02	9.88	1.75	17.71
Clump circumference	Cm	2.00	1.43	1.67	0.15	9.33
Clump diameter at a height of 20 cm from the ground	Cm	21.00	12.00	16.50	2.50	15.18
Mass/clump	Kg	1.76	1.21	1.48	0.15	10.49
Bulk density	kg/liter	0.112	0.109	0.11	0.001	0.01

Note: Max: Maximum value; Min: Minimum value; x: Mean; SD: Standard Deviation; CV: Coefficient of Variation.

The results obtained from the physical measurements of patchouli stem showed that the average height, stem diameter, clump circumference, clump diameter at a height of 20 cm from the ground surface, mass/clump and bulk density were 112.7 cm, 9, 88 mm, 1.67 m, 16.5 cm, 1.48 kg, 0.11 kg/L, respectively (Table 1). Ince [16] reported that the physical properties of sunflower stems were different at different heights. The physical characteristics of plant height need to be determined in the design of the harvester machine, so that plants can be cut at a height of 10–20 cm from the ground, so that the transportation process can be carried out to the conveyor. Information on the physical characteristics of the main stem diameter needs to be determined for the analysis of the cutting knife to be used. Analysis of other physical properties, i.e., the clump circumference and the clump diameter at a height of 20 cm from the ground, needs to be determined for the analysis of the transport load on the conveyor. Information about the physical properties of the mass per clump is useful for analyzing the retraction force so that the harvester machine works only for cutting patchouli plants without extracting the plants. Furthermore, the physical characteristics of specific gravity is related to the transportation process on the conveyor and chopper space analysis. The specific gravity is useful in consideration for calculating the conveyor load and chopper volume. All physical characteristics observed in patchouli plants will be used as a basis in determining the dimensions of the patchouli harvester machines.

3.2 Mechanical characteristics of patchouli plants

Measurement of mechanical characteristics was carried out to determine the strength of patchouli plants if they are subjected to forces (treatment) when harvesting using a harvester machine so that patchouli plants do not collapse/fall down before successfully cut. The harvester machine can cut patchouli plants without breaking the stem because it is needed for further growth. Some characteristics of the mechanical properties of patchouli plants from this research results are presented in Table 2.

Table 2. Mechanical characteristics of patchouli plants.

Parameter	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation (%)
Tensile strength (MPa)	10.51	17.15	5.68	3.54	2.93
Modulus of elasticity (GPa)	0.21	0.50	0.12	0.14	19.03
Retraction force (N)	68.89	93.10	50.96	12.07	17.52
Cutting resistance (N)	108.47	112.6	105.17	2.24	2.07
Laying force (N)	6.19	8.52	4.99	1.15	18.65
Angle of repose (°)	48.52	52.59	45.00	3.32	6.84
Friction coefficient	0.71	0.73	0.70	0.01	2.05

Note: MPa: Megapascal; GPa: Gigapascal.

3.3. Tensile strength

The tensile test resulted the maximum tensile strength value (highest) of 17.15 MPa with a maximum tensile load of 717.7 N, stem diameter of 7.3 mm and 25.09% water content. The minimum (lowest) tensile strength value of 5.68 MPa with a tensile load of 420.03 N under the stem diameter conditions of 9.7 mm and a water content of 32.26%.

The results of this study show that tensile strength increased with decreasing water content. Research conducted by Handayani [17] on bamboo plants showed that the lower water content of bamboo generated higher tensile strength of bamboo. When an object experiences a pull, the object will experience two forces in the pulling process, i.e., the external force that changes the initial conditions of the object and the internal force that describes the force originating from within the object. Tensile test results in the form of strain and stress are presented in Figure 4.

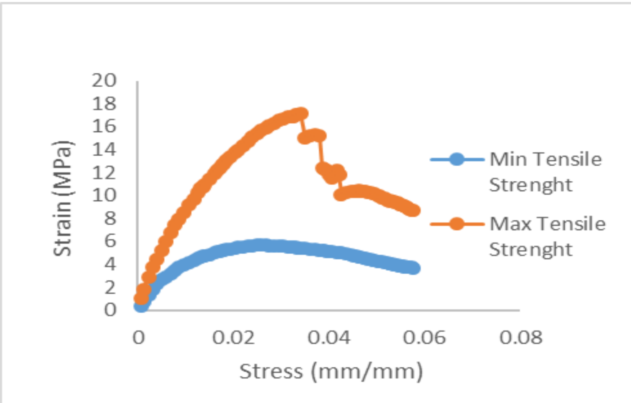

Figure 4. Maximum and minimum tensile strength.

Mechanical strength is also influenced by the content of the main chemical components of plant stems [18]. These components include cellulose, hemicellulose and lignin. The results of the main chemical components of patchouli plant stems aged 3 and 8 months are presented in Table 3.

The patchouli stem lignin content of 22.38% increased slightly at the age of 8 months (Table 3), indicating that patchouli plants have tensile strength. In bamboo plants, an increase in the tensile strength of a bamboo blade occurs along with an increase in lignin content and the number of vessel bonds. The cell wall lignin content to the highest point obtained (33%) still increases the tensile strength of the bamboo slats [19].

Table 3. Chemical contents of patchouli stems.

Chemical component	3 months old (content)		8 months old (content)	
	μ ± σ (%)	CV	μ ± σ (%)	CV
Celluloce	36.34 ± 0.15	0.43	36.71 ± 0.08	0.22
Lignin	22.11 ± 0.009	0.04	22.38 ± 0.08	0.38
Hemicelluloce	25.83 ± 0.35	1.37	26.86 ± 0.18	0.69
Extractive substances	15.52 ± 0.28	1.78	14.00 ± 0.20	1.43

Note: μ: Mean; σ: Standart deviation; CV: coefficient of variation.

3.4. Modulus of elasticity

The modulus of elasticity of patchouli plant was obtained from the tensile test results curve. The value of modulus of elasticity generated was around 0.12–0.5 GPa. The higher modulus of elasticity resulted smaller elastic strain that occurs at a given level of loading, so that the material is stiffer or the structure of the material network is harder. The harder tissue structure of the material indicates that the water content of the material is low. Ozbek [20] who examined the safflower stem also stated that the modulus of elasticity decreased with increasing water content of the safflower stem. Jahanbakhshi [21] in their research on carrots also stated that the higher modulus of elasticity resulted harder structure of the fruit tissue.

The modulus of elasticity of patchouli stems has a relationship to the lignin content in plant stems. The lignin content of stem significantly affects on the compactness of the vessel bundles on the stem. Lignin is also indirectly related to the stem stiffness property associated with nature material plasticity property [18]. Galedar [22] reported that lignification makes the cell wall thicker in the stem section thereby increasing the stiffness in that section.

3.5. Retraction force

The results of this study showed that the average retraction force on the patchouli plant clump was 68.89 N with the retraction rate of 12 stems/minute or 5 seconds/patchouli stem were obtained. Lisyanto [23] stated that differences in the pulling force requirement are thought to be influenced by root conditions, soil density, the number of stumps or stems in a clump. This study also obtained information related to the relationship between the retraction force and the stem diameter (Figure 5).

The relationship between the retraction force and the stem diameter (Figure 5) shows a linear relationship, in which the greater diameter of the stem generated greater retraction force applied. Maximum retraction force was 93.1 N for stem diameter of 13.56 mm and plant weight of 1.76 kg wet with a water content of about 30%. The average extraction time is around 5,045 seconds per plant family.

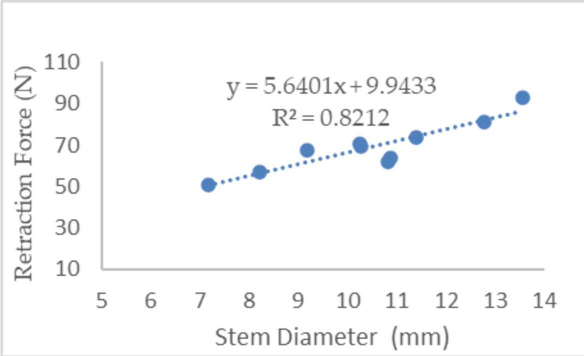

Figure 5. Relationship of between the retraction force and the stem diameter.

3.6. Cutting resistance

The characteristic of cutting resistance using the shear method showed the value of cutting resistance of patchouli plant stems valued 105.17–112.6 N with the average 108.47 N. The patchouli stem cut was in conditions of 30% water content at 8 months of harvest. Igathinathane [24] also reported that the use of shearing cut was efficient for reducing the size of corn stems. Figure 6 presents the relationship between stem diameter and cutting resistance.

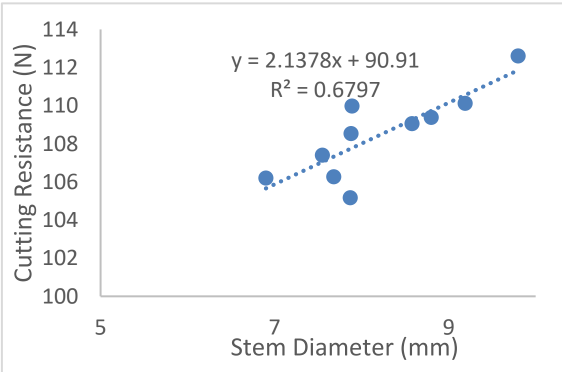

Figure 6. Relationship between stem diameter and cutting resistance.

The results showed that the cutting resistance would increase with increasing stem diameter as shown in Figure 6. The results of research by Dange [25] showed that the cutting force to cut pigeon pea stalks increased with the increase in the diameter of the pigeon pea. Igathinathane [26] reported that the larger size of the material to be cut causes greater cutting resistance of the material. Johnson [27] mentioned that the cutting energy of miscanthus is proportional to the cutting speed and stem diameter. The research results conducted by Dauda [28] also showed that the force needed to cut kenaf stems with high water content was lower compared to kenaf stems with low water content.

3.7. Laying force

The characteristic of the laying force of the patchouli plants at several variations of deviation (laying distance) is presented in Table 4. The results of the laying force measurement showed that the greatest laying force (8.52 N) occurred at 70 mm laying distance. The farther laying point generated greater force required to pull the patchouli clumps.

Table 4. Laying force of patchouli clump.

Clump type (C)	Laying force (N)		
	30[a]	50[a]	70[a]
R1	3.43	4.41	5.09
R2	4.70	5.19	6.07
R3	3.62	4.41	7.64
R4	3.52	4.80	4.99
R5	4.01	5.09	6.17
R6	3.72	5.19	6.56
R7	4.01	4.80	6.17
R8	3.72	4.31	4.99
R9	4.11	5.29	8.52
R10	3.03	4.11	5.68
Average	3.79	4.76	6.19
SD	0.45	0.42	1.15
CV	11.93	8.95	18.65

Note: SD: Standart Deviation; CV: Coefficient of Variation; [a]: Laying distance or deflection (mm).

3.8. Angle of repose and friction coefficient

The angle of repose was calculated based on the equation of Milani [12]. The angle of repose is indispensable in designing conveyors for harvesting machines. The determination of the angle of repose was carried out 3 times with an average value of 48° in wet patchouli conditions with a water content of 32%. In dry patchouli conditions with a water content of 15%, the angle of repose was 40°. This suggests that an increase in the angle of repose can occur with an increase in water content. In accordance with research conducted by Seifi [29], the maize angle of repose increased significantly from 49° to 58° in the water content range of 4.73% to 22%. El Fawal [30] in their research on grain crops recommended using stainless steel or galvanized iron in the manufacture of seed hoppers which can be used in planting machines, silos and storage containers with a slope angle of 40°. The friction coefficient characteristic based on the calculation of equation 6 ($Fk = \mu k\ N_f$) obtained an average value of the patchouli friction coefficient of 0.71 in wet patchouli plant conditions with 35% water content. The friction coefficient and angle of repose is very important for the design of conveyors and hoppers in seed planting machines [31].

3. Conclusion

It is very important to know the physical and mechanical properties of patchouli before designing a harvester machine. Physical characteristics of average plant height 112.7 cm, clump circumference 1.67 m, main stem diameter 9.88 mm, clump diameter at a height of 20 cm from the soil surface 16.5 cm, clump mass 1.48 kg and bulk density 0.11 kg/L were useful to determine the dimension of the patchouli harvester. The mechanical characteristics of average tensile strength 110.51 MPa, modulus of elasticity

0.21 GPa, retraction force 68.89 N, laying force 6.19 N, cutting resistance 108.47 N, angle of repose 48.52° and friction coefficient 0.71 were also determined in this study.

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Conflict of interest

All authors declare that have no conflict of interest.

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