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Physicochemical and Mechanical Properties of Different Morphological Parts of the Tea Tree (*Melaleuca alternifolia*) Fibres

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Abstract
Tea tree fibres as underutilised fibres were investigated physically, chemically and mechanically. From this study, it was found that the tea tree leaf (TTL) had the highest density - 0.42 g/cm^3*, and the highest percentage of water absorption - 69.9%. From the tensile strength, the tea tree trunk (TTT) gave the highest value - 65.44 MPa, followed by the tea tree branch (TTB) - 48.43 MPa and tea tree leaf (TTL) - 47.47 MPa. The chemical composition of fibres showed TTT had the highest cellulose content, which is 33.9%, followed by TTB -27.2%, and TTL - 13.5%. Meanwhile TTL had the highest extractive value - 16.4%, almost 3 times higher than TTB and TTT due to the existence of tea tree oil in TTL. From the FTIR result, TTL, TTB and TTT had similar spectra and no major differences. This paper aims to rationalise the potential of underutilised tea tree (Melaleuca alternifolia) waste as a novel source of natural fibre, to become a potential reinforcement or filler in the development of a new biocomposite.*

Key words: *biocomposite, filler, melaleuca alternifolia, natural fibre, reinforcement.*

Introduction

Melaleuca alternifolia, commonly known as the tea tree, is a tall shrub or small tree of the plant genus *Melaleuca*. The tea tree is native to Australia, where it is found from Queensland to north-east New South Wales. The Australian aborigines have long used tea tree leaves to treat cuts and wounds, where crushed leaves are applied directly to an injury, then held in place with a mud pack. This poultice helps fight infection in the wound. Rodney et al. [1] reported that there are tea tree plantations of approximately 10,000 trees/ha in Kimanis, Papar and Sabah. This evidence shows that the tea tree can be planted almost everywhere in the world. Rodney et al. [1] also mentioned that the propagation of the tea tree can be done by seedlings, cuttings and tissue culture. Tea tree oil was one of the success stories in Australian essential oil production during the early 90's, with prices topping AUD 65/kg, which attracted large numbers of new growers in those days [2]. The tea tree is popular for its oil, known as tea tree oil, which has been employed largely in various industries for its antimicrobial properties.

Tea tree oil is produced by steam distillation of the leaf, and the yield of oil is typically 1 - 2% of the wet weight of the plant [3]. Normally the tea tree leaf will be burned or composted after distillation. Richard [4] mentioned that in Australia, there are some companies that dry the residue leaf after distillation and then universally return it to the plantation as mulch. The issue of using this leaf as mulch is that it may contain some remaining tea tree oil, and as a consequence of the distillation process, it will take more time to be composted as the main agent in the composting process are microbes it-self [5]. For that reason, these underutilized fibres are undervalued as it is considered waste. No research work has hitherto been reported regarding the utilisation of tea tree fibre as a source for reinforcement or filler in biocomposite. However, various studies related to the development of biocomposites reinforced by natural fibres have been done before, from oil palm empty fruit brunch (EFB) [6, 7], oil palm stem plywood [8], rubberwood [9] and natural rubber [10], bamboo [11] and the sugar palm tree [12 - 17] to many more including banana pseudo-stem, coconut shell, kenaf, rice husk, coir, sugarcane bagasse, roselle, and wood [18]. As mentioned before, it is good to investigate the tea tree more as a novel source of fibres, and see how far it can compete with existing natural fibre, some of which was well established in the industry long ago.

Material and methods

Preparation of fibres

Throughout this study, all of the apparatuses, manufactured in Taiwan, were supplied by Sri Juta Riang Sdn Bhd. Tea tree fibres were taken from SEDIA's tea tree field at Demonstration Plot, located at Mile 30 Kimanis, Papar, Sabah, Ma-

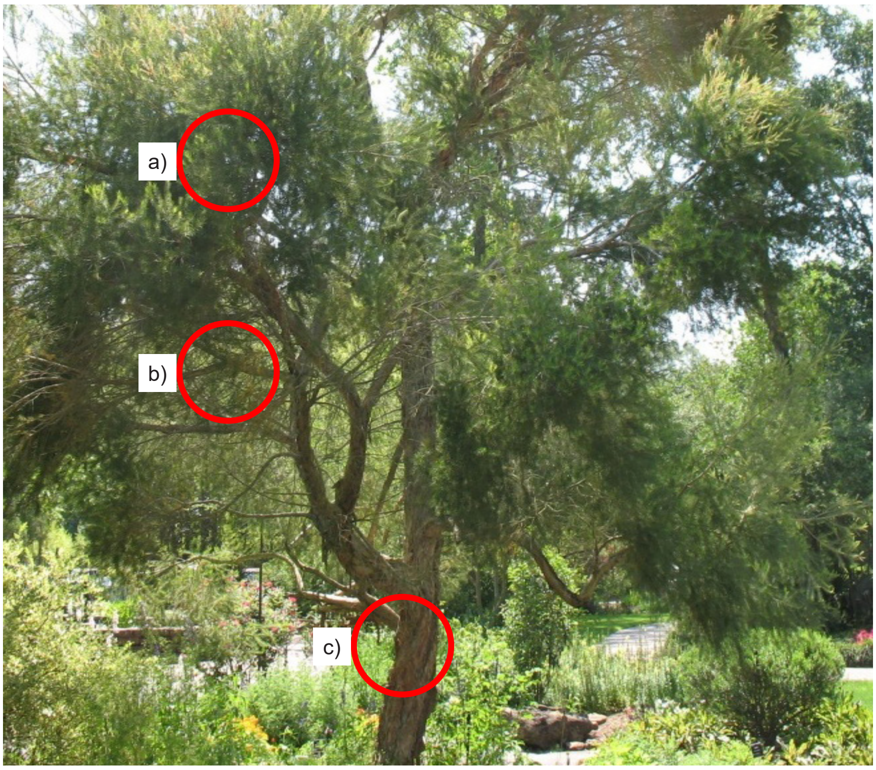

Figure 1. *Whole tea tree; a) TTL, b) TTB, c) TTT.*

laysia. A chainsaw was used to cut down the tree for easy ground harvesting of the fibres, which was done manually using a slashing knife. Fibre from different parts of the tree, which are tea tree leaf (TTL), tea tree branch (TTB), and tea tree trunk (TTT) were extracted as shown in ***Figures 2.a to 2.c***. In order to obtain the fibre, every part of the tea tree was cut separately and dried. The fibres themselves remain relatively unchanged during this process. A typical tea tree is shown in ***Figure 1***.

Measurement of density

The density (ρ) of fibres was determined using a specific gravity bottle and water as liquid. Initially the fibre was weighed (m) and then immersed into water. The amount of water before and after immersion was recorded as the volume (V) and used in the determination of the density of fibre.

$$\rho = m/V$$

where, ρ is the density of fibre in g/cm^3, m the mass of fibre in g, and V is the volume of water in cm^3.

Water absorption test

A water absorption test was carried out based on the ASTM D 750 standard. The percentage of water absorbed (WA) was calculated using the equation shown below:

$$WA(\%) = (W1 - W0)/W0 \times 100\%$$

where, W_A is the water absorbed in %, W_1 the final weight in g, and W_0 is the initial weight in g.

Figure 2. *Different part of tea tree; a) TTL fibre, b) TTB fibre, c) TTT fibre.*

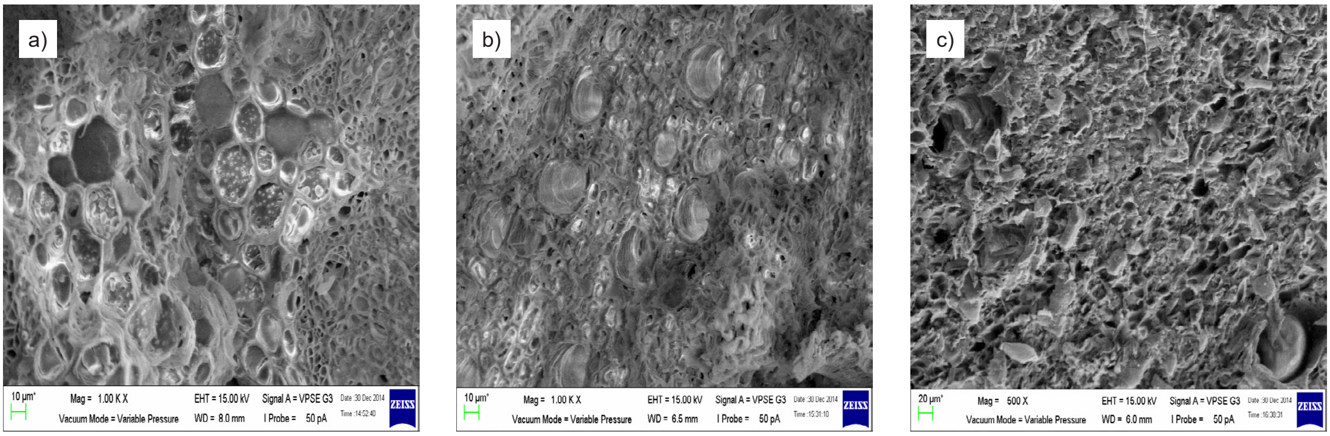

Figure 3. *SEM of different parts of tea tree fibre; a) TTL fibre, b) TTB fibre, c) TTT fibre.*

Scanning electron microscopy (SEM)

A scanning electron microscope, model Zeiss EVO-MA (Germany), with an operating voltage of 0.3 – 30 kV, was used to obtain SEM micrographs from the fractured tensile test sample cross section of tea tree fibres to evidence the different morphology of TTL, TTB and TTT.

Tensile properties of fibre

A single fibre tensile test was conducted based on the ASTM D 3379 standard. Ten specimens for each part of the tea tree, namely TTL, TTB and TTT were tested for their tensile strength with a 10 kN load using a universal testing machine, Gotech AI-7000M, manufactured in Taiwan. The gauge length was 20 mm, and the crosshead speeds used were 1 mm/min.

Chemical composition of fibres

In order to obtain the chemical composition of the fibre, every part of the tea tree was cut into chips and ground to pass through a BS 40 mesh sieve and be retained on a BS 60 mesh sieve. The fibre samples used for chemical composition in this study were roughly at equilibrium with the moisture of the air. The moisture content was considered when determining the percentage of extractive, holocellulose, lignin and ash. Determination of the extractive, alpha-cellulose, lignin and ash content was undertaken following TAPPI standard methods: TS os-73, T 203 os, T 222 os-74 and T 15 os-58, respectively, while the hollocellulose content was tested using the method created by Wise [19].

Characterization of fibres using FTIR

Fourier transform infrared (FTIR) spectroscopy was used in order to detect the presence of functional groups existing in sugar palm fibre. Spectra of the fibre were obtained using an IR spectrometer (Perkin-Elmer Spectrum 100, USA). About 2 mg of the sample in powder form was mixed with potassium bromide (KBr) and pressed into a disc of about 1 mm thickness. FTIR spectra of the sample were collected in the range of 4000 - 400 cm^{-1}.

Results and discussion

Density and water absorption of fibres

Table 1 shows the density of a tea tree leaf (TTL), tea tree branch (TTB) and tea tree trunk (TTT). It was found that the tea tree leaf (TTL) was of the highest density, followed by the tea tree branch and tea tree trunk. The water absorption of fibres, as seen in ***Table 1***, shows TTL was the highest, followed by TTB and TTT. TTL absorbed more water because of its position at the top of the tree. The higher the position, the younger their age will be, and hence more active in developing cells for the photosynthesis process. Water is also an important factor in regulating the productivity of a plant [15, 20]. ***Figure 3*** shows the SEM of different parts of tea tree fibres under 1000 x magnification. It can be observed that the pores in TTL fibre are larger than in TTB and TTT, supporting the fact that TTL absorb more water than TTB and TTT.

Table 1. *Density and water absorption of tea tree fibres; ± refers to standard deviation.*

Part	Density, g/cm^3	Water absorption, %
Tea tree leaf (TTL)	0.42 ± 0.06	69.90 ± 1.76
Tea tree branch (TTB)	0.24 ± 0.04	66.04 ± 2.43
Tea tree trunk (TTT)	0.18 ± 0.02	53.99 ± 2.47

Table 2. *Mechanical properties of tea tree and other fibres; ± refers to standard deviation.*

Fibre	Tensile strength, MPa	Elongation at break, %	Young's modulus, GPa	Reference
Tea tree leaf (TTL)	47.5 ± 2.6	44.5 ± 2.2	1.1 ± 0.05	Current study
Tea tree branch (TTB)	48.4 ± 2.3	105.5 ± 3.7	0.5 ± 0.02	
Tea tree trunk (TTT)	65.4 ± 2.1	47.5 ± 2.3	1.5 ± 0.05	
Bagasse	25 - 105	1 - 2	1 - 7	[21, 22]
Coir	131 - 220	15 - 40	4 - 6	[23]
Sugar palm	198 - 421	9.8 - 29.7	3.1 - 10.4	[15]

Tensile properties of fibre

The average values of ten samples of tea tree fibres of rounded circular shape and with variation of diameter were obtained. The cross section width for TTL is between 2.2 - 2.4 mm, for TTB - between 3.1 - 3.3 mm, and for TTT it is between 1.5 - 1.7 mm. ***Figure 4*** shows the tensile strength-elongation curve of fibres. The curves for all fibres shows a linear relationship between the tensile strength and elongation of the fibres. The tensile strength, modulus and strain of the tea tree fibre are shown in ***Table 2***.

The tensile strength of TTT was the highest, followed by TTB, and TTL. The tensile strength of tea tree fibre is similar to that of bagasse fibre in a study done by Cao et al. [21, 22], which are around 25 - 105 MPa. In the elongation analysis, TTB is the highest, followed by TTT and TTL. TTT and TTL elongation are within the range of coir, which is between 15 - 40% [23] and sugar palm trunk - 30% [15]. The gradient of the ten-

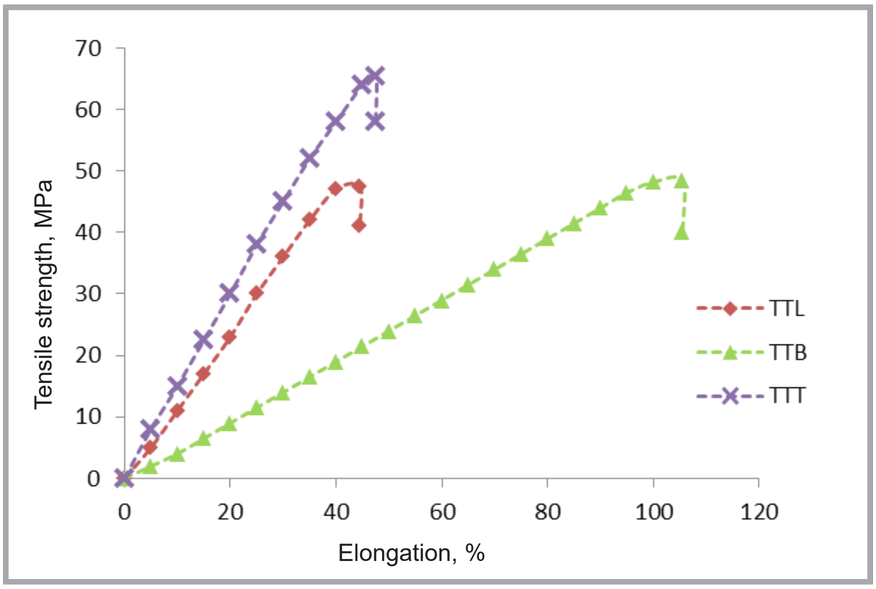

Figure 4. *Tensile strength-elongation curve of fibres.*

Table 3. Chemical composition of tea tree and other fibres; ± refers to standard deviation.

Description, %	Moisture, %	Extractive, %	Holocellulose, %	Cellulose, %	Hemicellulose, %	Ash, %	Lignin, %	Reference
Tea tree leaf (TTL)	40.8 ± 0.4	16.4 ± 3.8	50.0 ± 2.0	13.5 ± 0.01	36.5 ± 0.1	4.9 ± 0.3	0.2 ± 0.1	Current study
Tea tree branch (TTB)	14.3 ± 0.4	5.8 ± 0.3	66.8 ± 1.7	27.2 ± 1.1	39.6 ± 1.3	4.3 ± 0.5	0.2 ± 0.1	
Tea tree trunk (TTT)	23.9 ± 0.3	5.4 ± 0.02	71.1 ± 0.7	33.9 ± 0.3	37.2 ± 0.5	1.0 ± 0.2	0.1 ± 0.02	
Coir	8	-	-	32-43	0.15-0.25	-	40 - 45	[23]
Cereal straw	-	-	-	38-45	15-31	-	12 - 20	
Kenaf	-	-	-	45-57	21.5	-	8 - 13	

sile strength vs elongation graph gives the Young's modulus or tensile modulus. Young's modulus indicates the relative stiffness property of a material [16, 24]. From the ***Table 2***, TTT is the stiffest, followed by TTL and TTB. If we compare to other existing fibre, tea tree fibre is still not too far from the stiffness of oil palm mesacorp 0.5 GPa, oil palm empty fruit bunch 3.2 GPa, sugar palm fibre between 3 - 11 GPa, coir 4 - 6 GPa, cotton 5.5 - 12.6 GPa, oil palm fibre, 6.7 GPa, and banana 7 - 20 GPa [12, 23]. It shows that all parts of the tea tree are mechanically suitable to become the reinforcement in the biocomposite, which can be applied in various industries, especially in packaging and manufacturing, which are inter-linked and able to support the demands of other industries.

Chemical properties of fibres

Chemical composition

From ***Table 3***, it can be seen that TTT has the highest cellulose contents compared to others, followed by TTB and TTL. Plant fibres are composite materials designed by nature. Cellulose is the main structural component that gives strength and stability to plant cell walls and fibres [25]. Most plant fibres consist of cellulose, hemicellulose, lignin, extractive and ash [26]. The major component in most plants is cellulose, being the main element that provides strength and stability to the fibre [27]. This explain why TTT has the most tensile strength and tensile modulus compared to TTB and TTL, as the cellulose content is the highest, which is 33.9%. The cellulose content of tea tree fibre is similar to that of coir - 32 - 43%, cereal straw - 38 - 45% and kenaf - 45 - 57% [23].

From ***Table 3***, it is found that extractives and ash are minor components, which are 5 - 16% for extractives and 1 - 5% for ash. The existence of extractive material, especially in wood, influences the odour and colour of the plant, as discussed by Sahari et al. [15;17]. Lignin was found only in very small amounts in TTL, TTB and TTT, which was around 0.1 - 0.2%. Mohanty et al. [28] mentioned that lignin is the compound that gives rigidity to plants and also adds to wood's toxicity, causing more resistance to the decay brought about by insects. This means that the tea tree is not dependent on lignin for its rigidity. Moreover it can depend on tea tree oil to counter insects, as tea tree oil contains anti-insect properties, as reported by Benelli et al. [29], Williamson et al. [30], and Callender and James [31].

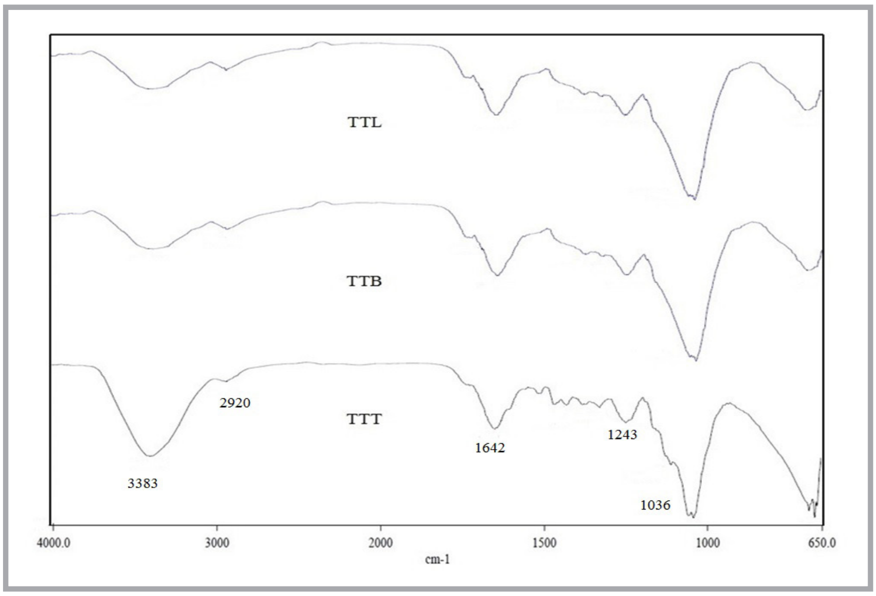

Figure 5. *FTIR spectra of tea tree fibre.*

Of all of them, TTL has the highest moisture content - 40.8%, as it is the place where the tea tree oil is stored [32]. This also explains why TTL has a high percentage of water absorption compared to TTB and TTT, which is the same reason why TTL has also the highest extractive value - 16.4%. This shows that TTL contains tea tree oil, where the aroma comes from. Ash was highest in TTL and TTB, showing that the inorganic compound can be found starting from TTB and TTL, as the existence of aromatic compounds are produced by tea tree oil [32].

It was also observed that during the grinding process in this study, the smells of aromatic tea tree oil sparked from TTB and TTL, while only wood chip smells came out from TTT grinding. Tea tree oil from *Melaleuca alternofilia* is a mixture of various monoterpenes, sesquiterpenes and their alcohols. The monoterpenes terpinen-4-ol, γ-terpinene, 1,8-cineol, p-cymen, α-terpineol, α-pinene, terpinolenes, limonene and sabinene account for 80 - 90% of the oil [3, 33].

From the observation in this study, it is interesting to state that tea tree fibre not only has the potential to act as a reinforcement or filler in biocomposite, but the fibre itself can protect against microbes as it contains tea tree oil. Tea tree oil has been widely used in cosmeceutical industries. The mixture of the oil and fibres themselves will lead to novel products depending on the creativity and innovativeness of the industrial players. From food, health, biomaterial, biomedical materials, automotive, interior design, to name but a few, the potential of tea tree fibres will contribute a great deal to society. However, in this study, our focus is to make this underutilised fibre a novel filler in a biocomposite which could serve the packaging and manufacturing industries.

Spectroscopic characterisation

FTIR spectroscopy is one of the most powerful tools used to evaluate the specificity of functional groups that exist in each morphological region. ***Figure 5*** shows the FTIR spectra for all types of tree fibre i.e. TTL, TTB and TTT. From the figure, it is shown that the spectra were almost the same among the 3 types of fibre. There are also no major differences observed if the spectraare compared with other established fibres. The peak at 3200 - 3500cm^{-1} indicates the presence of O-H groups, which is due to hydroxyl groups found in cellulose, hemicellulose and lignin [34]. The peak at 2850 - 3000 cm^{-1} shows the C-H stretching. The peak at at 1600 - 1800 cm^{-1} indicates the existence of carbonyl group C=O in the hemicellulose and lignin. The peak at 1475 - 1600 cm^{-1} corresponds to the stretching of aromatic groups present in lignin [35, 36]. The peak at 1000 - 1300 cm^{-1} shows the presence of C-O groups [37].

Conclusions

From this study, the physicochemical and mechanical properties of tea tree fibre i.e. tea tree leaf (TTL), tea tree branch (TTB) and tea tree trunk (TTT) were determined. TTL had the highest density - 0.42 g/cm^3 and highest percentage of water absorption, -69.9%. From the tensile test, TTT gave the highest value - 0 - 65.44 MPa, followed by TTB - 48.43 MPa and TTL - 47.47 MPa. The chemical composition of fibres showed that TTT had the highest cellulose content, which is 33.9%, followed by TTB - 27.2%, and TTL - 13.5%. Meanwhile TTL had the highest extractive value - 16.4%, due to the existence of tea trea oil in TTL. From the FTIR result, it shows that the TTL, TTB and TTT had similar spectra and no major differences. All in all, from this study, there are certain properties of tea tree fibres which are considered compatible compared to other established natural fibres. As such, all parts of those underutilised tea tree fibres have the potential to be used as a novel source of reinforcement or filler in new green biocomposite products which can serve the needs the packaging and manufacturing industries.

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