Branch Wood Properties and Potential Utilization of this Variable Resource

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Wood can be regarded as the single most important natural resource of the future, as it is a magnificent gift of nature. However, wood is a highly variable and complex material. Branch wood is a part of a tree that requires careful attention due to several disadvantages, making it less favorable for industrial use. This study was conducted to identify the basic properties of branch wood of *Acacia gerrardii*, *Tamarix aphylla*, and *Eucalyptus camaldulensis,* and to highlight its potential utilizations. Branch wood of all the examined species had several drawbacks that markedly limit its potential for commercial uses. It might not be favorable for particleboard, flakeboard, or fiberboard because of its high shrinkage. Even though all of the fibers showed suitability as a raw material for pulp and paper, the quality is low due to the high density of vessels or parenchyma proportions. However, branch wood of all examined species might be used as a blending material (papermaking and glued plates) or for light construction purposes. In considering the chemical composition of branch wood, classes of green products, such as biofuel, bioenergy, and biochar might maximize the value of branch wood. These offer numerous benefits to support human needs in the future.

Keywords: Wood variation; Branch wood; Basic properties; Potential utilizations

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INTRODUCTION

Wood is a highly variable and complex material that has inherent variability between species, within a species, and also within a tree (Zobel and Buijtenen 1989; Lindström 2000; Martin *et al.* 2010; Krishna *et al.* 2017; Tarelkin *et al.* 2019). Branch wood as part of a tree has been discussed broadly in recent publications (Shmulsky and Jones 2011; Dadzie *et al.* 2018; Zhao *et al.* 2019a,b). It can be used for papermaking or wood-based panels (Zhao *et al.* 2018), low-grade paper (Zhao *et al.* 2019a), or glued plates (Zhao *et al.* 2019b). However, branch wood is still less favorable for massive-scale industries due to several disadvantages. For example, branch wood contains a higher amount of bark and has non-uniform properties (Shmulsky and Jones 2011). It needs an intricate treatment before its utilization, and this can decrease harvester productivity (Nurmi 2007). Hence, an alternative strategy should be flexible, applicable, effective, and efficient to encompass the limitation of branch wood.

Ideally, the collection of branch wood can substantially increase the quantity of wood fiber per area of forest harvested. In harvesting activities, approximately 35 to 50% of the tree biomass is left in the forest in the form of stumps, branches, and crown (Okai and Boateng 2007). Shmulsky and Jones (2011) also reported that logging residues (especially branch wood) make up a significant quantity of wood volume, and its utilization is reported to increase yield by about 60%. By considering branch wood as a potential resource, it is time to deliberate what strategy might be used to manage branch wood limitations, therefore making it useful for commercial purposes. Once considered an expensive and irritating disposal problem, Shmulsky and Jones (2011) explained that forest residues (*e.g.* branch wood, bark, *etc.*) are now extensively favored as a ground cover, soil amendment, industrial fuel, and is a possible source of chemical feedstocks to produce several green products.

Furthermore, particular emphasis has been focused on branch wood utilization because of the decline in main stem wood resources (Leitch and Miller 2017; Dadzie *et al.* 2018; Zhao *et al.* 2019b) or the low resources availability per unit area, for example in arid and semi-arid regions (Andersen and Krzywinski 2007; Li *et al.* 2018). The efforts toward conserving and developing any resources in such regions are crucial. One of the conservation approaches is by avoiding over-cutting or illegal logging and promoting the utilization of branch wood of some common species. Several common tree species, for instance, are *Acacia* sp., *Tamarix* sp., and *Eucalyptus* sp. (UNESCO 1960; Chaudhary 1983; Badai and Aldawoud 2004; El-Juhany and Aref 2012; Sadegh *et al.* 2012; HCDR 2014). However, in spite of numerous studies in those species, no study has investigated the physical, anatomical, and chemical properties of their branch wood. Therefore, the present study aims are to identify the basic properties of branch wood of *Acacia gerrardii*, *Tamarix aphylla*, and *Eucalyptus camaldulensis* relating to its physical, anatomical, and chemical properties and to highlight its potential utilizations.

EXPERIMENTAL

Materials

The branch wood from three different tree species selected for this study were (1) grey-haired acacia (*Acacia gerrardii*), family Mimosaceae; (2) athel tamarisk (*Tamarix aphylla*), family Tamaricaceae; and (3) red gum (*Eucalyptus camaldulensis*), family Myrtaceae. All samples were obtained from Dirab Experiments and Agricultural Research Station, South of Riyadh (24° 24’ 31.93” N, 046° 39’ 41.16” E; 584 above sea level). The area has a Mediterranean climate within annual minimum and maximum temperatures about 5 and 45 °C, respectively. The annual precipitation is very low (maximum 30 mm/month). The rainfall is distributed as 80% in winter, 10% in late autumn, 10% in spring. The pH of this soil is slightly alkaline, about 7.5 (Mefarrej 2001).

Considering the pruning practice that mostly takes place at the bottom part of the tree crown, the samples were collected from one third of this area because that region is a non-productive area. Three trees for each species were cut just 20 cm above the basal collar/swelling to avoid any abnormality (Zhao *et al.* 2019b). Then, to confirm the specifications as a standard branch, the average diameter of the branch wood was determined about 6.02 cm from all branches and ranged from 5.8 to 6.2 cm. Three branches from each sample tree were chosen randomly to represent the average condition. The branches were covered with a moist fiber sack to reduce dehydration, then transferred and submerged into the water in a hermetically sealed plastic container at room temperature for 24 h to keep the moisture of branches.

Methods

Branch wood properties were studied without distinguishing between heartwood and sapwood, because the boundary between both areas cannot be assessed visually on cross-sections.

Physical properties

Specific gravity (SG) was calculated as oven-dry weight (105 °C, 48 h) divided by the green volume (freshly cut green wood) by following ASTM-D-2395–07a (2010). Five-centimeter-thick disc sample were taken just 20 cm above the basal collar/swelling. Two 1 cm x 5 cm blocks (from pith to bark) were sawed from each disc by considering the above and below branch wood position in the standing tree. Then, each block was divided into block I and II. Block I (about 1 cm x 1 cm) was used to measure the wood specific gravity after oven-drying in the oven. Block II (about 1 cm x 4 cm) was used to observe the fiber dimensions. The samples were then polished and measured by using the water displacement method. The anisotropic directions were also measured by considering tangential (length), radial (width), and longitudinal (height) direction. The samples were oven-dried and weighed several times until reaching the constant weight. The anisotropic directions were re-measured at this stage. Furthermore, SG, moisture content (MC), and shrinkage were calculated based on the measured values.

Anatomical properties

Initially, soaking the sample in water was required to avoid damage to cell structures. The sample was cut perpendicular to the axial orientation for analyzing cross sections. The sample with a thickness of approximately 10 to 20 µm was produced and treated by following Gärtner and Schweingruber (2013). For maceration, two match stick sized specimens were prepared from each of the anatomical subsamples and treated according to Mahesh *et al.* (2015). High resolution digital images of anatomical sections were captured with a camera and mounted on an optical microscope. After the image was produced, the "ImageJ" analysis software (National Institute of Health, Bethesda, MD, USA) was used to quantify the anatomical features. The measurement procedure involved calculating the wood element percentage, vessel diameter, and fiber dimensions by following Scholz *et al.* (2013). Photomicrographs were taken from the sections and fiber slides were macerated separately at 4x magnification (wood element (WE), vessel diameter, and fiber length (FL)) and 20x magnification (fiber diameter (FD), two-cell wall thickness/D-CWT, and lumen diameter (LD)). A total of 54 photomicrographs (3 replicates by 3 species by 3 trees for each species by 2 block areas) with image sizes of 4140 by 3096 pixels were used for investigating wood elements. Then, fifty pores from each photomicrograph (total 2,700 pores; 50 by 54) were observed for measuring the diameter of the vessel (VD). Next, about 225 photomicrographs (3 replicates by 3 species by 25 fields) with image sizes of 4140 by 3096 pixels were used for observing fiber dimensions. Fiber lengths and vessel ferret diameters were manually determined using the straight-line method in the "ImageJ" software. In determining the proportions of the four main wood elements (vessels proportion/VP, fiber proportion/FP, rays proportion/RP, and parenchyma proportion/PP), a square mm (1 mm^2) was plotted in the center of the micrographs. Then, each element was delineated to calculate the percentage of wood elements.

Chemical properties

Chemical components were obtained using the following test procedures. A small portion of wood was cut from the disc samples and ground to 40- to 60-mesh sizes. For the extractive determination (TAPPI-T264. 1997), the samples with a known dried weight were extracted in a Soxhlet apparatus by an ethanol-benzene mixture (in the ratio of 1 to 2 by volume) for 6 h, followed by 95% ethanol for 4 h, and lastly by hot distilled water for 4 h with changing the water every hour. For cellulose determination (TAPPI-T429. 2001), the extractive-free wood meal was treated with 20 mL of nitric acid (3%) for 30 min and treated with 25 mL of sodium hydroxide (3%) for the next 30 min. For hemicellulose determination (ASTM-D-1104–56 1978), the extractive-free wood meal was treated with 100 mL of sulfuric acid (2%) for 1 h under a reflux condenser. For the ash determination (TAPPI-T211 2002), the extractive-free wood meal was placed into a crucible, heated gradually, and then ignited at 525 ± 25 °C until the sample was completely combusted. For the Klason lignin determination (TAPPI-T222 2006), the extractive free wood meal was treated with 15 mL of sulfuric acid (72%), kept in a water bath at 20 ± 1 °C for 2 h, diluted with distilled water to 3% concentration of sulfuric acid, and boiled for 4 h.

Statistical analysis

These experiments were performed to study the branch wood basic properties among tree species under completely randomized design (CRD). The tests involved 3 different tree species, 3 discs from each tree, 2 strips from each disc, and with 3 replicates. So, the total experimental units were 54 samples. All data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) software (SAS, ver 9.2, SAS Institute Inc. Cary, NC, USA). Least Significant Difference (LSD) test at 0.05 level will be used to compare the significant difference among the means. Correlations among variables were also calculated, particularly between physical and anatomical properties.

RESULTS AND DISCUSSION

Physical Properties

The experiment and statistical analysis showed that both specific gravity (SG) ($p < 0.00$) and moisture content (MC) ($p < 0.00$) were significantly influenced by the type of tree species. The highest SG value was obtained by *E. camaldulensis* (0.71), followed by *A. gerrardii* (0.61), and *T. aphylla* (0.59). However, the last two species were not significantly different. In contrast with SG, *T. aphylla* (100.8%) contained the highest MC, followed by *A. gerrardii* (90.8%) and *E. camaldulensis* (60.2%) (Table 1). Zanuncio *et al.* (2014) mentioned that SG is a key property that has a huge effect on wood products and wood utilization. The SG of branch wood in this study were different in comparison to the stem wood values reported previously. For *A. gerrardii*, the SG of branch wood was 14% lower when compared to Nasser and Aref (2014), who reported that the SG of stem wood was about 0.71 at breast height. For *T. aphylla*, the SG of branch wood was 4% lower when compared to Dykstra (2010), who found that the SG of stem wood was about 0.62. For *E. camaldulensis*, the SG of branch wood is more miscellaneous due to its worldwide distribution. In Sudan, Malik and Abdelgadir (2015) found that the mean SG of stem wood ranged between 0.49 to 0.75. In India, Kothiyal (2014) reported that the mean SG of stem wood ranged between 0.63 to 0.75. An important point is that the SG of branch wood is higher than stem wood in some species and lower than stem wood in others.

Results showed that a higher moisture content in a piece of wood was correlated with a lower SG. Table 3 presents the correlation analysis and shows that SG was negatively correlated with MC. Similarly, Longuetaud *et al.* (2016) obtained a strong negative correlation between SG and MC. They also found that SG correlated negatively with geo-climatic factors, such as latitude, altitude, rainfall, and temperature. Shmulsky and Jones (2011) stated that the considerable variation of MC depended on the location, age, season of harvest, and tree size. The authors also mentioned that moisture content in wood is essential to support harvesting design, transportation equipment, and cost estimation.

Table 1. Mean of Specific Gravity and Moisture Content

Species	SG	MC (%)
A. gerrardii	0.61 [b] ± 0.01	90.84 [a] ± 1.88
T. aphylla	0.59 [b] ± 0.03	100.85 [a] ± 10.44
E. camaldulensis	0.71 [a] ± 0.01	60.23 [b] ± 0.81
*Mean ± SE; Different letters correspond to significantly different values		

Another parameter that is strongly related to SG and MC is wood shrinkage. Three different directions reflect wood as an anisotropic material, *i.e.*, the tangential (length in the direction of the annual growth rings), radial (width across the rings), and longitudinal (height along the grain) directions. Generally, the trend of wood shrinkage follows the sequence of the tangential shrinkage being greater than the radial shrinkage, and the radial shrinkage being greater than the longitudinal shrinkage (Simpson and TenWolde 1999; Glass and Zelinka 2010). In the present study, *T. aphylla* had the highest shrinkage (tangential and radial), followed by *A. gerrardii* and *E. camaldulensis*. Moreover, the highest shrinkage appeared in the tangential direction of *T. aphylla* (19.8%), which was significantly different from *A. gerrardii* (14.1%) and *E. camaldulensis* (9.1%) ($p < 0.00$). Commonly, longitudinal shrinkage is negligible (less than 1%) and it was not significantly different among tree species ($p = 0.99$) (Table 2).

Table 2. Mean of Shrinkage Percentage of the Examined Species

Shrinkage Properties	*A. gerrardii*	*T. aphylla*	*E. camaldulensis*
T (%)	14.14 [b] ± 0.59	19.78 [a] ± 0.89	9.11 [c] ± 0.36
R (%)	8.87 [b] ± 0.60	15.47 [a] ± 1.04	6.26 [c] ± 0.62
L (%)	0.85 [a] ± 0.11	1.28 [a] ± 0.23	1.09 [a] ± 0.15
Ct	0.0016 [b] ± 0.0001	0.0023 [a] ± 0.0003	0.0015 [b] ±0.0001
Cr	0.0010 [b] ± 0.0001	0.0018 [a] ± 0.0002	0.0010 [b] ±0.0001
Cl	0.0009 [b] ± 0.00001	0.00014 [ab] ± 0.00001	0.00018 [a] ± 0.00001
V (%)	22.40 [b] ± 0.80	32.99 [a] ± 1.39	15.74 [c] ± 0.56
*Mean ± SE; Different letters correspond to significantly different values; T: tangential shrinkage; R: radial shrinkage; L: longitudinal shrinkage, Ct: coefficient of tangential shrinkage; Cr: coefficient of radial shrinkage; Ct: coefficient of longitudinal shrinkage; V: volumetric shrinkage			

Results revealed that the higher the SG of branch wood, the higher the ability of a portion of the wood to persist from shrinkage. In contrast, the higher the MC of branch wood, the higher the shrinkage will occur. These findings were also supported by the correlation analysis (Table 3) that shows the SG and MC negatively and positively correlated with all of the shrinkage properties, except for longitudinal shrinkage. Hence, the findings suggest that the amount of shrinkage is proportional to the amount of water removed from the wood. Consequently, branch wood is less favorable as a raw material for fabricating several products, such as particleboard (Zaidon *et al.* 2007), flakeboard, and fiberboard (Shmulsky and Jones 2011).

Table 3. Correlation Analysis among Physical Properties

Branch Wood Properties	MC	T	R	L	V
SG	-0.962**	-0.691*	-0.646*	-0.098	-0.690*
MC	1	0.793**	0.773**	0.226	0.805**
*Significant at $p < 0.05$, ** Significant at $p < 0.01$					

Anatomical Properties

Comparison of wood elements

The proportion of wood elements mainly consisted of fiber (FP) ranging between 33.6 and 60.3%. Additionally, the proportions of rays (RP), vessels (VP), and parenchyma (PP) were in the ranges of 17.6 to 38.8%, 10.7 to 12.8%, and 7.9 to 38.0%, respectively (Table 4). Jourez *et al.* (2001) reported that the diameter and frequency of vessels in tension wood may decrease in comparison to normal wood. Also, he found that the number of rays are higher in tension wood. Zhao *et al.* (2019a) judged that a high proportion of vessels and parenchyma can lead to poor mechanical pulp quality. Aligned with SG value, *E. camaldulensis* had the highest FP (60.3%). It possibly generates denser wood. The other species seem more porous, which was apparent from the PP of *A. gerrardii* (38.0%) and the RP of *T. aphylla* (38.8%). Thus, both species had a lower SG. Ziemińska *et al.* (2013) reported that the lower fiber proportion implied that there was a higher vessel or parenchyma proportion. In accordance with the present study, the FP was positively correlated with the SG of branch wood and reached significant levels ($p < 0.01$) (Table 5), which suggest the branch wood with a higher FP may have a higher SG. Hence, it may be used for light construction purposes (Zhao *et al.* 2019b).

Table 4. Mean Proportion of the Wood Elements Percentage

Species	VP (%)	FP (%)	PP (%)	RP (%)
A. gerrardii	10.73 ^{a} ± 1.05	33.61 ^{b} ± 1.64	38.03 ^{a} ± 1.49	17.63 ^{b} ± 0.56
T. aphylla	12.05 ^{a} ± 1.50	36.35 ^{b} ± 1.91	12.85 ^{b} ± 1.88	38.75 ^{a} ± 1.36
E. camaldulensis	12.81 ^{a} ± 1.32	60.27 ^{a} ± 1.48	7.93 ^{c} ± 0.93	18.9 ^{b} ± 2.14
*Mean ± SE; Different letters correspond to significantly different values				

Table 5. Correlation Analysis on Specific Gravity and Anatomical Properties in Wood of Examined Species

Branch Wood Properties	FL	FD	LD	DCWT	VD	VP	FP	PP	RP
SG	-0.691*	-0.797**	-0.772**	0.426	0.194	0.583	0.908**	-0.567	-0.481
*Significant at $p < 0.05$, ** Significant at $p < 0.01$									

Comparison of vessel diameters

The mean vessel diameter of *A. gerrardii* (63.0 µm) was larger than that of the other species. However, it was only significantly different from *T. aphylla* (50.9 µm). *A. gerrardii* was assumed to be more porous than *T. aphylla*. *T. aphylla* looked more porous because it had the lowest SG and the highest MC, even though the vessel diameter of *T.*

aphylla was the lowest when compared to the other species. The middle size of the vessel appeared in *E. camaldulensis* with a vessel diameter of 60.8 μm. Generally, the vessel of branch wood is denser and lower in diameter than those of stem wood. Baas (1982) noted that the vessel of root wood was generally wider than those of the trunk. In addition, vessel diameters increase following the basipetal direction from top to bottom and they are usually greatest in roots (Tyree and Zimmermann 2002). This is one of the basic organizing principles of the hydraulic architecture of a tree (Zimmermann 1983). Basically, the smaller size of the vessel in branch wood may increase the stability of lumber and can also reduce the vessel picking issues in pulp and paper (Rakkolainen *et al.* 2009). However, as mentioned above, the high density of vessels and parenchyma can lead to poor mechanical pulp quality (Zhao *et al.* 2019a).

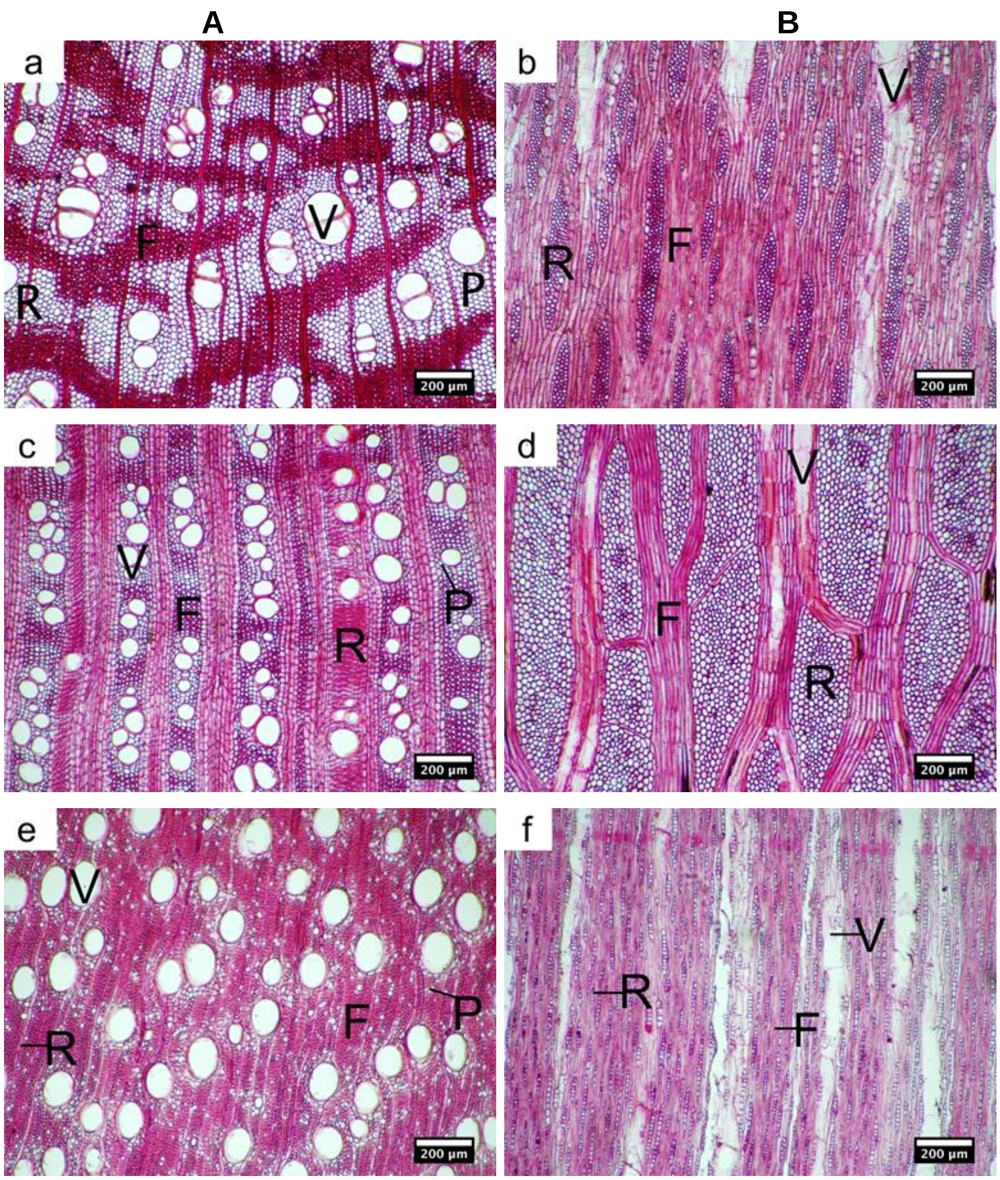

Fig. 1. Xylem sections displaying anatomical features in the branch wood of *A. gerrardii* (a)(b), *T. aphylla* (c)(d), and *E. camaldulensis* (e)(f), in (A) transversal and (B) tangential section with bar scales represent 200 µm; F: fiber; V: vessel element; P: parenchyma; R: ray.

Comparison of fiber dimensions

Fiber length (FL), fiber diameter (FD), lumen diameter (LD), and double cell wall thickness (D-CWT) were significantly different ($p < 0.00$) among the three species in the present study. Overall, FL of *A. gerrardii* (945.6 µm) is longer than that of *T. aphylla* (728.9 µm) and *E. camaldulensis* (596.0 µm). The FD and LD of *T. aphylla* are wider when compared to the other species (Fig. 2). Interestingly, D-CWT of both *E. camaldulensis* and *A. gerrardii* was thicker than that of *T. aphylla* with a value of 9.76 µm, 9.47 µm, and 8.6 µm, respectively (Table 6). Consequently, it appeared that the LD and D-CWT have a great influence on SG and MC. Moreover, the correlation analysis revealed that FL, FD, and LD negatively correlated with SG (Table 5). In agreement with the results, Beeckman (2016) also found that fiber cell wall thickness has a strong effect on SG. The author stated that fiber cell wall thickness has substantial correlation to wood performance.

According to Wang (1998), fibers with an average length of greater than 400 µm are suitable for papermaking. Also, Zhao *et al.* (2019b) suggested that branch wood might be suitable for papermaking and glued plates because of its intermediate fiber length. Thus, all of the fibers in this study showed suitability as a raw material for pulp and paper. Despite this, the quality is quite low due to the high density of vessels or parenchyma proportions (Zhao *et al.* 2019a).

Table 6. Mean of Fiber Dimensions

Species	FL (µm)	FD (µm)	LD (µm)	D-CWT (µm)
A. gerrardii	945.56 ^{a} ± 29.71	17.07 ^{b} ± 0.32	7.60 ^{b} ± 0.37	9.47 ^{a} ± 0.25
T. aphylla	728.93 ^{b} ± 14.09	20.90 ^{a} ± 0.42	12.30 ^{a} ± 0.4	8.60 ^{b} ± 0.21
E. camaldulensis	596.05 ^{c} ± 11.50	14.00 ^{c} ± 0.24	4.24 ^{c} ± 0.24	9.76 ^{a} ± 0.18
*Mean ± SE; Different letters correspond to significantly different values				

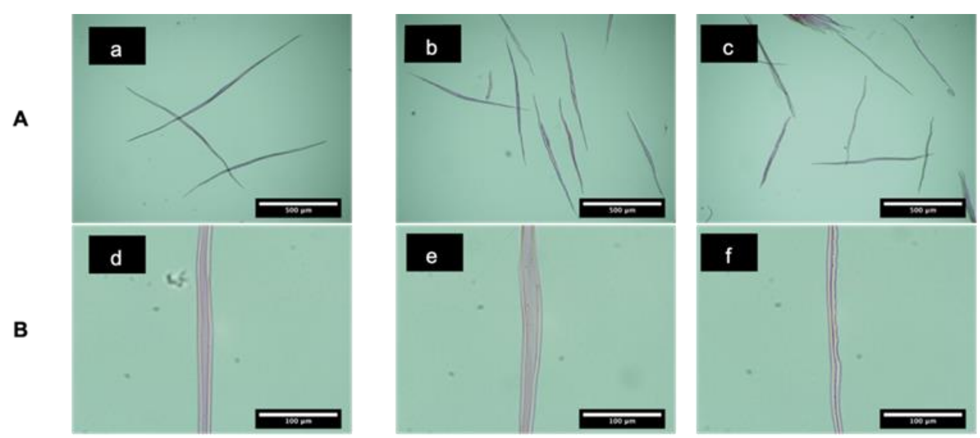

Fig. 2. The appearance of fiber *A. gerrardii* (a)(d), *T. aphylla* (b)(e), and *E. camaldulensis* (c)(f), in (A) 4x and (B) 20x magnification with bar scales represent (A) 500 µm and (B) 100 µm.

Chemical Properties

The values of each of the chemical components were varied among the studied species. Moreover, extractive and ash contents were the most varied components among all chemical components. The quantity of extractive and ash content ranged from 4.77 to 8.76% and 0.86 to 6.28%, respectively. *T. aphylla* had the highest extractive and ash contents, while *E. camaldulensis* contained the lowest amounts. There was significant difference among each species ($p < 0.01$). The quantity of cellulose and hemicellulose content ranged from 31.1 to 34.1% and 33.2 to 39.1%, respectively. These chemical components were quite similar among species. Hence, there was only significant difference at α equal to 10% (cellulose with $p = 0.096$; hemicellulose with $p = 0.055$). The quantity of lignin content ranged from 17.7 to 25.0%. It was significantly different at α equal to 5% ($p = 0.023$). According to Stalnaker and Harris (1997), generally, cellulose accounts for 45 to 50% of the weight of completely dry wood, hemicellulose amounts to 20 to 25%, and lignin accounts for approximately 20 to 30%. Compared to the results in the present study, cellulose and lignin were lower than the reference, while hemicellulose was higher. This could be because branch wood had a higher sapwood percentage than that of stem wood (Zhao *et al.* 2019a). Hence, branch wood still contained a large amount of holocellulose (64.3 to 73.2%) and it has the potential for producing green products, such as biofuel, bioenergy, and its by-product named biochar (Lee 2013; Victor *et al.* 2015).

Biochar is a carbon negative product that is produced by the smokeless biomass pyrolysis process. There are several benefits of biochar over charcoal, activated carbon, and other pyrogenic materials. Biochar could be used as a soil amendment to increase water holding capacity, preserve the nutrients in the soil, increase crop productivity, provide biofuel and bioenergy, suppress soil emissions of CH_4 and N_2O, and absorb contaminants and pollutants in water bodies (Shackley *et al.* 2013; Ussiri and Lal 2017). Moreover, wood combustion and pyrolysis processes do not contribute to global warming or greenhouse gases, and they contain little sulphur, nitrogen, and ash (Shmulsky and Jones 2011; Nath 2017). However, biochar is a complex substance that requires knowledge relating to its characteristics and benefits. Generally, feedstock properties and production conditions (especially temperature) may strongly affect biochar's properties (Weber and Quicker 2018). Hence, it is important to explore various types of branch wood as a feedstock for obtaining the suitable biochar product that will be valuable in satisfying human needs in the future.

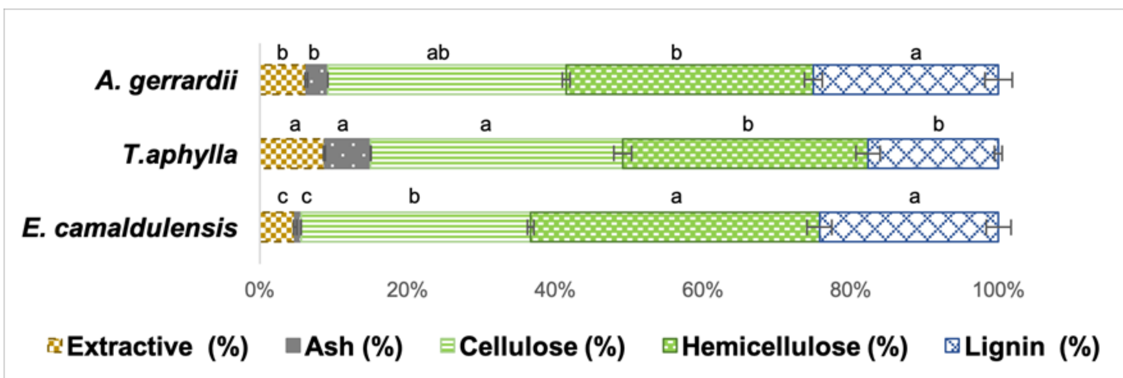

Fig. 3. The chemical content percentage of the examined species. Different letters (a, b, c) indicate the significant difference for each variable among chemical content ($p < 0.05$).

CONCLUSIONS

1. Branch wood in the present study exhibited several disadvantages relative to potential structural uses. The disadvantages included high shrinkage percentage and high proportion of vessels or parenchyma.

2. Branch wood of all examined species might be used for light construction purposes or as a blending material in papermaking and glued plates.
3. In view of the chemical properties (particularly the amount of holocellulose 64.3 to 73.2%), branch wood has the potential for producing several green products (*e.g.* biofuel, bioenergy, and biochar) that might maximize the limitation of branch wood.
4. The proportion of fiber (FP) may become a good indicator to predict the SG value of branch wood. As of the results showed that FP positively correlated with the SG of branch wood and reached significant levels.

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