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EFFECTS OF SEWAGE EFFLUENT IRRIGATION ON THE CHEMICAL COMPONENTS AND MECHANICAL PROPERTIES OF *MELIA AZEDARACH* L WOOD

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ABSTRACT

This study was carried out at the beginning of 2006 to investigate the effect of sewage effluent on the chemical and mechanical properties of the (*Melia azedarach* L) chinaberry wood as well as to study the differences between juvenile and mature wood in those properties. Six trees (9-years old) were chosen from *Melia azedarach* L grown in southwest Alexandria city (New Borg El-Arab). The small clear specimens from juvenile and mature wood were prepared and tested according to British Standard Specification. Three mechanical tests were done namely static bending, compression parallel to grain and Janka hardness. Based on extractive-free and the oven-dry weight, cellulose, hemicellulose, lignin, and ash contents were determined according to the standard methods. The results indicated that using sewage effluent in irrigation significantly increased cellulose, lignin, ash and extractives content of wood. The decreased in hemicellulose content for the trees irrigated with sewage effluent compared to tap water was not significant. With exception for ash content, the effects of sewage effluent irrigation on the chemical constituents of wood are quit low. The highest effect of sewage effluent on chemical components was obtained with ash content. Mature wood had significantly higher average cellulose, hemicellulose and extractives contents than juvenile wood. However, lignin and ash contents of juvenile wood were significantly higher than mature wood. Sewage effluent significantly increased wood specific gravity of

chinaberry. Sewage effluent had a notable better effect on all mechanical properties of chinaberry wood especially modulus of elasticity (MOE) as compared to tap water. Wood chemical components were clearly correlated with each of modulus of rupture (MOR), MOE and maximum crushing strength (C_{max}). There were negative correlations between hemicellulose content and each of MOR, MOE and C_{max}. However, other relations between were positive.

INTRODUCTION

Many developing countries, including Egypt, do not posses adequate forest reserves to cover their needs for fuel wood, industrial wood, sawn wood, and wood-based composition panels. The annual wood and wood products exportation in Egypt is estimated at 640 million dollars in 2004 (Ali, 2005) and 874 million dollars in 2007. Planting fast growing trees is one of different strategies which used to reduce the annual import of wood products. In order to meet increasing demand, Egypt has been planted fast growing tree species and used sewage effluent to irrigate forest trees as it is not recommended for edible crops. Water is becoming an increasingly scare resource in many arid and semi-arid regions. It is essential to develop water resources through untraditional ways (Selim, 2006). Reuse of wastewater is one of these resources. In the middle of the 19th century, many European and North American cities adopted crop irrigation as their means of wastewater disposal (Arar, 1999). The wastewater generated from Alexandria City is about 1.5 million m^3 per day and the expected amount by the year of 2020 is 2.5 million m^3per day (Selim, 2006).

Many investigators have been concluded that wastewater, in addition to its beneficial nutrients, also contains contaminants (pathogens, disease-causing viruses, bacteria, protozoa and helminthes) and toxins (heavy metals) which are toxic to both people and plants (Ralph and Black, 1998, Al-Jamal *et al*, 2002, Hassan *et al*, 2003, Kayad *et al*, 2005, and Ali, 2005). So that, the reuse of wastewater for irrigation trees, seems to be the most promising method. The safe use of the wastewater after primary treatment is irrigating tree plantations, forestlands, green belts around the cities and non-food crops. Most of these studies were focused to detect the changes in the physical and chemical properties of soil by use of sewage effluent (El-Nennah *et al*, 1982, Kanekar *et al*, 1993, Hassan *et al*, 2003, and Ali, 2005). Other studies were investigating the effects of irrigation with sewage effluent on the growth parameters of some forest trees, tree biomass potential and allocation of its components (Kerr and Stopper, 1982, Hopmans *et al*, 1990, Ali, 2005, and Hassan *et al*, 2006). However, the effects of irrigation with sewage effluent on the specific gravity, fiber length and volumetric shrinkage of forest trees have been studied by many researchers (Szopa *et al*, 1977, Abohassan *et al,* 1988, Kayad *et al*, 2005, Hassan *et al*, 2006) these properties were selected because of their strong relationship with wood substances which used by wood users to classify the quality of wood produced from trees. On the other hand, no studies were conducted to evaluate the effect of irrigation with sewage effluent on the mechanical properties of wood.

Some studies report that the sewage effluent treatment had a significant effect on the specific gravity and fiber length of wood produced from different wood species (Szopa *et al*, 1977, Ali, 2005 and Hassan *et al***,** 2006). However, Kayad *et al* (2005) on *Melia azedarach* L. wood indicated that sewage water had slight effect on those properties but volumetric shrinkage increased significantly from 13.4 to 14.73%. Abdel-Aal *et al* (2008) evaluated the effect of sewage sludge application on chemical composition of *Casuarina cunninghamiana* grown in Egypt. They found that the sewage sludge treatment increased extractive and ash content.

Melia azedarach (chinaberry) is a fast growing and a deciduous hardwood tree in the Meliaceae family, native to Himalayan region of Asia. It has been used as a promising woody tree that grows up to 20 m high. Chinaberry wood is used for turnery, furniture, decorative veneers, novelty items, boxes and chests (Chudnoff, 1984).

Finally, chemical composition and mechanical properties of wood are the important technological properties which assess wood users to suggest the proper utilization of wood (Hygreen and Bowyer, 1982). Therefore, these technological properties are essential to evaluate the suggesting proper utilization of wood.

Wood formed at an early age in a tree is commonly referred to as juvenile wood and wood produced later is known as mature wood (Haygreen and Bowyer, 1982 and Roos *et al*, 1990). The effect of juvenile wood on softwood has been extensively explored (Bendsen and Senft**,** 1986, McAlister and Clark, 1992 and Abdel-Gadir and Krahmer, 1993), however, comparatively little research of juvenile effects on hardwoods has been done (Roos *et al*, 1990 and Evans *et al*, 2000).

It would appear from this literature survey that controversy continues to appear concerning the influence of sewage effluent irrigation on the chemical and mechanical properties of wood. Greater knowledge of both juvenile and mature wood properties in chinaberry as a hardwood species is needed. The work to be reported here represents the first attempt to provide basic information regarding this point. This information will help wood users to suggest the suitability of wood for wood industries (i.e., pulp and paper industry and wood composite panels), fuel and construction purposes.

The objectives of this study were firstly to investigate the effect of sewage effluent on the chemical and mechanical properties of the chinaberry wood and secondary to study the differences between juvenile and mature wood in those properties. Finally the study aims to find the relationship between those properties.

MATERIALS AND METHODS

Nine years old trees with a straight trunk were randomly chosen from *Melia azedarach* L trees (six trees) grown in two sites in southwest Alexandria city. For more detail about plantation, management, site description, growth characters, biomass production, analyses of wastewater and soil were reported in a study by **Kayad *et al*,** (2005). The experiment was carried out at new Borg E-Arab city (31^0 00^0 N, 29^0 33^0 E). Sewage effluent used to irrigate the plantation was derived from industrial and municipal sources. It treated primary, then stored in lagoons temporarily before irrigation. In the control treatment, the trees were irrigated with tap water. The analysis of wastewater used in the current study is presented in Table (1).

After the trees were felled in the beginning of 2006, one 60-cm bolt in length at about 140 cm from the ground level were removed. The two ends of the bolts were coated with tar to prevent moisture losses. The bolts were then transported to the Wood Testing Laboratory, Faculty of Agriculture, Alexandria University. The bolts were then piled and machined green resembling the ASTM D-134 (1989). From each bolt, two adjacent diametric strips (3*3 cm) were removed. Each strip removed from each bolt was re-sawn longitudinally into four sticks. Two sticks of them were near the bark (mature wood or outer zone) and the others near the pith (juvenile wood or inner zone) according to McAlister and Clark (1992). The specimens were stacked on pallets for air-drying in the laboratory until the equilibrium moisture content (EMC) was reached.

Mechanical Testing Procedure:

The small clear specimens were prepared and tested according to British Standard Specifications (BSS) No. 377 (1957). In this specification, the 2-cm system of testing was used which one of the principle schemes accepted internationally for the testing of small clear specimens. The performed tests are listed in Table (1). All mechanical tests were carried out using Instron Universal Testing Machine model 1195 at the Wood Testing Laboratory, Department of Forestry and Wood Technology, Faculty of Agriculture, Alexandria University, Egypt.

In static bending test, the load at proportional limit (P_{PL}), maximum load (P_{max}) and deflection (y) were obtained from load-deflection curves, then the modulus of elasticity (MOE), and modulus of rupture (MOR) were calculated using the equations seen in Table (2). In compression parallel to grain, increasing load was applied to the individual test specimens until a failure occurred and maximum crushing load value was recorded, then the maximum crushing strength (C_{max}) was calculated (Table 2). On the other hand, Janka hardness test was conducted in radial and tangential directions with ball diameter of 11.28 mm (100 mm^2 projected area) and the hardness strength (Janka hardness number, JHN) was calculated as maximum load (kN), which equal to maximum load (kN). The dimensions of test specimens, loading rates and the calculated parameters from each test are shown in Table (2).

Table 2. Dimensions of mechanical test specimens, loading rates and calculated parameters for each test.

Test	Dimensions (cm)		Loading	Calculated parameters
	Cross Section	Length	Rate	
Bending	2 x 2	30	6.6	MOR= $(1.5 \times P_{max})\backslash(b \times h^2)$ MOE= $(P_{PL} \times L)\backslash(4xDxbxh^3)$
Compression // to grain	2 x 2	6	0.63	$C_{max}=P_{max}\backslash(b \times h)$
Janka Hardness	2 x 2	8	6.3	JHN in radial direction JHN in tangential direction

P_{max}=maximum load, P_{PL}=load at proportional limit, b and h=breadth and depth of specimen. Loading rate is the rate of load applied in mm\min.

Specific gravity and moisture content of wood:

Upon the completion of the bending test, the moisture content and specific gravity were determined by removing two pieces (2x2x1.5 cm) near the failure point. Specific gravity was calculated based on oven-dry weight and volume at test measured by dimensions using digital caliper to the nearest 0.01 mm. However, moisture content was determined based on oven-dry weight basis.

Chemical analysis of wood:

After the mechanical tests were completed, each sample was divided into small pieces and milled in a laboratory Wiley mill to obtain a 40-60 mesh meals. Total extractives content was determine based on oven-dry weight of the wood meals according to ASTM D-1105 (1989). Based on extractive-free and the oven-dry weight of wood meal, cellulose, hemicellulose, lignin, and ash contents were determined according to Nikitin (1960), Rozmarin and Simionescu (1973), ASTM D-111 (1989), and NREL (1994), respectively.

Statistical analysis:

The data were analyzed using split plot design. In addition, Duncan's multiple range test was used in order to examine the significance of differences among the mean values of chemical and mechanical properties using the least significant rang at 95% level of confidence ($LSR_{0.05}$) when significant differences were revealed by Statistical Analysis System (SAS) Program. In the second stage of this analysis and to establish the relationship between each of mechanical property as dependent variable versus each of chemical components as independent variables, multiple regressions were used to reach the full model. Then, the best reduced model representing the relationship studied was extracted from the full model using a type of backward elimination procedures (Snedecor and Cochran, 1967). The choice of the best reduced model was based on the significant of each terms as well as coefficient of determination, R^2 (Draper and Smith, 1967). Simple regression analysis were also undertaken in order to have an indication of the trend of relation between each of independent variables and mechanical properties.

RESULTS AND DISCUSSION

Effect of sewage effluent on wood chemical constituents

Basic information concerning the effect of sewage effluent irrigation on wood properties is little and limited. The current study is an attempt to provide this information regarding some of the important wood properties of chinaberry lumber which related to wood quality. In the present study, the statistical effect of sewage effluent on chemical constituents of chinaberry wood was small, but highly significant with exception for hemicellulose content which was not significant.

The mean values for the chemical constituents of the chinaberry wood as affected by irrigation treatments are shown in Table (3). It can be seen from this table that the sewage effluent significantly increased cellulose, lignin, ash and extractives contents of wood. The decreased in hemicellulose content for the trees irrigated with sewage effluent compared to tap water was not significant (24.04% vs. 24.20% for control).

Table (3) and Fig (1) showed that sewage effluent irrigation gave higher mean values of cellulose (42.41%), lignin content (33.36%) and ash content (0.468%) compared to control treatment (tap water). The increase in cellulose content at sewage effluent irrigation may be due to increase in latewood compared to earlywood or thicker fiber walls especially in S_2 layer (Abohassan *et al.*, 1988).

The increased in cellulose, extractives and ash contents of wood as affected by sewage effluent is in agreement with those obtained by Kherallah (1982) on *Eucalyptus camaldulensis* and Abdel-Aal *et al* (2008) on *Casuarina cunninghamiana*. They found that plantation irrigated with sewage effluent contained significantly higher extractives, cellulose and ash contents. Contrary, the significant increase in lignin content in the current study with sewage effluent irrigation (33.36% vs. 32.54% for control) is disagreement with Abdel-Aal *et al* (2008) who found that irrigated of *Casuarina cunninghamiana* trees with sewage sludge slightly decreased the lignin content (28.98%) as compared to control treatment (29.18%).

The insignificant decreased in hemicellulose content in the present work is disagreement with Kherallah (1982) who reported a highly significant decrease of hemicellulose in *Eucalyptus camaldulensis* irrigated by sewage effluent (28% vs. 31.0% for control) and Abdel-Aal *et al* (2008) who found the same trend in *Casuarina cunninghamiana* (25.27% vs. 27.70% for control).

With exception for ash content and using the change percentage of wood chemical constituents to tap water (control), it can be noticed from Table (3) that the effects of sewage effluent irrigation on the chemical constituents of wood are quit low, which ranged between 2.46% to 6.60% for lignin and extractives contents, respectively. The highest effect of sewage effluent on chemical components was obtained with ash content which increased from 0.39% to 0.47% with the change percent of 17.52%. These results are in agreement with the conclusion of Kayad *et al* (2005) who reported that although sewage water enhanced the growth of chinaberry trees it had slight effect on wood properties. They concluded that wood taken from trees irrigated by sewage effluent did not differ much than normal wood that irrigated with tap water. Chemically and from a practical point of view, our results demonstrated that although trees irrigated by sewage effluent had a significant effect on the chemical components of chinaberry but wood taken from trees irrigated by sewage effluent did not differ much than normal wood that irrigated with tap water with exception for ash content.

Table 3: Effects of sewage effluent irrigation on wood chemical components

Chemical Components (%)*	**Irrigation treatments**		**Difference** (%)**	**$LSR_{0.05}$**
	Control (Tap water)	**Sewage effluent**		
Cellulose content	40.46 (1.95)	42.41 (2.34)	4.60	0.32
Hemicellulose content	24.20 (0.60)	24.03 (0.72)	-	NS
Lignin content	32.54 (2.71)	33.36 (2.50)	2.46	0.26
Extractive content	11.74 (0.73)	12.57 (0.88)	6.60	0.03
Ash content	0.386 (0.06)	0.468 (0.09)	17.52	0.26

*** Each value is an average of 18 specimens.**

**** The difference between tap water and sewage effluent values as a percent of the later.**

$LSR_{0.05}$ is least significant rang at 5% level of probability by Duncan Multiple Test.

NS: Not significant. ( ) Values between parentheses are standard deviations.

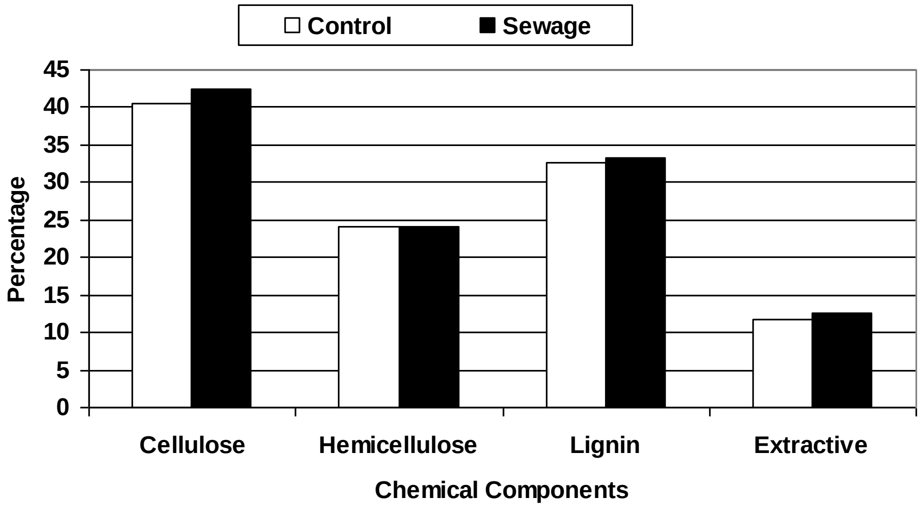

Fig. 1. Wood chemical components (%) as affected by sewage effluent irrigation

Chemical compositions of juvenile and mature wood as affected by sewage effluent

Based on fundamental differences in the structure and properties of the wood, the tree stem can be characterized as two regions, juvenile and mature (Panshin and Zeeuw, 1980). Juvenile wood (core wood) is found in both softwoods and hardwoods, and is usually of lower quality than mature wood (Hygreen and Bowyer, 1989).

The mean values of wood chemical components for juvenile and mature wood of chinaberry, and the relative differences between them expressed as a percentage of the mean mature value, are tabulated in Table (4). It can be seen from this Table and Fig. (2) that the mature wood had significantly higher average cellulose (43.48%), hemicellulose (24.70%) and extractives (12.92%) contents than juvenile wood (39.40, 23.52 and 11.39%, respectively). However, lignin and ash contents of juvenile wood were significantly higher than mature wood and the relative differences between the two types of wood were 16.46 and 34.62%, respectively. The results indicated that ash content exhibited the largest difference between juvenile and mature wood, 34.62 percent, while hemicellulose content exhibited the least difference between the two types of wood, where the juvenile wood was 4.78 percent lower than the mature wood.

These results are in agreement with Bendsen (1986) who reported that juvenile wood had the lowest extractives and lignin contents and the highest cellulose content as compared to mature wood.

Table 4: Properties of juvenile and mature wood of *Melia* azedarach L.

Wood chemical components (%)*	Maturity of wood		Difference** (%)
	Juvenile wood	Mature wood	
Cellulose content	39.40^{B} (0.95)	43.48^{A} (1.27)	10.30
Hemicellulose content	23.52^{B} (0.26)	24.70^{A} (0.29)	4.78
Lignin content	35.45^{A} (0.44)	30.44^{B} (0.68)	-16.46
Extractive content	11.39^{B} (0.36)	12.92^{A} (0.54)	11.84
Ash content	0.490^{A} (0.07)	0.364^{B} (0.05)	-34.62

*** Each value is an average of 18 specimens.**

**** The difference between the juvenile and mature wood values as a percent of the later.**

Negative values mean adverse effect.

( ) Values between parentheses are standard deviations.

Values with the same letter in the same row do not vary significantly at 0.05 level of probability according to Duncan's Multiple Range Test. NS: not significant.

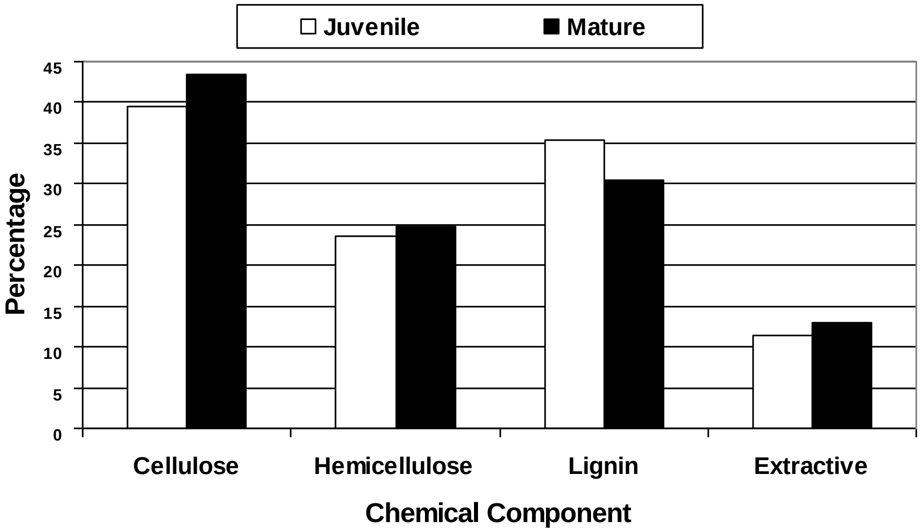

Fig. 2. Wood chemical components (%) of juvenile and mature wood of chinaberry.

The interaction between irrigation treatments and maturity level of wood indicated that juvenile and mature wood resulted from the trees irrigated by sewage effluent had the highest average values of cellulose and extractives contents as compared with those values obtained from trees irrigated by tap water. In the same time, mature wood for each of tap water and sewage effluent irrigation gave the highest cellulose and extractives content (Fig. 3).

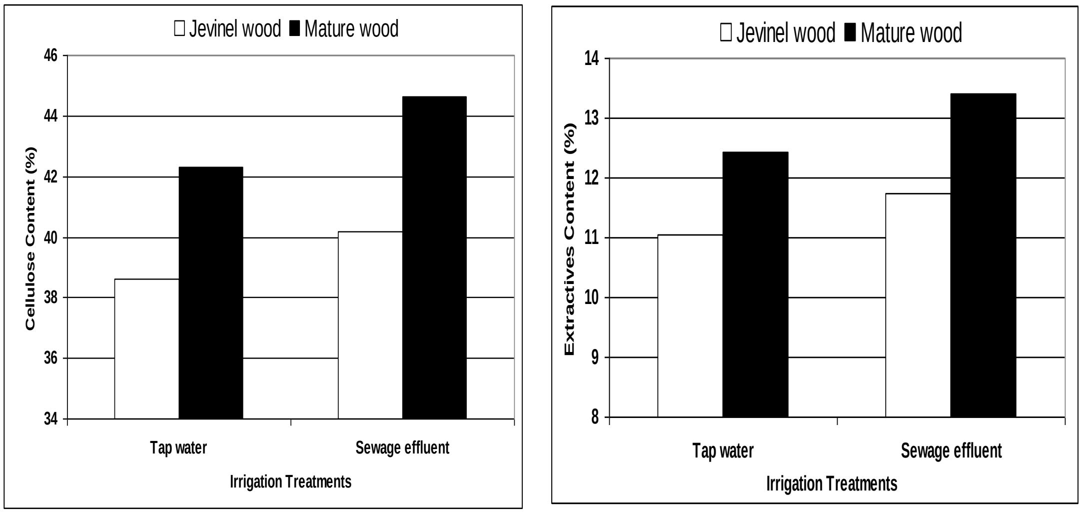

Fig. 3. **Effect of sewage effluent irrigation on the cellulose (left) and extractives (right) contents of juvenile and mature wood.**

Effect of sewage effluent on physical and mechanical properties of wood

The mean values for the physical and mechanical properties of wood as affected by irrigation treatments are shown in Table (5). The differences among irrigation treatments, wood maturity levels and the interaction between them were not significant (Table 5). It can be said that all test specimens in the current study were about the same moisture content which ranged between 11.97 to 12.25% without any significant differences. This means that all the specimens were carefully conditioned before test and the specimens were reached the equilibrium moisture content before test (about 12%).Therefore, the values of mechanical properties *i.e.* MOR, MOE and C_{max} were not adjusted for differences in moisture content.

The results tabulated in Table (5) indicated that using sewage effluent significantly increased wood specific gravity of chinaberry (0.595 vs. 0.55 for control) and the difference between the two mean values was higher (7.56%), but small than tap water. These results are in harmony with those of Szopa *et al.* (1977) when they studying *Quercus alba*, Hassan (1996) on *Leucaean leucocephala* and Kayad *et al.* (2005) on *Melia azedarach*, and Ali (2005) on different wood species. They concluded that sewage effluent irrigation slightly increased specific gravity of wood. In general, although most mechanical properties of wood are closely correlated to density which has been demonstrated by several investigators (El-Osta *et al.,* 1981, Hermandez**,** 2007, and El-Sayed *et al.,* 2009), the small change observed in the current study in specific gravity is not sufficient to account for the relatively large differences in the mechanical properties observed due to irrigation treatments. This result is in agreement with Roos *et al.* (1990) on *Populus tremuloides* and Korkut and Guller (2008) on *Ostrya carpinifolia*. The large change in mechanical properties with increasing age may reflect the combined effects of increasing specific gravity, cell dimensions, and increasing fibril angle in the secondary cell wall (Roos *et al.*, 1990).

It can be noticed from Table (5) that sewage effluent irrigation had a significant effect on all the mechanical properties of wood. The results indicated that mechanical properties of wood increased with trees irrigation by sewage effluent. Modulus of elasticity (MOE) had the largest difference between the two mean values of tap water and sewage effluent, 15.98%. there is a significant difference between the two means of MOE for the trees irrigated with sewage effluent (11413.5 N.mm^{-2}) and the others, which irrigated with tap water (9589.3 N.mm^{-2}) according to least significant rang by Duncan's multiple test. The least difference between the two irrigation treatments was obtained with Janka hardness number (JHN) in radial and tangential directions (6.39 and 6.19%, respectively). It can be seen from Table (5) that JHN in the radial direction was lower (4.72 vs. 5.03 kN for control) than those values in the tangential direction (5.53 vs. 5.17 kN for control). The data in Table (5) indicated that trees irrigated with sewage effluent gave higher mean values of modulus of rupture, MOR, (118.2 N.mm^{-2}) and maximum crushing strength, C_{max}, (47.7 N.mm^{-2}) as compared to trees irrigated with tap water (106.2 and 42.8 N.mm^{-2}, respectively).

Based on the above results, it can be concluded that sewage effluent had a notable better effect on all mechanical properties of chinaberry wood especially modulus of elasticity (MOE) as compared to tap water. In the main time, this study is the first attempt made to provide basic information regarding the effect of sewage effluent on mechanical properties of wood.

Table 5: Physical and mechanical properties of wood as affected by sewage effluent irrigation

Irrigation treatments	MOR (N.mm^{-2})	MOE (N.mm^{-2})	C$_{max}$ (N.mm^{-2})	JHN (kN) in Tangential	JHN (kN) in Radial	MC (%)	SG
Tap water (Control)	106.2	9589.3	42.8	5.17	4.72	12.25	0.550
	(16.5)	(2009)	(4.2)	(0.91)	(0.90)	(0.58)	(0.04)
Sewage effluent	118.2	11413.5	47.7	5.53	5.03	11.97	12.25
	(15.5)	(2039)	(4.8)	(0.98)	(0.92)	(0.17)	(0.58)
Relative Difference*	**10.15**	**15.98**	**10.16**	**6.39**	**6.19**	**-2.34**	**7.56**
LSR$_{o.o5}$	4.6	377.8	1.3	1.14	0.97	NS	0.012

*** Each value is an average of 18 specimens.**

**** The difference between tap water and sewage effluent values as a percent of the later.**

+ SG is based upon volume at test and oven-dry weight.

LSR$_{0.05}$ is least significant rang at 5% level of probability by Duncan Multiple Test.

NS: Not significant.

( ) Values between parentheses are standard deviations.

Physical and mechanical properties of juvenile and mature wood:

The mean values of physical properties and mechanical test data for juvenile and mature wood and the relative differences between them as a percentage of the mean mature wood are given in Table (6).

Table 6: Physical and mechanical properties of juvenile and mature wood

Maturity of wood	MOR (N.mm^{-2})	MOE (N.mm^{-2})	C$_{max}$ (N.mm^{-2})	JHN (kN) in Tangential	JHN (kN) in Radial	MC (%)	SG
Juvenile wood	98.0^{B}	8605.1^{B}	41.4^{B}	4.44^{B}	4.00^{B}	12.15^{A}	0.523^{B}
	(8.6)	(1166)	(2.8)	(0.23)	(0.22)	(0.31)	(0.02)
Mature wood	126.4^{A}	12397.6^{A}	49.1^{A}	6.26^{A}	5.74^{A}	12.07^{A}	0.621^{A}
	(9.4)	(992)	(3.4)	(0.26)	(0.21)	(0.56)	(0.04)
Relative Difference**	**22.47**	**30.59**	**15.68**	**29.07**	**30.31**	**-0.66**	**15.78**

*** Each value is an average of 18 specimens.**

**** The difference between the juvenile and mature wood values as a percent of the later.**

( ) Values between parentheses are standard deviations.

Values with the same letter in the same row do not vary significantly at 0.05 level of probability according to Duncan's Multiple Range Test.

It can be seen that for all mechanical properties of wood, mature wood had the highest values and the least average values was obtained for juvenile wood and the differences between them were significant. The mean values of MOR, MOE and C_{max} for mature wood were 126.4, 12397.6 and 49.1 $N.mm^{-2}$, respectively. The largest differences between juvenile and mature wood were obtained for MOE, and Janka hardness number in radial and tangential directions (30.59, 29.o7 and 30.31 %, respectively). However, maximum crushing strength (C_{max}) exhibited the least difference between the two types of wood, 15.68%. The same result was reported by Roos *et al* (1990) in quaking aspen (*Populus tremuloides* Michx.). Generally, these results are in harmony with the finding of the conifers and hardwoods previously studied (Schniewind and Gammon, 1989 and Roos *et al*, 1990). These results permitted the discrete separation of juvenile and mature wood material was needed due to the presence of significant differences between them.

Relationships between chemical components and mechanical properties:

The correlation coefficients matrix among each of physical, mechanical and chemical properties of juvenile and mature wood are summarized in Table 7. Examination of these simple correlation relationships for juvenile wood revealed that good correlations (r= 0.47 to 0.96, $p<0.01$) were found between all mechanical properties and each of wood chemical components. These coefficients were significant or highly significant. This means that wood chemical components were clearly correlated with each of MOR, MOE and C_{max}. There were negative correlations between hemicellulose content and each of MOR, MOE and C_{max}. However, other relations between each of chemical components and mechanical properties were positive correlations. These results are in agreement with those of El-Osta *et al* (1981) and El-Sayed *et al* (2009). For mature wood, it can be noticed the same trend which obtained for juvenile wood except the correlation coefficients belong to hemicellulose and ash contents were not significant (Table 7).

Extractives content showed significant positive correlation with each of mechanical properties of either juvenile (r= 0.55 to 0.83) or mature wood (r= 0.50 to 0.89) as shown in Table (7). This means that the higher the extractives content of wood the greater the mechanical properties. These results are in harmony with the conclusion reached by many authors (El-Osta *et al*, 1981, Junior and Moreschi, 2003, Korkut and Guller, 2008 and El-Sayed *et al*, 2009) which led them to suggest that extractives have an important role in reinforcing the cell walls. Grabner *et al*, (2005) reported that sapwood extraction had a minor effect on the mechanical properties, while in heartwood the effect was great. This affirms that removal of high extractives contents of *Ceteris paribus* had a significant consequence on C_{max} and MOE. On the other hand, our result is disagreement with Badran and El-Osta (1977) and Al-Mefarrej (1985). The former concluded that extractive content did not affect the maximum crushing strength significantly and the later found that the extractives content of *Tamarix aphylla* was not significant correlated with bending strength parameters (MOR and MOE). This disagreement may be attributed to the fact that exact location of extractives in wood tissues is not well defined. If the extractives were located on the lumen surface of cell wood the major repository in wood structure, they would not be expected to influence strength (Badran and El-Osta, 1977). However, if these extraneous substances were to be located within the cell wall structure, i.e., the amorphous regions, then their influence on strength properties would be considerably pronounced (**El-Osta**, 1981). Hernandez (2007) concluded that the differences of mechanical properties of wood should be explained both density and presence of extractives.

There were significant positive correlations between wood specific gravity (SG) either for juvenile or mature wood and each of mechanical properties of wood (Table 7). Good correlations were found (r= 0.57 to 0.90 for juvenile wood and 0.67 to 0.91 for mature wood). As a general rule, the relationship between wood SG and mechanical properties varies according to the considered properties and to the different wood species, but in most cases it is linear. With increasing SG, strength also increases and this is because SG is a measure of the wood substance contained in a given volume (Tsoumis, 1999). These results are in agreement with Arganbright (1971), El-Osta *et al* (1981), Schniewind and Gammon (1986) and Pometti *et al* (2009). They concluded that strength properties of wood are closely correlated with specific gravity and the higher the specific gravity the greater the strength.

In the second stage of this analysis, multiple regressions were used to reach the full model. Then, the best reduced model representing the relationship studied was extracted from the full model using a type of backward elimination procedures (Snedecor and Cochran, 1967). The choice of the best reduced model was based on the significant of each terms as well as coefficient of determination, R^2 (Draper and Smith, 1967).

The multiple regression equations in reduced model for each of the mechanical properties versus each of the variables of the chemical components of juvenile and mature wood as well as all wood combined are presented in Table (8). It is clear from the data in this table that after the elimination of non significant variables based on the test of each partial regression coefficient (R^2) from the full model, all regression equations in the table account 67.9% to 96.5% of the total variation on all mechanical properties studied herein (Table 8). It is clear that these equations were the best reduced models to describe the total variations of each of the mechanical test data *i.e.,* MOR, MOE,.. etc in the current study. It can be seen also that for the same mechanical property, there was a differences between the equations which explained the variations according to type of wood (juvenile, mature or combined). These results permitted the discrete separation of juvenile and mature wood for further research. This finding is in agreement with the conclusion of Roos *et al* (1990).

Simple regression analysis revealed that the coefficients of determination (R^2) between SG and each mechanical property range from 0.32 to 0.81 for juvenile wood and from 0.45 to 0.83 for mature wood. This means that even for statistically significant regressions, 32% up to 83% of the total variation in mechanical properties can be explained by SG variation. Some of these relations which have relatively high degree of association between specific gravity and some of the mechanical test parameters are plotted in Figs. 4-6. It can be seen from these figures that specific gravity is a good indicator to explain and detect the mechanical properties of wood. These results are in agreement with voluminous researches carried out to study the relationship between SG and mechanical properties (El-Osta, 1985, Schniewind and Gammon, 1986 and Pometti *et al,* 2009).

Table 8. Regression equations (reduced models^{+}) and coefficient of determination (R^2) of juvenile wood, mature wood and all wood combined

Property (Y)	**Wood type**	**Equation**	**R^2**
MOR	Juvenile	Y= 39.05 + 120.4Ash**	0.867
	Mature	Y= 391 – 12.62 Hem* + 128.6Ash**	0.794
	Combined	Y= 91.22 -4.30Lig** +10.63Ext** +78.49 Ash**	0.868
MOE	Juvenile	Y= -49066 + 1058Lig* + 1768Ext**	0.770
	Mature	Y= 17658+414Cell*–900Hem*–614Lig*+1366Ext*	0.939
	Combined	Y=-5095.0 -305.8Lig** +1914.4Ext** +5634.4Ash**	0.940
C_{max}	Juvenile	Y = -148.3 +4.55Lig** +2.50Ext**	0.933
	Mature	Y= -94.3 + 4.71 Lig**	0.909
	Combined	Y = 3.07 – 1.18 Hem* +5.80 Ext**	0.903
JHN radial	Juvenile	Y = -10.96 + 0.30 Lig* + 0.48 Ext** – 2.34Ash*	0.650
	Mature	Y = 2.59 + 0.18 Ext* + 2.10 Ash*	0.681
	Combined	Y =4.51 - 0.18 Lig**+ 0.517Ext**	0.965
JHN tangential	Juvenile	Y = -23.3 +0.59 Hem**+ 0.37 Lig* + 0.37 Ext*	0.679
	Mature	Y = -1.14 + 0.10 Cell* + 0.39 Ext* – 2.0Ash*	0.844
	Combined	Y = -0.76+0.13Cell*-0.09Lig**+0.37Ext**-0.51Ash*	0.965

+ Carried out using least square method a stepwise elimination technique (Draper and Smith, 1967**).**

Cell: Cellulose Hem: Hemicellulose Lig: Lignin. For other code see Table 1.

***, ** Significant differences at 0.05 and 0.01 probability levels, respectively.**

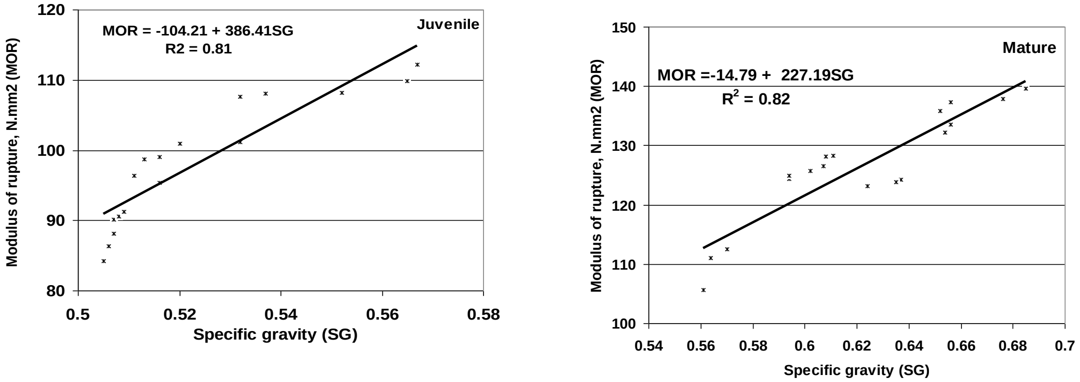

Fig. 4. Relationship between modulus of rupture (MOR) and specific gravity (SG).

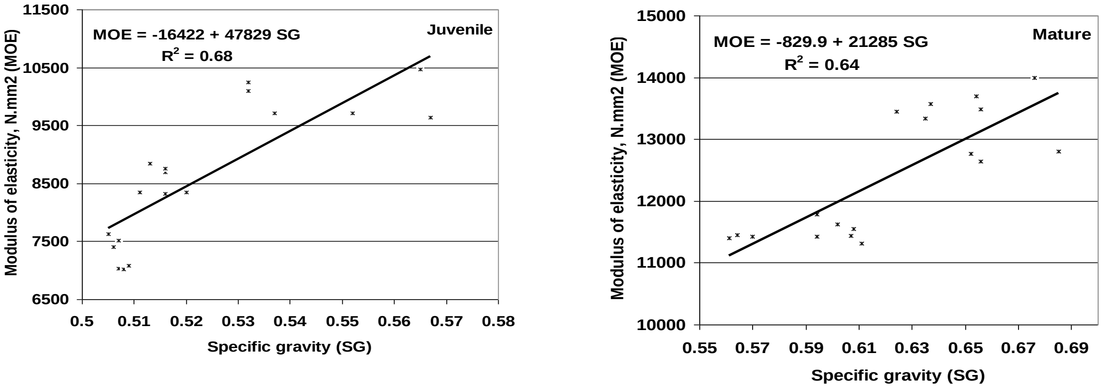

Fig. 5. Relationship between modulus of elasticity (MOE) and specific gravity (SG).

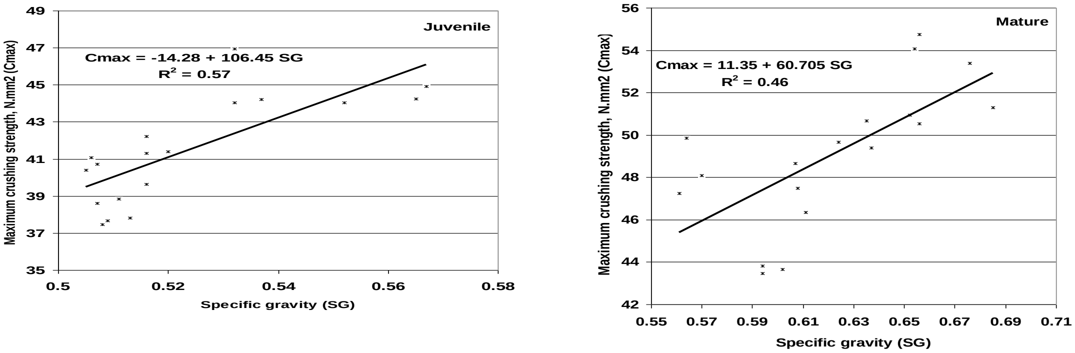

Fig. 6. Relationship between maximum crushing strength (C_{max}) and specific gravity (SG).

CONCLUSIONS

Based on the results of the current study on the effect of sewage effluent on the chemical and mechanical properties of the chinaberry wood as well as the differences between juvenile and mature wood in those properties, the following conclusions are drawn:

1- The effect of sewage effluent on wood chemical constituents was small, but highly significant with exception for hemicellulose content which was not significant.
2- Sewage effluent significantly increased cellulose, lignin, ash and extractives contents of wood and decreased hemicellulose content.
3- With exception for ash content, the effects of sewage effluent irrigation on the chemical constituents of wood are quit low, which ranged between 2.46% to 6.60% for lignin and extractives contents, respectively.
4- The highest effect of sewage effluent on chemical components was obtained with ash content which increased from 0.39% to 0.47% with the change percent of 17.52%.
5- Our results demonstrated that although trees irrigated by sewage effluent had a significant effect on the wood chemical components but wood taken from trees

irrigated by sewage effluent did not differ much than normal wood that irrigated with tap water with exception for ash content.

6- For all mechanical properties, mature wood had the highest values while the least average values was obtained for juvenile wood and the differences between them were significant
7- Separation of juvenile and mature wood material was needed due to the presence of significant differences between them.
8- Good correlations (*r*= 0.47 to 0.96, *p<0.01*) were found between all mechanical properties and each of wood chemical components.
9- Extractives content showed significant positive correlation with each of mechanical properties of either juvenile or mature wood.
10- There were significant positive correlations between wood specific gravity either for juvenile or mature wood and each of mechanical properties of wood.
11- Specific gravity variation can be explained from about 32% up to 83% of the total variation in mechanical properties.

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الملخص العربي

تأثيرات الري بمياه الصرف المعالج على المكونات الكيميائية والصفات الميكانيكية لخشب الزنزلخت ***Melia azedarach*** **L**

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أجريت تلك الدراسة اوائل علم 2006 لبحث تأثير الري بمياه الصرف الصحي المعالج على الصفات الكيميائية والميكانيكية لخشب الزنزلخت وكذلك لدراسة الاختلافات بين الخشب الغير ناضج (الشاب) والخشب الناضج في تلك الصفات. تم اختيار ست أشجار (عمر 9 سنوات) من أشجار الزنزلخت *Melia azedarach* L النامية في موقعين جنوب غرب مدينة الاسكندرية (مدينة برج العرب الجديدة وكنج مريوط). تم تجهيز واختبار عينات صغيرة خالية من العيوب من الخشب الغير ناضج والخشب الناضج تبعاً للمواصفات القياسية البريطانية (BSS). أجريت على العينات ثلاث اختبارات ميكانيكية هي اختبار الانحناء الاستاتيكي، اختبار الضغط الموازي للألياف واختبار جانكا للصلادة ثم قدرت المكونات الكيميائية للخشب من سيليلوز، هيميسيليلوز ولجنين ورماد على عينات خالية من المستخلصات وذلك تبعاً للطرق القياسية. اوضحت النتائج حدوث زيادة معنوية في محتوي الخشب من السيليلوز، اللجنين الرماد والمستخلصات نتيجة الري بمياه الصرف المعالج بينما كان النقص غير معنوي في محتوى الخشب من الهيميسليلوز نتيجة الري بمياه الصرف مقارنة بالكنترول. دلت النتائج إلى انه باستثناء محتوى الخشب من الرماد، فان تأثير الري بمياه الصرف المعالج على محتوي الخشب من المكونات الكيميائية كان قليلاً وان اعلى تأثير حدث في محتوي الرماد حيث زاد زيادة معنوية وكبيرة. أعطى الخشب الناضج محتوى أعلى بصورة معنوية في السيليلوز، الهيميسليلوز والمستخلصات الخشبية مقارنة بالخشب الغير ناضج بينما كان محتوى الخشب الغير ناضج أعلى معنوياً في كل من اللجنين والرماد مقارنة بالخشب الناضج. دلت النتائج على ان جميع الصفات الميكانيكية تحسنت نتيجة الري بمياه الصرف المعالج خاصة معاير المرونة MOE مقارنة بالكنترول. واظهرت النتائج أن المكونات الكيميائية ارتبطت بصورة جيدة وواضحة بكل من معاير الكسرMOR، الـ MOE والمقاومة القصوى في الضغط C_{max} كما وجدت علاقة ارتباط عكسية بين اي من تلك الصفات وبين محتوي الخشب من الهيميسليلوز في حين كانت باقي العلاقات معنوية موجبة. وخلصت الدراسة إلى ان الري بمياه الصرف المعالج يؤثر معنوياً ولكن بصورة قليلة على محتوى الخشب من المكونات الكيميائية باستثناء محتوى الخشب من الرماد في حين يؤثر الري بمياه الصرف معنوياً وبصورة مقبولة على الصفات الميكانيكية للخشب. كما اشارت الدراسة إلى ضرورة الفصل بين الخشب الغير ناضج والخشب الناضج نظراً لوجود اختلافات معنوية وكبيرة في التركيب الكيميائي والصفات الميكانيكية.