CHARACTERIZATION OF ANATOMICAL, MORPHOLOGICAL, PHYSICAL AND CHEMICAL PROPERTIES OF KONAR (*ZIZIPHUS SPINA-CHRISTI*) WOOD

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ABSTRACT

The goal of this research is to investigate some morphological (fibre length, fibre diameter, cell wall thickness, Runkel coefficient, flexibility coefficient, slenderness coefficient, rigidity coefficient, Luce's coefficient, solid coefficient), physical (dry wood density, volumetric shrinkage) and chemical (cellulose, hemicellulose, lignin, ash and acetone soluble extractives contents) composition of Konar (*Ziziphus spina-christi*) wood grown in Hormozgan province, Iran. For this purpose, three normal trees were selected randomly and a disk was cut from each one at breast height. Anatomical inspection revealed that the species was diffuse porous, with distinctive growth rings, simple preformation plate, with polygonal openings, and banded or diffuse-in aggregates parenchyma. The average values of wood dry density, fiber length, fiber diameter, cell wall thickness, Runkel coefficient, flexibility coefficient, felting coefficient, Luce's coefficient, solid coefficient, rigidity coefficient were 0.926, 52.1, 77.85, 0.57, 163 $\times 10^3$ μ^3 and 0.48. Cellulose, hemicellulose, lignin, acetone soluble, extractives, ash contents were 43.34, 19.98, 33.9, 6.42 and 2.78%, resp.

KEYWORDS: Konar wood, *Ziziphus spina-christi,* density, fiber, morphological properties.

INTRODUCTION

Konar tree (*Ziziphus spina-christi*) is widely distributed in the Middle East and Iran southern provinces due to its compatibility with the unfavorable environmental conditions like dehydration, high environment temperature, pests and diseases. Konar tree is a deciduous hardwood species. Konar zone covers Africa to Middle East including Southern regions of Iran. Konar belongs to Rhamnaceae family which includes 70 genera and 1500 species of shrubs and small to medium-size trees. It is a drought hardy tree that is adapted to grow in water-stressed habitats (Gupta and Saxena 2011). Konar is widely cultivated for its fruit due to its medical features. Other applications of Konar trees are fodder for livestock, stock-proof hedge, living fence and timber. However, new applications of Konar species such as the production of activated carbon (Abshirini et al. 2019), production of cellulose nanocrystals (Hindi 2017), production of silver nanoparticles (Alajmi et al. 2019), and production of surfactants to increase the extraction of oil wells (Shahri et al. 2012) have also been reported. Konar wood is very hard and resistant to termites (Lizardi-Mendozaet al. 2016). For this reason, it is a superior species for producing posts, roofing beams, tool handles, utensils, artistic woodwork, cabinet making, and windows in regions with high possibility of termite attack.

Forests sources in Iran have been recently diminished mainly due to aggressive harvest and unsustainable silvicultural practices (Bahmani et al. 2020, Nazari et al. 2020). For this reason, dry tolerant wood species like Konar have been recently gained much attention. Therefore, understanding the properties of drought-tolerant wood species in arid regions is necessary to optimize their usage as well as encourage forest owners to cultivate them. One of the industries consuming Konar wood in the southern regions of Iran is boat construction which is increasing the number of such boat construction companies at the moment. This led to increasing in the wood demand for this wood species. In addition to *Ziphus spina-christi,* wood species like *Prosopis spicigera*, *Tectona grandis*, and *Acacia nilotica* were also applied in the boat construction industry. Schirarend (1991) measured some anatomical properties of *Ziziphus jujube* and *Ziziphus mauritiana*. He reported that 28 and 10 vessels per square millimeter, 142 and 125 μm, vessel diameter and 352-410 μm, vessel length in *Ziziphus jujube* and *Ziziphus mauritiana*, respectively. The average value of fiber diameter in *Ziziphus jujube* and *Ziziphus mauritiana* were 1002 and 780 μm, respectively. Gupta and Saxena (2011) studied the wood microstructure of the Rhamnaceae family which is native to India. It was stated that the wood species in Rhamnaceae family are diffuse porous with distinct growth rings boundaries. It was reported that the mean value of vessel frequency, vessel diameter and vessel length, were 5-37 mm, 110-145 μm, 352-577 μm, resp. These values for the mean fiber length and fiber diameters were 903-1018 μm and 14-17 μm, resp. To our best knowledge, no studies have been conducted on the wood properties of Konar tree (*Ziziphus spina-christi*) in Iran. Considering the importance of Konar tree in preventing soil erosion and desertification, resistance to pests and drought as well as its wide distribution and application in different industries especially in the boat construction industry in the southern parts of Iran and Middle East, identifying and understanding the wood properties of Konar seems necessary. As *Ziziphus spina-christi* has

considerable potential, the goal of the present study is to investigate wood structural properties, fiber morphology, chemical and physical properties of this wood species.

MATERIAL AND METHODS

Study area and sampling

The study area is located between 54° 4' 34" N and 26° 53' 59" E in the Dahi Kand region of Hormozgan, Iran. The mean annual precipitation and temperature of the study area are 220 mm and 32°C, resp. Three 7-year old *Ziziphus spina-christi* normal trees were selected randomly and a disk 3 cm in thickness, was cut from each one at breast height.

Wood anatomical parameters

Small blocks of about $5 \times 5 \times 20$ mm were cut from each disk. The wood was softened by boiling to remove extra air, followed by immersion in distilled water. 20-30 μm thin transverse, radial and tangential sections were cut with a sliding microtome, bleached, stained and rinsed in an ethanol series (50, 95 and 100%) until all traces of excess stain in an ethanol series (50, 95 and 100%) until all traces of excess stain and water were removed. After bleaching, staining and dehydrating, sections were mounted in Canada balsam for subsequent microscopic examination using optic microscope. The description of the anatomical characters followed the IAWA "List of Microscopic Features for Hardwood Identification" (IAWA 1989).

Biometric properties

Separation of individual wood fibre was performed using Franklin (1964) method through which a wood specimens with the dimension of $15 \times 10 \times 2$ mm were saturated in a mixture (1:1) of acetic acid and oxygenized water in test tubes. Afterwards, the specimens were kept in an oven with $65 \pm 3°C$ for 48 h. After maceration, the specimens were washed (2-3 times) in distilled water and then immersed with distilled water. In the next step, shacked and the biometric parameters, as fiber length (*L*), fiber diameter (*D*), cell wall thickness (*W*), lumen diameter (*d*) were evaluated by light microscopic. From each slice, at least 50 fibers were used for the measurements. From the data, the average morphological properties (fiber indices) were then calculated according to the following equations (Saikia et al. 1997):

Runkel coefficient: 2W/d   (1)

Flexibility coefficient: d/100D   (2)

Slenderness coefficient: FL/FD   (3)

Rigidity coefficient: 2W/D   (4)

Luce's coefficient: $D^2\text{-}d^2/D^2\text{+}d^2$ (5)

Solid coefficient: $(D^2\text{-}d^2) \times L$ (6)

Physical properties

Wood samples were prepared from the disks cut from Konar stem. In detail, samples with dimensions of 30 × 20 × 20 mm were prepared in accordance with ISO 13061-14 (2016) for the investigation of oven-dry density and volumetric shrinkage and volumetric swelling. Sample dimensions were measured in green (saturated) and oven-dry condition with a slide caliper; oven-dry mass was determined with an electric balance to an accuracy of 0.01 g. Volumetric swelling was calculated using the dimensional change from the green to oven-dry condition. The physical properties were calculated according to the following equations:

$$D_0 = P_0 / V_0 \qquad (g \cdot cm^{-3}) \tag{7}$$

$$\alpha_v = (V_s - V_0)/ V_0 \qquad (\%) \tag{8}$$

where: D_0 - oven dry density ($g \cdot cm^{-3}$), α_v - volumetric swelling (%), V_s - volume in the saturate state (cm^3), V_0 - volume in state of oven-dry (cm^3), P_0 - weight in state of oven dry (g).

Chemical properties

The chemical constitutes were performed according to the TAPPI test methods: Cellulose (T 257 cm-85), the lignin (T 222 om-98), ash (T 211 om-93), and solubility alcohol-acetone (T 204 cm-88). The cellulose content of oak wood was determined according to the nitric acid method (Rowell et al. 1997). All measurements were repeated three times, and the mean value was used.

RESULTS AND DISCUSSION

Wood anatomy

Microscopic analysis of the axial planes clearly indicates that wood is diffuse-porous, with distinctive growth rings (Fig. 1). Vessels are located next to radial rows. Mean diameter of the vessel is 124.5 µm. Vessel diameter for the majority of the European wood species is much higher, namely ranging from 100 µm (beech) to 400 µm (oak), what classifies these vessels as extremely large (Wagenfuhr 2007) and about equal to those of *Ziziphus jujube* and *Ziziphus mauritiana* with 142 and 125 µm, respectively (Schirarend 1991). Pores of Konar wood are generally occurred as solitary; thus, we classify them as solitary pores, with 5 to 6 pores per mm (Fig. 1). Vessels are connected through simple preformation plate, with polygonal openings. There are no helical thickenings observed on the cell wall. Tangential vessels are much thinner than axial ones. The diameter of vessel lumina in the tangential direction is 124.5 µm. Besides vessels, there are fibre cells present as well, what classifies Konar wood as wood consisting of fibre with tracheid to minutely bordered pits (Fig. 2). Axial parenchyma is present as well. It is banded or diffuse-in aggregates, include 4-8 cells in the tangential direction (Fig. 3). Distribution of rays is 4 to 5 rays per tangential mm. Average ray high was measured 402 µm. In procumbent ray cells, prismatic crystals were observed.

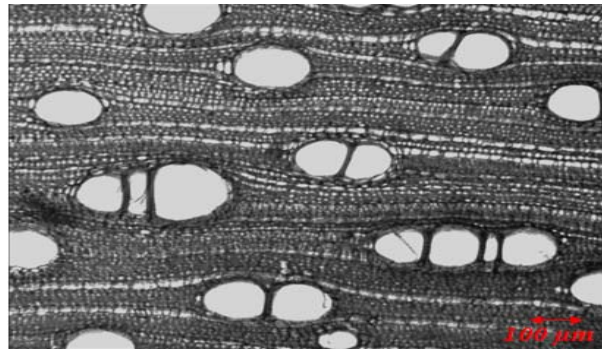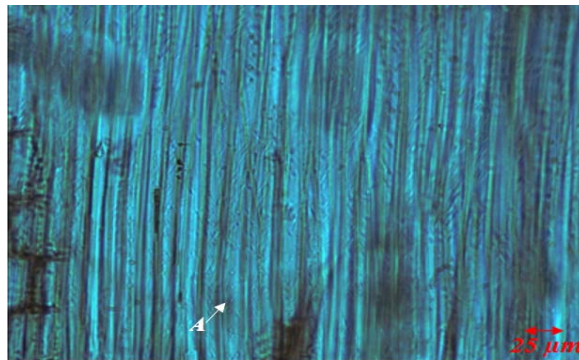*Fig. 1: Cross-section of Konar wood.*

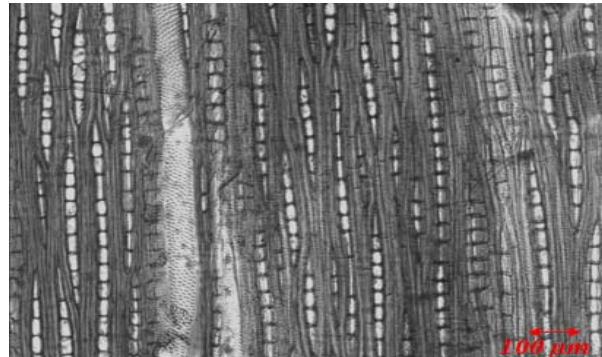*Fig. 2: Radial section of Konar wood: fiber- tracheid.*

Fig. 3: Tangential section of Konar wood.

Biometric properties

The average fiber length, fiber diameter, lumen diameter and cell wall thickness were measured 1109, 14.24, 7.43, 3.44 µm, resp. Fibers are classified into three groups (IAWA 1989): *(1)* short fibers with a length less 900 µm; *(2)* fibers of medium length between 900-1900 µm including Konar wood with an average fiber length of 1570 µm and fibers longer than 1900 µm.

Morphological properties

In addition to classic wood anatomy measurements, detailed biometric properties were determined according to Franklin method (Franklin 1954, Mehdikhani et al. 2019) to assess Konar wood fibers' suitability the production of lignocellulosic composites.

Runkel ratio is directly affected by cell wall thickness. Runkel ratios higher than one are characteristic thick-walled fibres with stiffer, lesser flexibility and difficult to collapsing properties, creating bulky structures with the lower bonded area and higher porosity (Ezeibekwe et al. 2009). The Runkel ratio lower than one describes fibres with flexibility and wet plasticity and a greater conformability degree. Thus, due to more flexibility, quickly collapsing and forming a structure with the larger bonded area and good strength properties, the fibres Runkel ratios lesser than one is suitable for fibrous networking and bonding (Mehdikhani et al. 2019). The Runkel ratio of Konar wood was 0.926, being very close to value 1. Another factor describing the properties of the fibre is Luce factor. This parameter is derived from fiber diameter and lumen diameter, directly affect fibrous sheet density and pulp digestibility. Fibers with low Luce's shape factor values give better mechanical strength of its pure and composite structures (Kaur and Dutt 2013). Luce factor for Konar wood was 0.57, being in the range of the Eucalyptus species (Ohshima et al. 2005). Solid factor directly affect fibrous sheet density. Similar to Luce's shape factor, species with low solid factor values give better strength of paper. At Konar wood fibres Solid factor of 163×10^3 μ^3 was determined. Rigidity coefficient is also recognized as wall coverage ratio or wall proportion: This parameter is an indicator for bending resistance and is related to fiber flexibility. At Konar wood rigidity factor of 0.48 was determined. Fiber diameter and wall thickness defines the fiber flexibility that can be expressed as flexibility coefficient. At Konar wood this value of 52.1 was measured. Felting ratio is also known as slenderness coefficient. At Konar wood value of 77.85 was determined. This indicator is related positively to pulping yield and negatively to digestibility.

Physical properties

Tab. 1 shows the results for oven-dry density and volumetric swelling for Konar wood. Density of the Konar wood was 0.61 $g.cm^{-3}$, between density of European beech (0.8 $g.cm^{-3}$) and Elm (0.56 $g.cm^{-3}$). Volume and other swelling are rather high (16.1%). For example volume swelling is in the range of the European beech (14-21%) (Wagenfuhr 2007). This is an important limitations of the use of respective wood species in oscillating climate.

Tab. 1: The average physical properties of Konar wood (according to TAPPI test methods).

Wood properties	Dry density (g.cm⁻³)	Longitudinal swelling (%)	Tangential swelling (%)	Radial swelling (%)	Volumetric swelling (%)
Average	0.61	0.47	8.3	6.7	16.1
Standard deviation	0.03	0.06	0.52	0.46	0.83

Chemical properties

Chemical composition of Konar wood can be resolved from Tab. 2. Ash content of 2.78% was measured. Ash content is wood species from temperate zones is much lower, ranging between 0.17% (European beech) and 0.51% (oak) (Voicea et al. 2013). Respective values of Konar wood are closer to ash content in the bark (Tsuchiya et al. 2010). In addition to ash content, Konar wood is characterized by high content of lipophilic extractives (6.42%).

Tab. 2: The average chemical composition of Konar wood (according to TAPPI test methods).

Wood properties	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Acetone soluble extractives (%)	Ash (%)
Average	43.34	19.98	33.90	6.42	2.78
Standard deviation	1.74	-	1.35	0.92	0.26

This value is higher than average. For example, *Eucalyptus pellita* contains only 0.25% of lipophilic extractives (Arisandi et al. 2020), while *Pinus pinea* can contain up to 15% of solvent soluble extractives (De Angelis et al. 2018). Cellulose content in Konar wood was 43.34%. This value is in the range typical for wood from temperate zones, that ranges between 39% (poplar) and 49% spruce. For example, cellulose content is some other wood fibers is much higher, namely 64% (hemp) or 76% (flex) (Madsen and Gamstedt 2013). Lignin content was in the range typical for hardwood species as well (33.9%).

CONCLUSIONS

Konar (*Ziziphus spina-christi*) wood grown in Iran is a diffuse porous hardwood with a semi-heavy density. Its anatomical properties do not differ meaningfully from congeneric. Ash content is lower than that of the wood species from temperate zones but lignin content is in the range of other hardwoods. Konar fibers would be classified as elastic, thin wall fiber resources with felting factor similar to softwoods (70-90). Konar fiber can provide suitable formation and compactness with good bonding ability in 3D cellulosic structures (paper and composites). It is suggested that in further investigations on the natural durability of Konar wood against fungi, insects, and termites.

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