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Vertical Variation of Wood Chemical Constituents in (*Albizia lebbeck* L. Benth.) Trees Grown in Egypt

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ABSTRACT

Basic knowledge of the within tree chemical components variation is essential which affects the wood end-use. Therefore, this study aimed to determine the chemical constituents (cellulose, hemicellulose, lignin, total extractive, ash contents, pH, and the solubility in hot water, cold water, and 1% NaOH) at five different levels (base, 25%, 50%,75%, and 100% of total merchantable stem height) of *Albizia lebbeck* trees grown in Egypt. The results showed that there was a significant effect of tree height levels on all the measured chemical constituents at 0.05 probability level. There was no specific pattern for the variation in cellulose, hemicellulose, and the solubility in 1% NaOH with the tree height levels. The cellulose and hemicellulose contents were markedly decreased at 100% of total tree height. The lignin content showed a significant gradual increase from the base up to the top of the stem. In contrast, the ash content, total extractives, and the hot and cold-water extractives showed a gradual decrease from the base to the top of the stem. Correlation analysis showed a good negative relationship between lignin and both cellulose and hemicellulose contents. Based on the results of this study, the differences in chemical composition with height along the stem must be taken into account when using the wood of these locally grown trees in various wood industries such as furniture, parquet, plywood, and paneling.

Keywords: *Albizia lebbeck*, cellulose, lignin, ash, wood solubility, axial variation, pH, stem height.

INTRODUCTION

Albizia lebbeck are deciduous trees belongs to the family Fabaceae, grown in several parts of Egypt, and in recent years are extensively cultivated in the southern governorates. In Egypt, for the shape of its distinctive flowers, these trees are planted for ornamental purposes and for providing shade.

The *A. lebbeck* wood is highly valued, which it is classified as very resistant against wood-decay fungi and white ants. In addition, it has multiple industrial applications such as lumber, parquet, plywood, musical instruments, tool handles, particleboard, furniture cabinets, paneling, and shipbuilding (Nazma *et al.*, 1981; Mahony, 1990; Scheffer and Morrell, 1998; and ITTO, 2020).

Generally, wood chemical constituents influence the end-use of wood and wood products (Walker, 2006). For instance, lignin and the crystalline regions in the cellulosic chains largely control the mechanical properties of wood (Walker, 2006). Lignin as a 3D polymer gives resistance to the wood cell wall against the attacking microorganisms (Schmidt, 2006). It is worth mentioning that in the pulp and paper industry, it is preferred that the raw material be high in cellulose and low in lignin (Rowell, 2012). In addition, the amount of extractives has a role in the natural resistance of wood against various attacking biological agents such as fungi, beetles, and termites (Shmulsky and Jones, 2011).

It is known that wood is acidic in nature and the woods differs among them in the pH value. The acidity is related to the type of extractives, hydrolyzable acetyl groups, salts, organic acids, and other hemicellulose components (Ingruber, 1958; Fengel and Wegener 1989; and Choon and Roffael, 1990). The importance of knowing the pH of any wood species is its effect on the susceptibility to coating, the bonding of wooden members (Nawawi *et al.*, 2005), and the degree of corrosion of metals contacting wood (Farmer, 1967). In addition, the acidity of wood raw material affects the adhesion process with resin in the particleboard manufacturing (Pizzi, 1994).

Generally, study the within tree variation in wood properties is important for wood quality evaluation and in biomass estimation (Longuetaud *et al.*, 2017). Several researchers have mentioned the existence of variability in wood properties along with the tree's height or from pith to bark but this variation is not consistent as it varies with the tree species. This within tree variation is attributed to the minute structure of wood, proportion of sap and heartwood, ring width, and juvenile wood (Tsoumis, 1969; Zobel and Buitenen, 1989). There are numerous studies have discussed the within tree axial variation for several species from different aspects. For example, from physical and mechanical properties point of view (Machado and Cruz, 2005; Moya and Muñoz, 2010; Lukašek *et al.*, 2012; and Kiaei and Farsi, 2016). However, there are few reports have discussed the variation in hardwood trees compared with softwoods (Topaloglu and Erisir, 2018). Moreover, no information could be found in the literature describing the chemical composition variability in *A. lebbeck* trees particularly those grown in arid and semi-arid regions as in Egypt. Therefore, this research was initiated to study the variation in the wood chemical constituents along the vertical stem of *Albizia lebbeck* trees grown in Egypt.

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MATERIALS AND METHODS

Two *Albizia lebbeck* trees free from any visible defects grown in Alexandria were selected and felled at 10 cm above the ground level. The tree height and diameter at breast height were (7 m and 27.4 cm) and (8.5 m and 25.3 cm) for tree No. 1 and No. 2, respectively. Five discs from each tree were cut to perform the chemical analysis at five levels (Base, 25%, 50%, 75%, and 100%) of total merchantable stem height. The discs were left to air dry at the laboratory of wood chemistry, Faculty of Agriculture, Alexandria University. Then wooden strips were sawed from each disc at a fixed distance (50% of the disc radius). The wooden strips were hammer milled and screened to obtain particles with a 40-60 mesh size. Total extractive content was determined according to ASTM D1105-96 (2007). Ash content was performed following TAPPI T211 om-93 (1993) through placing specimens in crucibles in a muffle furnace at 525°C. Kürschner and Hoffer cellulose content was determined according to Browning (1967). Acid-insoluble lignin according to (TAPPI T222 om-98, 1998) and the hemicellulose percentage calculated by subtracting from all the determined main chemical components including total extractives and ash. The solubility in (hot and cold water) and 1% NaOH were determined in accordance with (TAPPI T207 om-93, 1993) and (TAPPI T212 om-98, 1998), respectively. The pH was determined according to (Wang et *al.*, 2012).

Statistical analysis

Data were subjected to the Kolmogorov-Smirnov normality test. Then the analysis of variance and Duncan test methods (Freund and Wilson, 2003) were used to determine the statistical differences (alpha=0.05) among the sampling heights. Moreover, a correlation analysis was used to evaluate the direction of the relationship between lignin and (cellulose and hemicellulose).

RESULTS AND DICUSSION

The mean values of cellulose, hemicellulose, lignin, ash, pH, and the solubility for *A. lebbeck* wood at different heights from the base to top of the tree are presented in (Table 1).

The cellulose and hemicellulose percentages ranged between 42.48-47.05% and 16.19-19.60%, respectively. The highest values for cellulose and hemicellulose contents were at 25% and 50% of total stem height, respectively. The lowest values for cellulose and hemicellulose were observed at the 100% stem height level.

Table 1. Mean values of chemical constituents, solubility, and pH with tree height levels of *A. lebbeck* wood.

Items Tree Height levels	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Total extractives (%)	Ash (%)	Hot water solubility (%)	Cold water solubility (%)	1%NaOH Solubility (%)	pH
Base	46.42^{a} (0.07)	18.50^{a} (0.11)	20.70^{a} (0.08)	13.90^{a} (0.17)	0.48^{a} (0.06)	8.70^{a} (0.13)	7.20^{a} (0.12)	16.9^{a} (0.20)	4.7^{a} (0.35)
25%	47.05^{b} (0.13)	17.30^{b} (0.12)	21.71^{b} (0.16)	13.40^{b} (0.11)	0.54^{b} (0.09)	7.90^{b} (0.072)	6.50^{b} (0.07)	17.5^{b} (0.50)	4.6^{ab} (0.22)
50%	44.50^{c} (0.14)	19.60^{c} (0.09)	22.60^{c} (0.15)	12.60^{c} (0.21)	0.70^{c} (0.09)	7.40^{c} (0.068)	6.09^{c} (0.07)	17.4^{b} (0.05)	4.4^{bc} (0.19)
75%	45.19^{d} (0.06)	18.43^{a} (0.18)	23.74^{d} (0.14)	11.44^{d} (0.08)	1.20^{d} (0.09)	7.17^{d} (0.057)	5.92^{d} (0.06)	16.9^{a} (0.080)	4.6^{ab} (0.14)
100%	42.48^{e} (0.08)	16.19^{d} (0.85)	28.88^{e} (0.21)	10.75^{e} (0.48)	1.70^{d} (0.10)	6.85^{e} (0.11)	5.84^{d} (0.1)	17.0^{a} (0.04)	4.2^{c} (0.14)
Total mean	45.13	18	23.53	14.42	0.92	7.60	6.31	17.14	4.5

*** Values in parentheses are the standard deviation; means with different letters are significantly different at 0.05 probability level.**

Figures 1 and 2 showed an inconsistent variation pattern for cellulose and hemicellulose content with the stem height levels. The analysis of variance revealed a significant effect of tree height on both cellulose and hemicelluloses contents at 0.05 probability level. The total mean value of cellulose (Table 1) was found to be 45.13 %. This value was much higher than that value (35%) reported by Pettersen (1984).

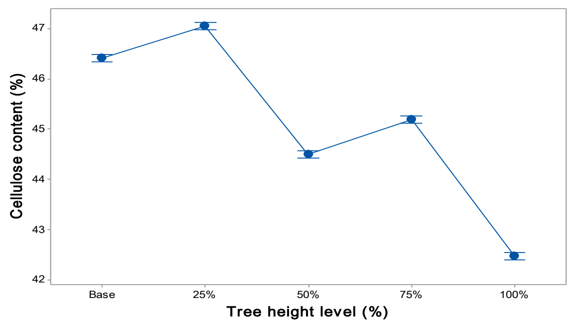

Fig. 1. Relationship between tree height level and cellulose content.

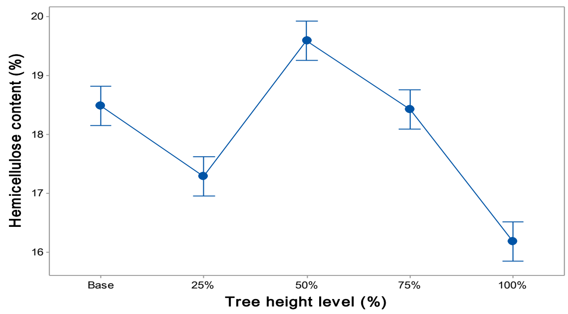

Fig. 2. Relationship between tree height level and hemicellulose content.

Table 1 showed that the whole tree lignin content ranged between 20.7% (base) to 28.88% (top). Generally, lignin content in hardwoods grown in temperate regions ranges from 18 to 32 %, this percentage increases in tropical hardwoods (23–39%) (Fengel and Wegener, 1989). The total mean value of lignin (Table 1) was found to be 23.53 %. This value was lower than that value (28%) reported by Pettersen (1984). Figure 3 showed a significant increase from the base up to the top level. These results were in agreement with (Campbell *et al.*, 1990) who found an increase in lignin content with stem height for lodgepole pine. Topaloglu and Erisir, (2018) reported that the lignin content of *Fagus orientalis and Abies nordmanniana* increased along the stem from the base to the upwards. In contrast to the findings of the current study, Ogunjobi *et al.*, (2014) found a linear decrease in lignin content from the base to the top of *Vitex doniana* stem**.** Adamopoulos *et al.*, (2005) found a decrease in lignin content from the base to the top in the heartwood of *Robinia pseudoacacia* stem.

Both total extractives and ash contents are from the secondary wood chemical components but have a great impact on the final utilization of wood, mainly the natural durability of wood. In addition, the high amount of extractives increases the density of wood, which also affects the wood end-use (Shmulsky and Jones, 2011).

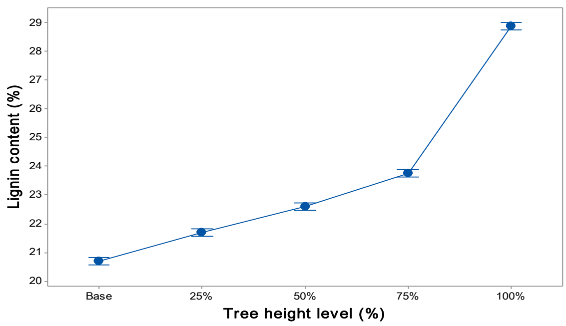

Fig. 3. Relationship between tree height level and lignin content.

The total extractive content ranged from 10.75% to 13.9% at 100% and the base of total tree height, respectively. In general, the percentage of extractives in woods ranges between 1 to 20%, this percentage depend on the tree species and location within the trees (Rowell, 2012).

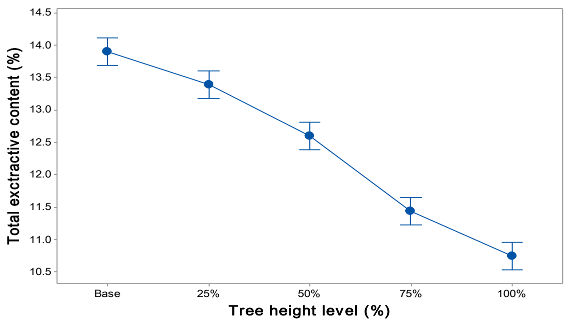

Fig. 4. Relationship between tree height level and total extractive content.

Figure 4 showed a significant decrease from the base to the top level. Campbell *et al.*, (1990) found a decrease in total extractive content with stem height for lodgepole pine trees. In contrast to the findings of this study, Stringer and Olson (1987) found no statistical differences in total extractives among sampling heights. The same trend of total extractives in the current study was also observed in hot and cold-water solubility, where a significant decrease was found from the base to the 100% of total stem height (Figures 5 and 6). The total mean value of hot water (Table 1) was found to be 7.6 %. This value was lower than that value (11%) reported by Pettersen (1984) for the same species. Adamopoulos *et al.*, (2005) found that hot-water extractive content in *Robinia pseudoacacia* heartwood was similar at the bottom and middle of the stem and increased at the top. Stringer and Olson (1987) found a positive linear relationship between hot-water extractives and tree height.

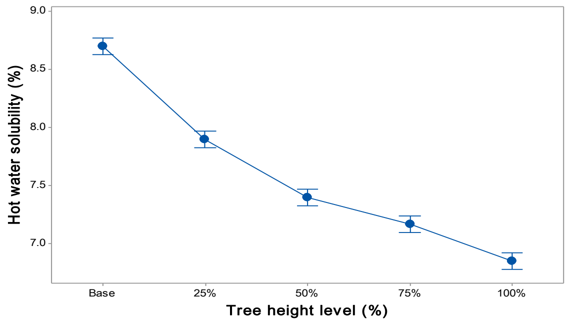

Fig. 5. Relationship between tree height level and hot water solubility.

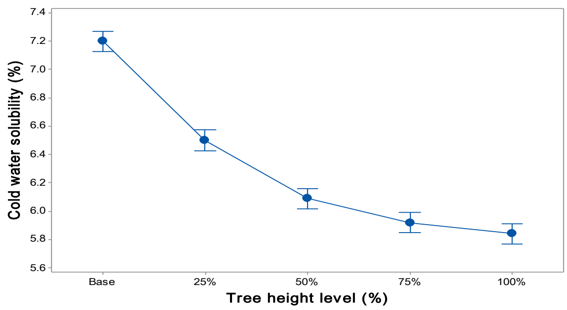

Fig. 6. Relationship between tree height level and solubility in cold water.

In contrast to the total extractive, cold, and hot water solubility, the mean values of solubility in 1% NaOH were varied with the stem heights and there is no specific trend was observed (Figure 7). The solubility in 1% NaOH showed statistically significant axial variability ($P \leq 0.05$). The highest values were found at 25% and 50% of stem height and the lowest mean values were 16.9% for both the base and 75% stem height level.

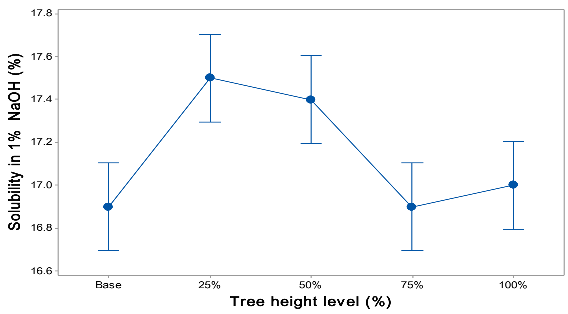

Fig. 7. Relationship between tree height level and solubility in 1% NaOH.

The ash content showed a positive relationship with the sampling heights (Figure 8). The lowest mean value of ash content was 0.48% at the base and the highest mean value was 1.7% at the 100% of total tree height. The total average value of ash content (Table 1) was found to be 0.92 %. This value was higher than that value (0.5%) reported by

(Pettersen, 1984). These results were in agreement with Campbell *et al.*, (1990) who found a positive increase in ash content with stem height for two lodgepole pine varieties. They attributed this increase to the presence knots and the higher percentage of juvenile wood. Adamopoulos *et al.*, (2005) found that the ash content increased from the base to the top of *Robinia pseudoacacia* stem. Stringer and Olson (1987) found a linear positive relationship for ash with stem height in young *Robinia pseudoacacia* trees.

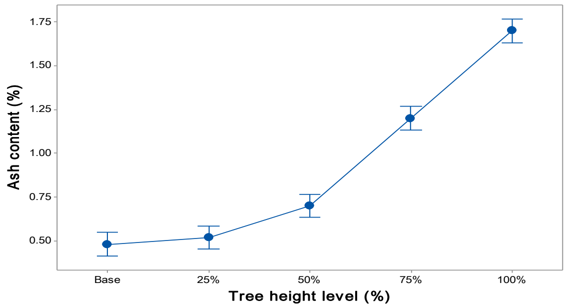

Fig. 8. Relationship between tree height level and ash content.

It is worth mentioning that there is no data found in the literature discussed the acidity of *A. lebbeck* wood. The mean values of pH for the base, 25%, 50%, 75%, and 100% of tree height levels were 4.7%, 4.6%, 4.4%, 4.6%, and 4.2%, respectively. Duncan's test revealed significant differences among the sampling heights at 0.05 significance level.

Figure (9) showed that the pH values decreased from the base to the 50% tree height level, then increased from 50% to 75% height level then a significant decrease was observed at the top level. Campbell *et al.*, (1990) found a positive correlation between stem height and pH for lodgepole pine (latifolia variety) but they found no correlation in another variety (murrayana) of the same species. Sandermann, (1959) found variation in pH from the base to the top of Douglas-fir stem. Adamopoulos *et al.*, (2005) found a positive relationship between stem height and acidity in *Robinia pseudoacacia* heartwood.

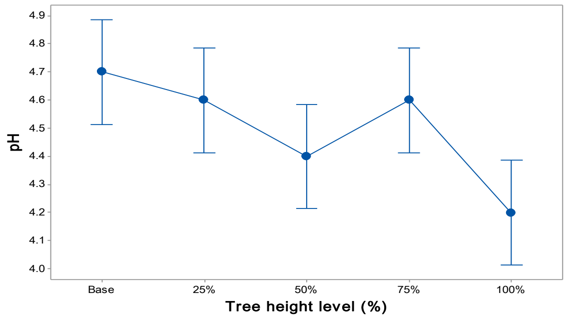

Fig. 9. Relationship between tree height level and pH.

The direction of the association between lignin and (cellulose and hemicellulose) was examined using correlation analysis (Table 2). The models were created with the grouped data of all the stem heights for each chemical component.

The results showed good negative correlation among the tested relationships. The correlation coefficients for (lignin vs. cellulose) and (lignin vs. hemicellulose) were -0.69 and -0.64, respectively. Very little information found in literature regards the relationship between the holocellulose and lignin. For instance, Poke et *al.*, (2006) found a significant negative correlation between cellulose and acid-insoluble lignin for *Eucalyptus globulus*. Zhang et *al.*, (2015) found a high negative correlation between holocellulose and lignin for hybrid Poplar clones.

Table 2. Relationship between lignin and (cellulose and hemicellulose) of *A. lebbeck* wood.

Items	Linear regression model	r	r^2
Lignin vs. Cellulose	y = -0.2295x + 50.322	-0.69	0. 47
Lignin vs. Hemicellulose	y = -0.2731x + 24.184	-0.64	0. 41

r^2, is coefficient of determination and r, is correlation coefficient.

CONCLUSION

The effect of the height along the stem of *Albizia lebbeck* trees on the amount of the chemical constituents was investigated. The results showed significant effect of the sampling heights on all the determined chemical components at 0.05 probability level. There was no specific pattern for the variation in the cellulose and hemicellulose with the tree height levels. A remarkable decrease for both cellulose and hemicellulose was observed at 100% of total tree height. The results showed a significant increase from the base to the top of the merchantable stem in lignin and ash. In addition, a decrease toward the top in total extractives and hot and cold-water extractives was observed. The effect of height level was not strong on the variation of the 1% NaOH solubility and pH.

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التباين الرأسي في التركيب الكيميائي للخشب في أشجار اللبخ النامية في مصر.

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المعرفة الأساسية للمكونات الكيميائية وتنوعها داخل سيقان الأشجار ضرورية حيث أنها تؤثر بدرجة كبيرة على الاستخدام النهائي للخشب. لذلك، هدفت هذه الدراسة إلى تقدير المكونات الكيميائية (السليلوز، الهيميسليلوز، اللجنين، المستخلصات الكلية، محتويات الرماد، الأس الهيدروجيني، والذوبانيه في كل من الماء الساخن، الماء البارد وهيدروكسيد الصوديوم (١%) عند خمسة مستويات مختلفة (القاعدة، ٢٥٪، ٥٠٪، ٧٥٪ و١٠٠٪) من الارتفاع الكلى لأشجار اللبخ النامية في مصر. وقد أظهرت النتائج وجود تأثير معنوي لارتفاع الساق على جميع المكونات الكيميائية التي تم تقديرها عند مستوى معنوية ٠,٠٥. إلا انه لم يكن هناك نمط محدد للتغير في السليلوز، الهيميسليلوز، والذوبانية في ١% هيدروكسيد الصوديوم عند مستويات ارتفاع الساق. كما انخفضت محتويات السليلوز والهيمسيلولوز بشكل ملحوظ عند ١٠٠٪ من إجمالي ارتفاع الساق. وقد أظهر محتوى اللجنين زيادة تدريجية كبيرة من القاعدة إلى أعلى الجذع. على النقيض من ذلك، أظهر محتوى الرماد، المستخلصات الكلية، والذوبانية في الماء البارد والساخن انخفاضًا تدريجيًا من القاعدة إلى قمة الجذع. وقد أظهر تحليل الارتباط وجود علاقة عكسية جيدة بين اللجنين وكل من (السليلوز والهيميسليلوز). بناءً على نتائج هذه الدراسة، يجب مراعاة الاختلافات في التركيب الكيميائي مع الارتفاع على طول الجذع عند استخدام خشب هذه الأشجار النامية محليًا في الصناعات الخشبية المختلفة مثل الأثاث، خشب الأرضيات، والابلاكاج.