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Anatomical Appraisal of Date Palm Rachis as Raw Material for the Wood Composite Industry

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ABSTRACT

Fronds of date palm (*Phoenix dactylifera* L., Arecaceae) constitute a renewable natural resource for manufacturing the value-added composite panels. The present study evaluates the anatomical features of leaf mid-rib (rachis) of female trees of cv. Barhy, Naboat-Saif, Sugaie and Sukkary cultivars of date palm. It focuses mainly on the structure, dimension and density of vascular bundles, vessel-lumen diameter, vessel-wall thickness, fibre length, fibre-wall thickness and the cellulose and hemi-cellulose contents in the basal and middle portions of the rachis. In general, date-palm rachis has a large number of conjoint, collateral and closed VBs of varying sizes embedded in the parenchymatous ground tissue. The xylem in the vascular bundle consists of 6-15 protoxylem and 2-3 metaxylem vessels. The peripheral and transitional zones of the rachis cross-section have large amount of fibres and high density of vascular bundles. Upper fibre caps of vascular bundles are thicker than the lower ones in these zones. In general, cv. Barhy shows a higher vessel density per vascular bundle than in other cultivars. Cultivar Naboat-Saif has the thickest vessel walls and maximum fibre area fraction but relatively short fibres, whereas cv. Sugaie possesses the highest vascular bundle density, longest fibres, narrow vessels and a considerably high fibre area fraction. Likewise, cv. Sukkary has the maximum vascular bundle area, narrow vessels and the maximum cellulose content. Although fronds of all the four cultivars provide a suitable raw material for wood composite industry, cvs. Sugaie and Sukkary seem to have an edge over cvs. Barhy and Naboat-Saif based on their anatomical characteristics.

Key words: Fibre-area fraction; fibre length; vascular bundle density; vessel diameter

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Introduction

Date palm (*Phoenix dactylifera* L., Arecaceae) is one of the most important fruit crops cultivated in arid regions of the Middle East and Arabian lands. Its fruits have a high nutritive and therapeutic value and are used in a variety of traditional systems of medicine such as Ayurveda and Unani systems of Indian medicine (Rahmani et al., 2014; Jain et al., 2018; Allaith, 2019). Arab countries are distinguished in having the date-palm belt extending from Morocco in the West to Iraq in the East, comprising of approximately 102.4 million palm trees (El-Mously & Saber, 2018). There are about 500 known date palm varieties distributed all over the world, of which 450 varieties are found in Saudi Arabia alone (Bashah, 1996). Date palm is a dioecious plant and its obligate out-breeding habit renders its progeny strongly heterogeneous (Munier, 1981). Under normal growth conditions, an average of 12–15 new leaves are produced annually by a palm tree and almost the same number of old leaves are removed every year as a part of its maintenance (Barreveld, 1993). In date palm orchards, female plants are grown in abundance with only a few male counterparts (Ashour et al., 2008), as one male tree can pollinate 40 to 50 females (Awad, 2010). Given this, the main bulk of waste material due to pruning comes from female plants, which constitute about 98% of date-palm tree populations.

It is germane, therefore, to evaluate this by-product of pruning as a renewable and sustainable resource for manufacturing the wood substitute composite panels, such as the medium-density fibreboards (MDF), particle boards, block boards, etc.

A large number of the date palm tree varieties growing in Arabian countries provide a huge quantity of non-fruit material, in particular the frond mid-rib (rachis). The potential of the rachis as the biological raw material is determined mainly by its anatomical structure. Rachis anatomy and its variability in quantitative characters such as fibre length, proportion of fibre tissue, number of vascular bundles (VBs), distribution of VBs in different locations along the mid-rib, thickness of vessel wall, and thickness of peripheral vascular sheath have a great impact on the mechanical strength of the rachis. Vascular bundles near the periphery are normally smaller, more numerous, circular in cross section and often with one or two meta-xylem elements, and have a fibre sheath around them (Megahed & El-Mously, 1995).

Across the rachis, different zones of VBs, such as the peripheral, transitional and inner zones, can be distinguished. In the first two zones, fibre sheath is thick, and VBs are numerous with small parenchyma cells between them. The third zone is the broadest, where the bundles attain their largest diameter. Fibre tissue percentage is higher in the peripheral and transition zones than in the inner or central zone (Megahed & El-Mously, 1995). The peripheral and transition zones have a high percentage of fibre tissue and large number of VBs, which affect the density and strength properties of the rachis. Fibre length is smaller in the middle part of the frond than at the base and the top (Megahed & El-Mously, 1995; Alotaibi et al., 2019). The average fibre length of date palm midrib lies within the average known for the hardwood species and is a little shorter than one in the stems of some other palm species (Bhat et al., 1993; Khiari et al., 2010). The structural and functional variations in the leaves of six Saudi Arabian date palm cultivars have been studied by Al-Khalifah and Khan (2006).

El-Mously (2001) evaluated the date palm fronds for manufacturing the lumber-core plywood (blockboard) and found that the frond rachis possesses mechanical properties comparable with those of imported wood (e.g., spruce and beech). El-Mously and Saber (2018) confirmed by their trial manufacture of medium-density fibreboard (MDF) that the MDF samples manufactured from the date palm secondary materials (rachis, leaflets, spadix, stem, etc.) satisfy the mechanical and physical requirements of international standards. Mechanical properties of particle board panels commercially manufactured in Egypt from date-palm rachis also met the required standards (El-Mously, 2019). Similar findings have emanated from a variety of reports (Iskanderani, 2008, 2009; Hegazy & Aref, 2010; Hegazy et al., 2015).

The present investigation was undertaken to examine the leaf mid-rib quality of some date palm cultivars available in Riyadh region of Saudi Arabia with respect to their richness in VBs and characteristics of fibres and vessels to ascertain their suitability as a wood substitute for manufacturing the added-value composite panels. This report is focused on female trees, the main producers of waste material due to pruning.

Materials and Methods

Leaflets were removed from the date palm (*Phoenix dactylifera*) fronds (one frond per tree) obtained from five female trees of each of cvs. Barhy, Naboat-Saif, Sugaie and Sukkary grown in the Riyadh region of Saudi Arabia. One small segment from the basal and one from the middle portion were obtained from each rachis and fixed in FAA, following Berlyn and Miksche (1976). After one week, the fixed samples were transferred to alcohol-glycerol solution (50% ethanol + 50% glycerol, V/V) for preservation and softening. Later, 8-10 µm thick transverse and longitudinal sections of these samples were cut on a sliding microtome (AO 860, USA), stained in double stain combinations of haematoxylin % safranin, haematoxylin % Bismarck brown (Johansen, 1940) and ferric chloride % lacmoid (Cheadle et al., 1953), and dehydrated in ethanol series. The stained and dehydrated sections were then mounted on glass slides in Canada balsam. These permanent slides were stored in wooden slide boxes for anatomical studies.

Maceration and fibre length determination

For maceration of the mid-rib tissue, five match-stick-sized specimens obtained from the rachis (from base and 1 m above, as well as from 2 mm thick peripheral zone and the inner zone) of each tree were put in a 1:1 (by volume) solution of glacial acetic acid and 30% hydrogen peroxide taken in a test tube, and then heated at 60ºC for 48 hrs. After delignification was completed, the macerated materials were washed several times in distilled water with mild shaking to separate the fibres, and then stained with Safranin (Franklin, 1945). Lengths of 10 randomly selected fibres from each sample ($n = 10\times5\times5 = 250$) were measured in wet condition to the nearest 0.01 mm, using a projection microscope connected to TV screen.

Determination of cellulose, hemi-cellulose and extractives contents

Cellulose content was determined by treating the extractive-free sawdust meal (one sample from one frond of each of the five trees) with nitric acid and sodium hydroxide: one gram of extractive-free sawdust meal was treated with 20 ml of nitric acid (3%) in a flask and boiled for 30 min. The solution was filtered in crucible G3. The residue was treated with 25 ml of a solution of sodium hydroxide (3%) and boiled for 30 min. The residue was then filtered, washed with warm water to neutral filtrate, oven-dried and weighed (Nikitin, 1960).

In order to determine the hemi-cellulose content, 1-2 g extractive-free wood meal was boiled with 50-100 ml sulfuric acid (2%) for 1 h under a reflex condenser and filtrated in crucible G2. The residue was washed with 500 ml of hot distilled water to free the acid, then dried in oven at 105 ± 2 °C, cooled in a desiccator and weighed (Rozmarin & Simionescu,1973).

Estimation of extractives (%) was carried out following the procedure # 10 of the laboratory analytical procedure, National Renewable Energy Laboratory, USA (Sluiter et al., 2008). Air-dried sawdust meal was operated in a Soxhlet extraction after adjusting the heating rate so as to give 4-5 solvent exchanges per hour in the Soxhlet thimble. Approximately 120 ml solvent (95% ethanol) was used during the 24 hour period. The percentage of extractives was calculated based on the oven-dry weight of the sawdust samples.

Anatomical data collection and analysis

The vascular bundle density, vessel width, vessel-wall thickness, and vessel density per VB were recorded in five transverse sections from each of the selected positions on the rachis of each tree. Data were collected from sections covering the region from periphery to the center of the basal and middle segments of rachis. Width of vessels was measured in all the VBs from periphery to center of rachis segments, and the tangential and radial diameters and wall thickness of vessels were worked out with Olympus CX41 microscope. Analysis of area fractions of VBs, vessel lumen, fibre-wall thickness and ground parenchyma in the basal and middle parts of the rachis from all five replicates (trees) of each cultivar was done from digital images (n= 10×5 = 50).

Transverse sections were photographed using a digital camera (Olympus DP 72) attached to an Olympus BX 51 microscope and a computer. Ten prints of each replicate covering the vascular bundles and ground parenchyma were used to analyze the area occupied by vessel lumen, ground parenchyma and fibre-wall thickness. Scanner Epson Expression 1680 (Scan 300 dpi, Black & White, 130 threshold) and software Area Scan Ver. 1.0 were used with image resolution 300 dpi to analyze the area occupied by these tissues. The data obtained for each cultivar were analysed using analysis of variance (ANOVA) and the differences between cultivars detected, at the 5% level, using Fisher's least significance difference (L.S.D.) test using SAS 9.1.3 (SAS 2000).

Results

General structure of rachis

Mid-ribs of fronds of all the four cultivars were characterized by the presence of a large number of conjoint, collateral and closed vascular bundles (VBs) of varying sizes embedded in a parenchymatous ground tissue. Of the vascular tissues, xylem contained 6-15 protoxylem and 2-3 metaxylem elements (Fig. 1B, D). The peripheral and transition zones across the midrib were characterized by a large number of bundles and hence a high percentage of fibre tissue (Fig. 1A, C). The scattered VBs in these zones were surrounded by fibre caps of varying thickness and the upper (outer) fibre caps were quite thicker than the lower (inner) ones (Fig. 1A, C). However, thickness of the outer and inner caps was almost equal in the VBs located in the inner part of the rachis (Fig. 1B).

Variation across cultivars

Table 1 presents the mean values of the densityand areas of VBs, vessels, fibres and ground-tissue in the cross-sectional view of the rachis. Cultivar Naboat-Saif had the largest midrib cross-sectional area at the basal and middle segments (21.3 cm^2 and 9 cm^2 respectively), which is followed by cvs. Sugaie and Barhy. The number of VBs per cm^2 (VB density) was the highest in the basal segment of cv. Sugaie (122), followed by cvs. Naboat-Saif (98) and Barhy (90), while the lowest (81) was recorded in cv. Sukkary. In the middle segment, however, cv. Sugaie had the highest VB density (205), followed by cvs. Barhy (162) and Sukkary (152). As regards the area occupied by VBs in the basal segment, cv. Naboat-Saif had significantly higher value (37%) than the other cultivars. In the middle segment, however, cv. Sukkary had the highest VB area fraction (45%), followed by cv. Sugaie (40%).

Cultivar Naboat-Saif showed a significantly larger (23%) fibre-wall area fraction in the basal segment,

Table 1. Variation in (mean±SD) VB density and the relative proportion of component tissues in the rachis of female trees of different date-palm cultivars (n = 5 for each rachis segment).

Date palm cultivar	Rachis segment	Cross-sectional area (cm^2)	VB density per cm^2	Ground tissue area (%)	Vascular bundle area (%)	Vessel area (%)	Fiber area (%)
Barhy	**Basal**	17.36±2.42^b	90±7.20^b	73±5.11^a	27±1.89^b	11±0.88^c	16±1.28^b
	Middle	5.73±0.62^c	162±10.53^b	66±4.95^a	34±2.55^c	22±1.65^b	12±0.91^c
Naboat-Saif	**Basal**	21.26±1.59^a	98±6.86^b	63±4.41^b	37±2.59^a	15±1.08^a	23±1.62^a
	Middle	9.03±0.89^a	109±7.08^c	70±4.90^a	30±2.20^d	12±0.85^d	18±1.26^b
Sugaie	**Basal**	19.93±2.59^a	122±7.56^a	72±5.40^a	28±2.10^b	12±0.96^{bc}	16±1.28^b
	Middle	7.20±0.63^b	205±12.30^a	60±4.20^b	40±2.81^b	18±1.35^c	22±1.65^a
Sukkary	**Basal**	12.26±1.09^c	81±5.67^c	71±4.61^a	29±2.03^b	14±1.12^{ab}	15±1.20^b
	Middle	4.96± 0.28^c	152±10.64^b	55±4.12^c	45±3.37^a	26±1.95^a	19±1.42^b
L.S.D. Basal segment		1.90	8.36	4.65	3.65	2.85	2.78
L.S.D. Middle segment		1.24	10.13	4.54	2.96	3.78	2.92

Means with the same letters in the same column are not significantly different according to Fisher's L.S.D. test (p = 0.05).

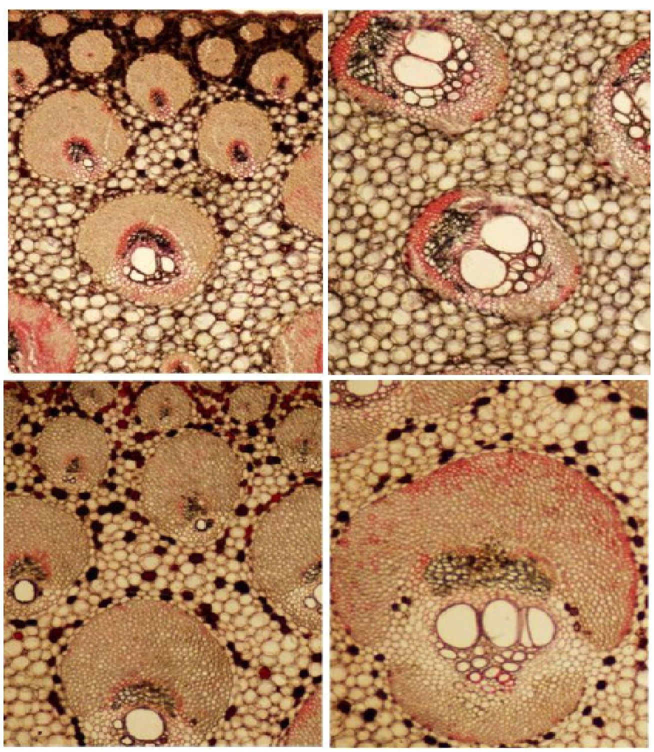

Figure 1 (A-D): Cross sections of leaf midrib of female date-palm trees: (A) cv. Barhy - peripheral zone of middle segment showing vascular bundles of diverse size, rich in fibres and scattered in the parenchyma ground tissue; (B) cv. Barhy - inner zone showing vascular bundles with two metaxylem and many protoxylem elements and covered by upper and lower fibre caps of equal thickness; (C) cv. Sukkary - peripheral zone of basal segment showing vascular bundles of diverse size, rich in fibres and scattered in the parenchyma ground tissue; (D) cv. Sukkary - transition zone of basal segment showing vascular bundles with a broad upper fibre cap (all at 10x4).

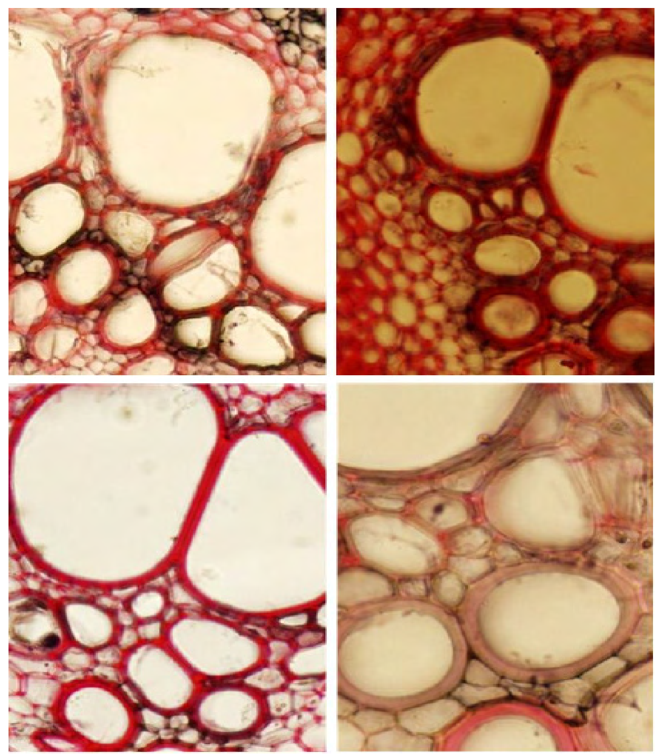

Figure 2 (A-D): Cross sections of leaf midrib of female date-palm trees of (A) cv. Barhy showing thick-walled vessels and high vessel density; (B) cv. Naboat-Saif showing thick-walled vessels and lowest vessel density; (C) cv. Sugaie showing thin-walled vessels and low vessel density; and (D) cv. Sukkary showing thick-walled vessels in abundance (A-C at 10x20, D at 10x40).

compared to the other cultivars. In the middle segment, cv. Sugaie surpassed the other cultivars with a mean value of 22%. Fibre proportion was higher in the basal segment than in the middle segment in cvs. Barhy and Naboat-Saif, whereas the reverse applied to cv. Sugaie and Sukkary (Table 1).

Table 2 presents mean values for the diameters and density of vessels (vessel number per VB) in the four cultivars. In the basal segment of rachis, the tangential, radial and average diameters fell within the range of 61.51-80.15 µm, 46.63-61.14 µm and 54.07-70.64 µm respectively; the maximum values occurring in cv. Barhy and the minimum in cv. Sugaie. In the middle segment, the range of the tangential and average diameters were 50.61-76.54 µm and 44.04-62.55 µm respectively, the maximum values occurring in cv. Naboat-Saif and the minimum in cv. Sukkary. The radial diameter (37.48 - 49.71 µm) had its maximum in cv. Barhy and minimum in cv. Sukkary. The minimum and maximum values of the tangential, radial and average vessel diameters differed significantly from each other at 5% level. Moreover, thickness of vessel wall varied with cultivar (Fig. 2A-D). Cultivar Naboat-Saif had the thickest vessel wall in both the basal (4.22 µm) and middle (5.02 µm) segments of rachis, and was followed by cv. Barhy (4.05 µm) (Fig. 2A, B). Cultivar Sugaie possessed the thinnest vessel wall of 2.9 µm (Fig. 2C). However, vessel number per VB was significantly lower in cv. Naboat-Saif than in other cultivars.

Variation in rachis fibre length

Mean values of fibre length obtained from two positions along the rachis length (base and 1 m above), and from two zones (peripheral and central zone) across the rachis width of the four cultivars indicate that fibres were longer at 1 m above the base than at the base of the rachis, and in the 2 mm peripheral zone than in the central zone (Table 3). Further, the fibres in the rachis of cv. Naboat-Saif were relatively short (0.87 and 0.97 mm) at both locations along the rachis length and in both zones (0.91 and 0.93 mm) of the rachis cross-section. Fibre length was found to be significantly affected by the cultivar ($P < 0.0001$) but not by different locations along the rachis length. On the other hand, zone locations (peripheral or central) caused a significant effect on the fibre length ($P<0.0112$). Properties of fibre strands in a VB are important in determining the strength of date palm leaves.

Variation in rachis chemistry

Data in Table 4 indicate that the cellulose content does not differ significantly among the fronds of different cultivars studied, and that the proportion of cellulose is more at 1 m above the base of the rachis (47.1-48.3%) than at the base (43.4- 44.6%) across the cultivars. Similarly, hemicellulose content does not show significant inter-cultivar differences. However, the amount is greater at the rachis base (24.6- 29.7%) than at 1 m above the base (19.9- 23.1%) across the four cultivars (Table 5). Both the cellulose and hemicellulose contents were not affected significantly on the basis of cultivar, but the location on the rachis has a highly significant effect on the amount of these compounds (both $P < 0.0001$).

Values presented in Table 6 indicate higher mean values of extractives (chemical compounds extractable from tissues with neutral solvents, like organic solvents or water) at the base than at 1 m ahead along the rachis length in all the cultivars except cv. Sukkary. On the whole, cvs. Naboat-Saif and Sugaie have larger mean values (24.6 and 25.6%; respectively) than cvs. Barhy and Sukkary (20.3 and 20.6% respectively). To be more precise, cv. Sugaie showed the highest mean extractives value among all cultivars (Table 6). The cultivar and also the sample location on the rachis had a significant impact on the extractives percentage mean values.

Discussion

In the composite panel industry, spray of fine resin droplets requires strong clean sites for better adhesion contact between the superimposing flakes of the constituent material. These favoured sites are provided by the VBs interface area and not by the parenchyma tissue surrounding the VBs. This means that if the flakes obtained from a specific date palm cultivar have a large number of VBs, they would create more sites available for stronger particle adhesion, resulting in mechanically more efficient and stronger panels (Hegazy & Ahmed, 2015; Hegazy et al., 2015). The size and shape of fibre strands in the VB are considered to be most important in determining the mechanical strength of fronds. Cross-sections of the basal and the middle segments of rachis of each of the selected date-palm cultivars were examined in the present study to find out whether the rachis could be used as a wood substitute in manufacturing the value-added composite panels. Features of VBs and fibres observed across the

Table 2. Variation in (mean±SD) vessel properties in the rachis of female trees of different date-palm cultivars (n = 5 for each rachis segment).

Date palm cultivar	Rachis segment	Vessel tangential diameter (µm)	Vessel radial diameter (µm)	Vessel mean diameter (µm)	Vessel wall thickness (µm)	Vessel density per VB
Barhy	**Basal**	80.15±5.61^{a}	61.14±4.28^{a}	70.64±4.95^{a}	4.05±0.28^{a}	18.0±1.26^{a}
	Middle	65.41±4.48^{b}	49.71±3.48^{a}	57.56±4.03^{b}	3.69±0.26^{b}	14.0±0.91^{b}
Naboat-Saif	**Basal**	77.89±5.45^{ab}	54.60±3.82^{b}	66.24±4.64^{b}	4.22±0.30^{a}	10.0±0.78^{d}
	Middle	76.54±5.36^{a}	48.55±3.40^{ab}	62.55±4.38^{a}	5.02±0.35^{a}	8.0±0.64^{d}
Sugaie	**Basal**	61.51±4.31^{c}	46.63±3.26^{c}	54.07±3.78^{c}	3.67±0.26^{b}	12.0±0.96^{cd}
	Middle	64.37±4.51^{b}	46.46±3.25^{b}	55.42±3.88^{b}	2.90±0.20^{c}	11.0±0.99^{c}
Sukkary	**Basal**	74.68±5.23^{b}	58.22±4.08^{a}	66.45±4.65^{b}	3.71±0.26^{b}	15.0±1.20^{b}
	Middle	50.61±3.54^{c}	37.48±2.62^{c}	44.04±3.08^{c}	3.77±0.29^{b}	17.0±1.23^{ab}
L.S.D. Basal segment	5.16	3.58	4.07	0.31	2.51	
L.S.D. Middle segment	4.68	3.05	3.86	0.38	2.63	

Means with the same letters in the same column are not significantly different according to Fisher's L.S.D. test (p = 0.05).

Table 3. Variation in fibre lengths at two positions along the length, and in two zones of cross-sectional view, of the rachis of different date-palm cultivars.

Date palm cultivars	Total value of FL (mm)	FL at the base of mid-rib (mm)	FL one meter above above the base (mm)	FL in peripheral zone (mm)	FL in central zone (mm)
Barhy	1.09^{a}	1.09^{a}	1.10^{a}	1.11^{a}	1.09^{a}
Naboat-Saif	0.92^{b}	0.87^{b}	0.97^{b}	0.91^{b}	0.93^{b}
Sugaie	1.12^{a}	1.11^{a}	1.13^{a}	1.14^{a}	1.09^{a}
Sukkary	1.07^{a}	1.08^{a}	1.06^{ab}	1.20^{a}	0.98^{b}
L.S.D	0.058	0.065	0.097	0.061	0.091

Means with the same letters in the same column are not significantly different according to Fisher's L.S.D. test (p = 0.05), Values are the mean of 150 measurements (50 fibers from 3 slides each) for each position.

Table 4. Variation in mean cellulose content of tissues at two positions along the rachis - the base and 1 m above the base - in different date palm cultivars.

Cultivar	Average value for rachis (%)	At the base of rachis (%)	1m above the base (%)
Barhy	45.84a	44.58a	47.11b
Naboat-Saif	46.00a	43.81ab	48.19a
Sugaie	45.86a	43.39b	48.33a
Sukkary	46.17a	44.42ab	47.92a
L.S.D	0.82	1.05	0.77

Values followed by the same letters in the same column are not significantly different according to Fisher's L.S.D. (p = 0.05). Five replicates were analyzed for each rachis segment.

Table 5. Variation in mean hemi-cellulose content of tissues at two positions along the rachis -the base and 1 m above the base - in different date palm cultivars.

Cultivar	Average value for rachis (%)	At the base of rachis (%)	1m above the base (%)
Barhy	23.87^{a}	24.64^{c}	23.09^{a}
Naboat-Saif	24.27^{a}	28.36^{ab}	20.18^{c}
Sugaie	24.78^{a}	29.70^{a}	19.86^{c}
Sukkary	24.69^{a}	27.10^{b}	22.29^{b}
L.S.D	2.26	1.07	0.63

Values followed by the same letters in the same column are not significantly different according to Fisher's L.S.D. (p = 0.05). Five replicates were analyzed for each segment of the rachis.

rachis conform to the earlier findings of Megahed and El-Mously (1995).

Anatomical study of the palm midrib has shown that its outer zone differs from the inner part in having a higher density of smaller fibro-vascular bundles, the structural unit of the cross-section, indicating that this outer zone possesses better mechanical properties, as compared with the average properties of the midrib. El-Mously (1995) divided the rachis cross-section into peripheral, transitional and core layers and found that the peripheral zone possesses higher mechanical properties than the core region. El-Shabasy and El-Mously (1997) mentioned that the peripheral zone (1.25 mm) of the palm midrib had a tensile strength (~ 25

Table 6. Variation in mean concentration of tissue extractives (percentage) at two positions along the rachis - at the base and 1 m above the base - in different date-palm cultivars (n = 5).

Cultivars	Tissue extractives in rachis	at the base	1 m above the base
Barhy	20.30[b]	21.60[b]	18.99[c]
Naboat-Saif	24.63[a]	27.37[a]	21.88[b]
Sugaie	25.55[a]	28.11[a]	22.99[a]
Sukkary	20.64[b]	18.52[c]	22.76[a]
L.S.D	2.70	1.07	0.65

Values followed by the same letters in the same column are not significantly different according to Fisher's L.S.D. (p = 0.05). Five replicates were analyzed for each segment of the rachis.

kg/mm^2) comparable with that of the commercial steel, and the specific strength (i.e., tensile strength per unit weight) of this zone was 4 times higher than that of steel, thus showing the suitability of palm rachis for use in bio-composites as a substitute to non-renewable materials such as glass fibres.

El-Shabasy and El-Mously (1997) reported sufficiently long fibres (1.366 mm and 1.288 mm) in the rachis of cvs. Baladi and Siwi, respectively. However, the date-palm rachis studied by Khiari et al. (2010) depicted relatively short fibres (length 0.89 mm and width 22.3 µm). Alotaibi et al. (2019) enunciate that fibres present in the leaf stalk and fruit-bunch stalk of date palm are more thermally stable (with a higher degradation temperature) than those in other parts of the plant such as leaf sheath or tree trunk. Using the modern analytical techniques, Boumediri et al. (2019) made a comparative study of two lignocellulosic strands, *viz.* fibre strand (FS) and vascular bundle strand (VBS), in rachis of the Ghars variety of date-palm, common in Algeria, and found that both have a rough surface and similar chemical composition and functional groups. Fibre strands had a higher crystallinity index (56.68%) in comparison to VBSs (47.82%); the higher the crystallinity index, the better the tensile strength. Their tensile strength was more than 4 times greater than that of VB strands. They also had a slightly smaller crystallite size, higher density and lower thermal stability, as compared to VBs. Thus, FSs seem to have a greater potential for being used as a reinforcement material in different manufacturing processes of bio-composites (Boumediri et al., 2019).

The cellulose and hemicellulose contents did not differ significantly among cultivar but the position on the rachis had a significant effect. Concentrations of extractives, despite being usually lower than those of cell-wall polymers in most cases, have a decisive impact on plant chemistry and forms the basis of chemotaxonomy. In woody plants, extractives are the predominant contributors to wood color, fragrance and durability, and also influence the pulping, drying, adhesion, hygroscopic and acoustic properties of wood. Unlike cellulose and hemicelluloses, concentration of extractives is influenced significantly not only by the sample location on rachis but also by different cultivars.

In conclusion, the present study indicates that cv Barhy is characterized with a higher vessel density per VB than the other cultivars at the basal position of rachis. The rachis of cv. Naboat-Saif has the largest cross-sectional area, thickest vessel wall, and maximum fibre area fraction, but fibres are relatively short in length. The rachis of cv. Sugaie is superior in having the maximum VB density (number of VB per cross-sectional area), longest fibres, narrowest vessels, a considerably high fibre area fraction and the highest concentration of extractives. The rachis of cv. Sukkary has an edge over the other cultivars in having the maximum VB area, narrowest vessel (vessel width almost equal to that in cv. Sugaie) and the maximum cellulose content, the level of hemicelluloses being almost similar in cvs. Sugaie and Sukkary. In general, fibres are longer at 1 m distance above the base than at the base of the rachis, and in the peripheral zone of the rachis cross-section than in the central zone, though the difference in length is non-significant in most cases. On the whole, it may be concluded that although fronds of all the four cultivars provide a suitable raw material for wood composite industry, cvs. Sugaie and Sukkary have an edge over cvs. Barhy and Naboat-Saif, as their fronds characteristically have a relatively high VB density, longer fibres, narrower vessels, and higher concentrations of cellulose, hemicelluloses and cell extractives, which collectively have a direct bearing on the physical strength of the rachis.

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