EXAMINING THE SUITABILITY OF THE HEARTWOOD AND SAPWOOD IN THE WHITE POPLAR TO PULP MAKING IN TERM OF FIBER MORPHOLOGY

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Abstract. Nowadays, decreasing raw material for the production of pulp from wood has led to search for alternative sources. For this reason, the possibilities of using existing natural species in pulp production are being investigated. White poplar (*Populus alba* L.), which is a widespread naturally-grown in many parts of Turkey, has the potential to be an alternative pulp raw material. In this study, the fiber dimensions of heartwood and sapwood of white poplar were prepared for microscobic measurements. Also, the relationships between fiber dimensions measured were examined with a specific view to fiber morphology to evaluate their suitability for pulp production. The fiber length of heartwood is higher due to having more 5 year-old groups on it. The changes in the fiber diameter of the sapwood and heartwood by the ages usually showed a polynomial course. The age-related changes were increased from min to average values in the fiber wall width of the heartwood. The felting rate of heartwood indicated that a pulp with proportionally more heartwood would yield a paper with better physical properties, especially tear strength. Based on the results the muhlstep ratio of heartwood and sapwood that both woods are suitable for paper production.
Keywords: *fiber dimensions, pulp, Shultze's macerattion method, fiber length, felting power*

Introduction

The demand for forestry resources increases along with the diversity and volume of forestry industrial products. Forests are important sources with biodiversity including species richness and endemic species due to the sustainability and renewability of the wood (Kharkwal et al., 2004; Standavor and Kenderes, 2003). Given easy processing, adaptability to technological developments, aesthetics, high resilience, mechanic and acoustic characteristics of wood, the forests provide one of the most convenient materials for human use (Istek et al., 2010). Suitability for use and quality of the wood largely depend on the growth rate of the tree and its location, which define the formative characteristics as well as its age, diameter, heartwood-sapwood ratio, morphological characteristics (Gultekin, 2014; Bozkurt, 1971; Dogu, 2002; Hernandez, 2013; Bamber, 1987; Cobas et al., 2013; Eroglu and Usta, 2004).

White poplar grows naturally in almost every region of Turkey. This species grows on banks of streams and roads (*Fig. 1*) (Yaltirik and Efe, 1994).

The dimensions of the fiber (length, width and diameter of fiber) and the relationship between the dimensions of the fiber (felting ratio, coefficient of elasticity, runkel ratio, modulus of rigidity and F factor) is important in the determination of the paper strength properties from pulp (Horn, 1978; Seth and Page, 1988; Horn and Setterholm, 1990; Ververis et al., 2004; He et al., 2014). It can be explained by these parameters;

- Fiber length affects paper resistance properties positively.
- Thickness of fiber also has an effect on the strength indivudial fibers.
- Pulp made up very thin cell wall thichness of fibre gives high strength properties except low tear strength otherwise if pulp from thick fiber particularly. It gives lower strength properties and volumes of papers (Kirci, 2003). The bursting and tensile strength of paper from hardwoods gives morphological effects similar to those made from softwoods (Horn, 1978).

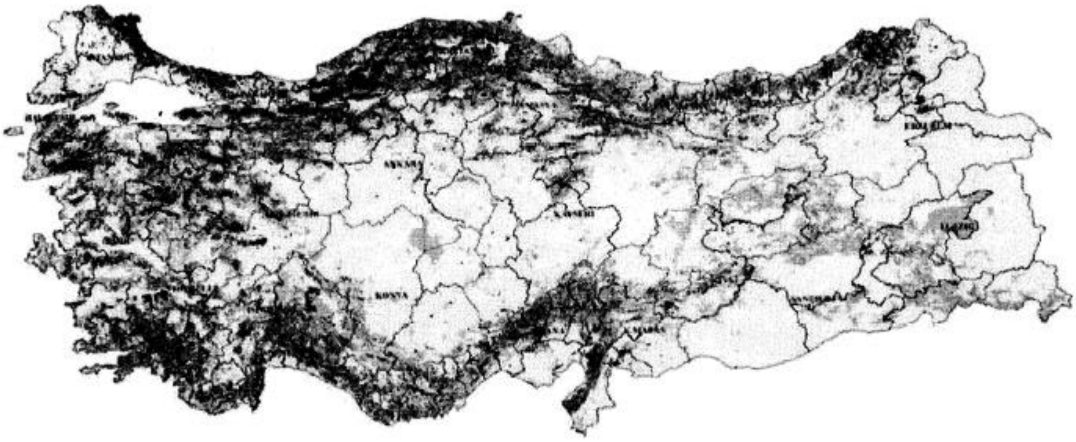

Figure 1. *The map of Turkey Forests of presence (Republic of Turkey General Directorate of Forestry, 2018)*

Suitability of the wood used as raw material for paper production is evaluated over the resistance characteristics of the pulp through the fiber lengths and the relationships between the dimensions of the fibers. This study aims at investigating the effects of sapwood and heartwood of white poplar wood on suitability in pulp and paper industry thanks to its rather easier and faster growing and shorter maintenance period. The study attempts at determining the suitability for pulp production through determination of the dimensions of the fibers of sapwood and heartwood and its proportion.

Materials and metods

Materials

Naturally grown the white poplar (*Populus alba* L.) samples were supplied from Bahçeköy-Istanbul. The average of the measurements conducted on different positions showed that the tree was approximately 60-62 years old. Age measurements were taken on the disk samples in the form of pie slice. The discs which were obtained at approximately breast height of tree stems (1.30 m) and then were divided into annual ring groups with five-year ages from heartwood to sapwood. Two samples of a thickness of 3 mm were taken from the disks. Each five-year segment of heartwood (H) and sapwood (S) separately was classified and numbered starting from zero. The heartwood had 40 years of rings whereas the sapwood has 20 years of rings. These individual fiber chips were cut and prepared woods as heartwood and sapwood.

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Methods

When the suitability of raw materials for paper making is assessed, the relationships between fiber dimentions, fiber length, width, wall thickness and lumen width and fiber dimensions, give important clues about the possibilities presented by the raw material for pulp production. The specimens were subject to morphology analysis. The fibering process was performed using the Shultze's macerattion method (Mahesh et al., 2015; Chamberlain, 1915). After being washed thoroughly, fibers are blended for 3 min in a mixer. The obtained fiber suspension was strained in a Büchner funnel using a strainer with small holes. Then, the fibers that remained on the strainer were placed in small-sized tubes to be preserved by adding glycerin on them in order to prepare the microscope slides. While preparing the microscope slides, it is essential to pay attention to the cleanliness of lam and lamellae and to the prevention of air bubbles while the sample is being placed on the lam. The mixture that consists of fiber and glycerin is dripped on the lam while being spread in a homogeneous manner, the lamella is placed above it and stabilized with varnish.

They were measured with the aid of a projection microscope by projecting the images on a surface according to Tappi T232 cm-85 (1985) standards. Measured maximum, minimum and mean dimensions of fibers were determined to calculate the relationships between fiber dimension. The criterion used in determining the suitability of fiber morphological properties for pulp production are defined below.

- Elasticity ratio: (Lumen radius/fiber width) x 100.
- Felting power: Fiber length/fiber width.
- Runkel classification: Fiber membrane width/lumen radius.
- Rigidity coefficient: (Cell wall thickness/fiber radius) x100.
- F-factor: (Fiber length/cell wall thickness) x 100.
- Muhlstep classification: (Cell wall thickness area/fiber cross-sectional area) x100.

Statistical analysis

In this study, in order to determine the heartwood and sapwood fiber properties, 50 units of fiber length and 50 units of fiber width and cell wall of samples representing the same population were measured as fiber dimensions and their average was calculated. Hence, Microsoft Office (Excel-2003) was used for analysis and drawing charts. Statistical minimum, maximum, mean (μ) and standard deviation (σ) values of fiber dimension parameters measured as fiber length, fiber width, and cell wall thickness are calculated and their data mean is expressed as $\mu \pm \sigma$ (n= 50). In most studies, statistical evaluations are mostly done with 30 units of data number (n). This study was conducted with fiber length (n=50), fiber width (n=50), and cell wall thickness (n=50) units of data. Also, Averages of each parameter belonging to the relationships between fiber dimensions (felting power elasticity, rigidity coefficient, Runkel classification, Muhlsteph ratio, and F factor) were conducted with the heartwood (n=8) and sapwood (n=4) age groups.

Results and Discussion

In this study, heartwood and sapwood samples taken from a white poplar were classified as different sections of 5-year periods. A minimum number of 50 measurements were taken for each parameter indicating their fiber lengths, fiber widths and wall thicknesses. Max, min and average values obtained from measurements are given in *Table 1* below.

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Table 1. *The values fiber dimensions*

Species	Length (mm)	Width (μm)	Cell wall thick. (μm)	Reference
Sapwood *Populus alba*	0.84±0.03(n=200)	24.66±1.74(n=200)	3.68±0.25(n=200)	Current
Heartwood *Populus alba*	0.86±0.03(n=400)	21.3±1.48(n=400)	3.62±0.27(n=400)	Current
Populus tremula	1.41	26.87	6.06	Alkan et al., 2003
Eucalyptus camaldulensis	0.79	13.82	7.43	Huş et al., 1975
Populus nigra	1.25	27.17	4.98	Alkan et al., 2003
Fagus Orientalis	0.67	17.94	4.64	Akgul and Tozluoglu, 2009
Acer platanoides	0.26	21.35	3.54	Durmaz and Ates, 2016
Heartw. *Pinus nigra*	1442±245	38.5±4.9	12.5	Istek et al., 2010
Sapw. *Pinus nigra*	2647±349	44.0±5.9	6.9	Istek et al., 2010

F: Fiber; dia.: Diameter; thick: Thickness

In sapwood of 40-60 years' period, the change between max and min of measurements of fibers with 20 years of annual rings equals to 2.4% for fiber length, 2.3% for fiber width, 9.4% for fiber cell wall thickness and 8.2 % for lumen width (*Table 1*). In heartwood with 40 years of annual rings, on the other hand, the change between the minimum and maximum measurements of fibers in 0-40 years' period equals to 10% for fiber length, % 12 for fiber width, 12.8% for fiber cell wall thickness and 22.9% for lumen width (*Table 1*).

The relationships between the fiber length and age of the white poplar heartwood are indicated on the *Figs. 2-7.*

In the five-year age groups of white poplar heartwood, it is seen that the fiber length reaches its maximum level in the first five-year period and reduces to the minimum level at the last five-years period (*Fig. 2*).

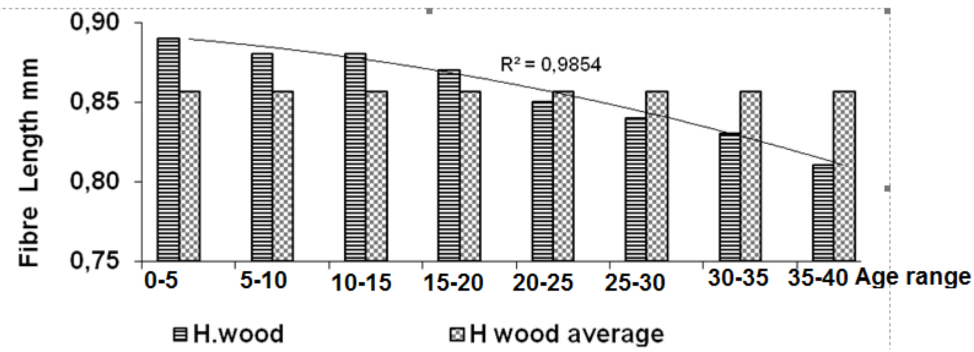

Figure 2. *Distribution of the fiber lengths of the white poplar heartwoods' with age*

It is thus concluded that the age is inversely proportional to the fiber length of heartwood. When fiber lengths of heartwood are compared with its average by age group, it is seen that the fibers of first fifteen years' age group are significantly longer and the difference start to reduce in the twentieth age group and by the age of twenty-five the average value is higher than the heartwood age groups. The fact that the biomass formation in some species of trees, which have higher fiber length than

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sapwood fiber in the first years of heartwood, is consistent with the literature (Istek et al., 2010). Gradual reduction of heartwood from the 20 years' annual rings until 40 years' annual rings might indicate that the fiber quality is reduced towards the pith with a shorter and harder structure.

The width of the sapwood starts from the borders of heartwood and continues up to the bark. It was observed that the fiber length changes of the sapwood, which starts equal to the average at 45 years' period, reduces to the minimum level at 55 years' period and reaches to the maximum level at 50 and 60 years (*Fig. 3*).

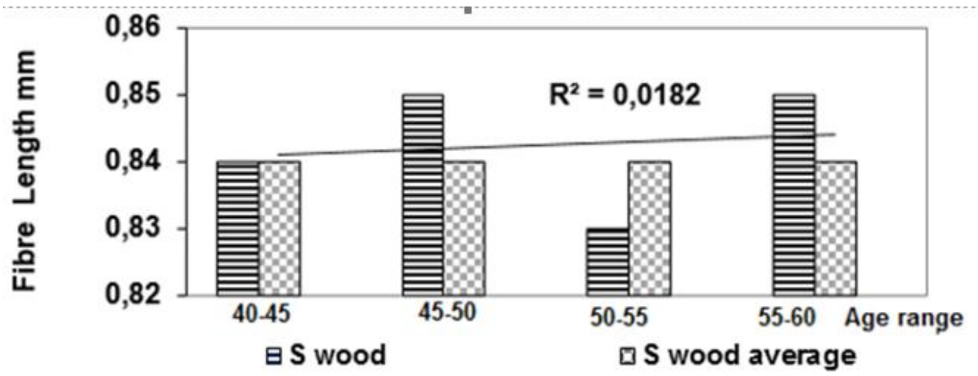

Figure 3. *Distribution of the fiber length of the white poplar sapwoods' with age*

It is known that the fiber length of the sapwood is generally higher than that of the heartwood. The ratio between the fiber lengths of heartwood and sapwood was found to be 1.02. This difference was caused by the fact that the sampled white poplar was an old tree and that the heartwood had 40 years of annual rings and thus the width of the heartwood is marginally high.

The average fiber lengths of both the heartwood (0.86±0.03) mm (n=400) and sapwood (0.84±0.03) mm (n=200) of the white poplar were a homogeneous fiber distribution. The fiber length of heartwood and sapwood was typically in the middle classification of the short fiber sequence of hardwood species (0.5-2 mm) (Cobas et al. 2013). These results of the white poplar were higher than those of *F. orientalis, Acer platanoides, E. camaldulensis* species whereas they remained lower than *Populus tremula and Populus nigra* species (Durmaz and Ates, 2016*;* Huş et al., 1975; Alkan et al., 2003; Akgul and Tozluoglu, 2009).

The fiber width of heartwood of white poplar was observed that the age-dependent changes in the fiber width of the heartwood was high in the formation period of the heartwood whereas, after reducing to the minimum levels, it expands to the levels equal to the average values in the last 35-40 annual rings (*Fig. 4*).

The ratio between the fiber width of heartwood and sapwood was found to be 0.86 μm Changes in the width of the sapwood by the ages showed a polynomial course which reaches slightly higher than the average at the earlier years (45 years) and then in the annual rings of 50-55 years reduces to the minimum levels and reaches its maximum level which is slightly higher than the average, during the later years (the annual rings of 60) (*Fig. 5*).

The fiber width values on average for the heartwood and sapwood were respectively (21.3±1.48) μm (n=400) and (24.66±1.74) μm (n=200). Although the fiber width of sapwood was wider than that of heartwood, its fiber distribution demonstrated 32 %

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more deviation while heartwood demonstrated a more homogeneous distribution (*Figs. 4 and 5*). The ratio between the fiber lengths of heartwood and sapwood was found to be on average values (0.98). This indicates their fiber lengths are close to each other.

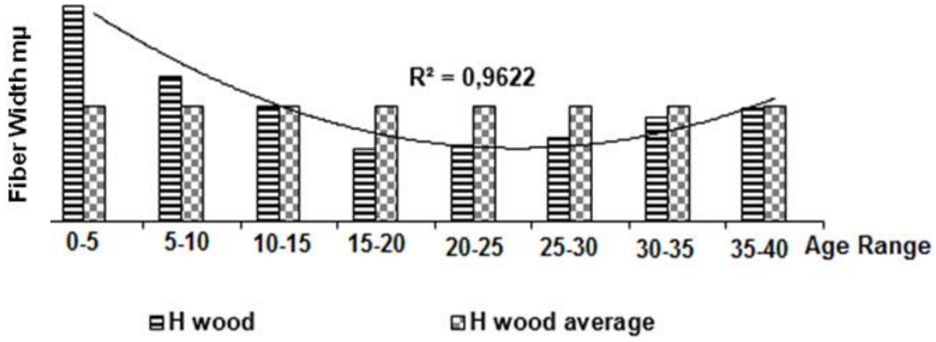

Figure 4. *Distribution of the fiber width of the white poplar heartwoods' with age*

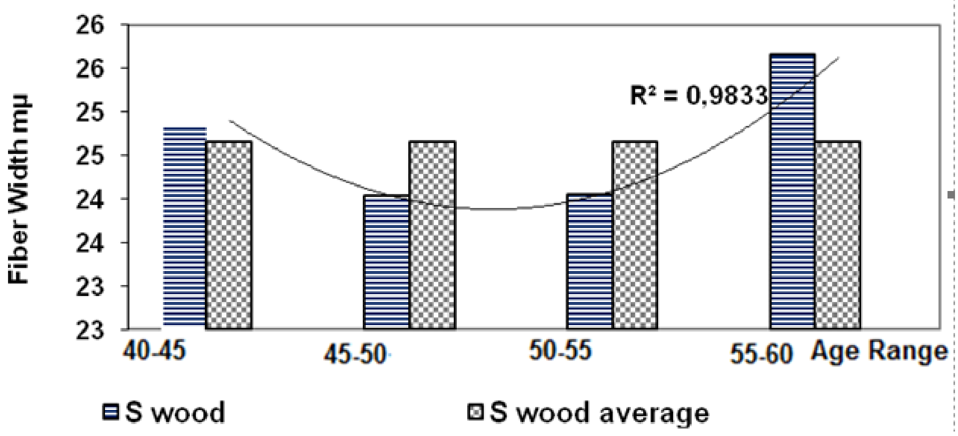

Figure 5. *Distribution of the fiber width of the white poplar sapwoods' with age*

Cell wall thickness of fibers impact on strength properties of paper. Long-fiber and thin-wall width fibers form non-porous tightly bonded paper which is collapsible and flexable (Akpakpan, 2012; Syed et al., 2016).

The average cell wall thickness of sapwood (3.68±0.25) µm (n=200) were thicker than the heartwood (3.62±0.27) µm (n=400) of the white poplar that was a more homogeneous fiber distribution (deviation 7.4%).

It was observed that the age-dependent changes in the cell wall thickness of the heartwood is at minimum levels in the first five years whereas it becomes equal to the average value in 10 years annual ring and showed a polynominal relationship course in later years (*Fig. 6*).

It was further observed that the cell wall thickness sapwood starts well below its average and then gradually increases linearly (*Fig. 7*).

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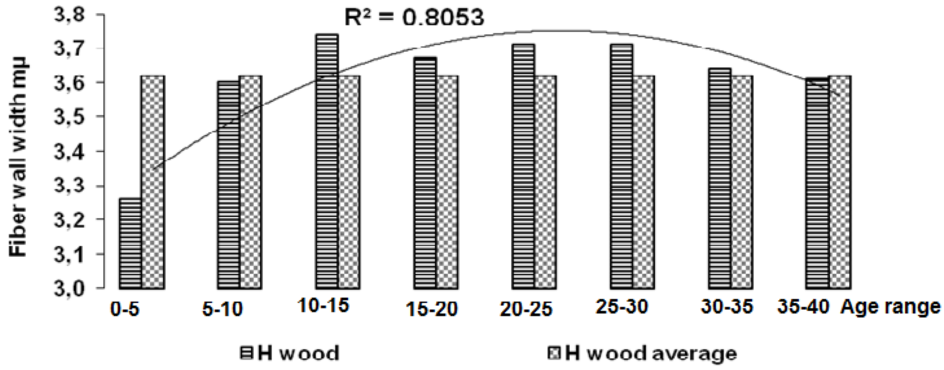

Figure 6. *Distribution of the fiber wall width of the white poplar heartwoods' with age*

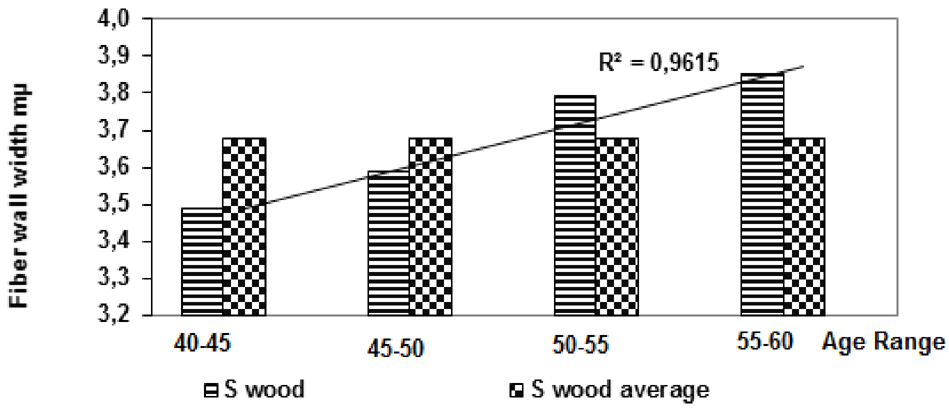

Figure 7. *Distribution of the cell wall thickness of the white poplar heartwoods' with age*

The relationships between the fiber dimensions

The relationships between the fiber dimensions of the sapwood and heartwood of white poplar were given in the *Table 2* and *Figs. 8-19*.

The felting power (slenderness ratio) is calculated by proportion of the fiber's length to its diameter. The optimum felting power for softwoods is 70. This number is lower for hardwoods (Dutt et al., 2004; Kirci, 2003). It is known that this ratio has a systematic relationship especially with the tear resistance according to the results of physical tests conducted on the paper (Kirci, 2003).

The felting power of heartwood reached minimum 33.2 at 40 years' age and maximum 42.5 at 20 years's age with an average rate of 40.2 (*Fig. 8*). It was observed that juvenile heartwood has high strength properties at 25 annual ring.

The felting power of white poplar sapwoods' reached minimum 33.13 at 45 years ring and maximum 37.74 at 50 years ring with an average rate of 34.2 (*Fig. 9*). It was determined that the average felting rate of heartwood (40.2±3.06; n=8) is 15.2 % higher and a heterogenous distribution than that of sapwood (34.2±2.04; n=4). When compared with the felting power of hardwoods, the felting rate of white poplar wood is higher than those of hybrid poplar, *Fagus Orientalis*, *Acer platanoides* L. and lower than those of other hardwood species (*Table 2*) (Akgul and Tozluoglu, 2009; Durmaz and Ates,

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2016). Some researchers posite that the resistance properties do not depend merely on the felting rate but also on the cell wall thickness (Ates et al., 2008).

Table 2. *The relationships between the fiber dimension of white poplar and some hardwoods*

Sample	Felt. Pow.	Elas. Coff.	Runk. ratio	Rig. coeff.	F factor	Muh. Ratio	Reference
Heartwood *Populus alba*	40.2±3.06	67.84±3.54	0.51±0.07	16.07±1.77	236.7±28.01	56.4±4.81	current
Sapwood *Populus alba*	34.2±2.04	69.82±1.54	0.4±0.03	15.09±0.77	229±12.50	50.8±2.16	current
Heartwood *R. seudoacacia*	54.2	64	0.56	18	-	59.0	Ozdemir et al., 2015
Sapwood *R. seudoacacia*	58.1	64.8	0.4	17.6	-	58.0	Ozdemir et al., 2015
Populus nigra	46.0	65.1	0.56	18.3	250.8	57.6	Alkan et al., 2015
E.camaldulensis	57.7	53.8	0.86	23.1	249.1	71.1	Huş et al., 1995
F. Orientalis	59.7	27.6	2.9	37	159.6	93.0	Tank, 1971
F. Orientalis	37.17	48.29	1.1	25.9	140.4	76.7	Akgul and Tozluoglu, 2009
A. platanoides	12.1	71.9	0.76	16.6	141.7	48.4	Durmaz and Ates, 2016

Felt. Pow.: Felting Power; Elas.: Elasticity; Runk: Runkel; Rigid: Rigidity; Muh: Muhlsteph; Coff: Coefficient

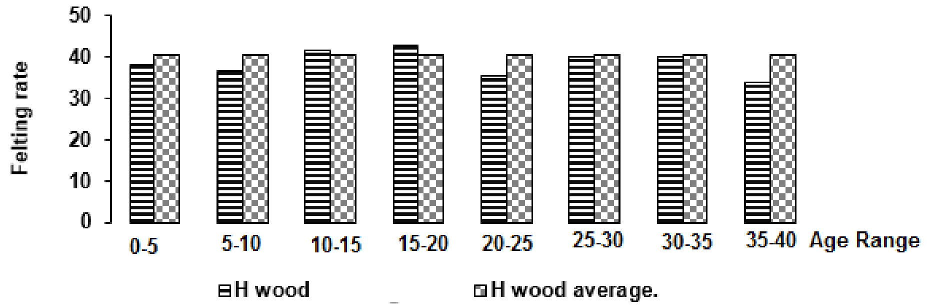

Figure 8. *Distribution of the Felting power of the white poplar heartwoods' with age*

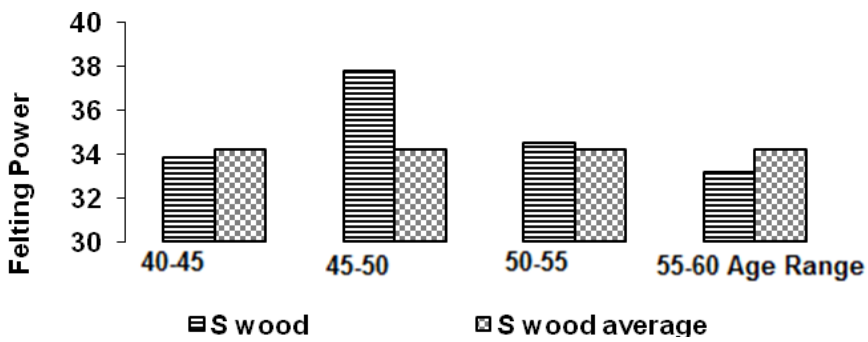

Figure 9. *Distribution of the Felting power of the white poplar sapwoods' with age*

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Coefficient of elasticity (CE) is a ratio that defines the density of the hardwood (Istas et al., 1954). This coefficient calculated as 100 times the ratio of lumen width to fiber diameter, is evaluated under four groups. 1st Group >75, 2nd Group 50<CE<75, 3rd Group 30<CE<50, 4th Group CE<30 (Tank, 1971; Kirci, 2003). This coefficient for heartwood was calculated as around 70 with minimum 64.1, maximum 67.84 and an average of 67.84±3.54 (n=8) in all age groups (*Fig. 10*). The average of heartwood is within the range of 2nd group and has a density between 0.5-0.55 $g.cm^{-3}$. This indicates that good physical properties will be obtained in paper to be made from such raw material that has fiber dimensions with a thin walled wide lumen.

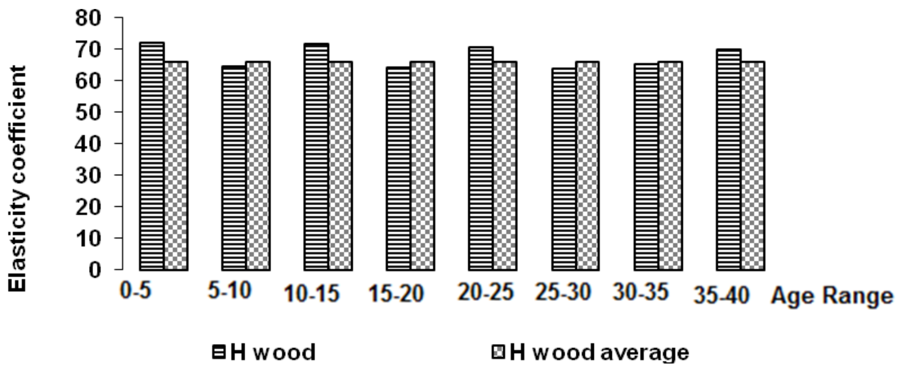

Figure 10. *Distribution of the Elasticity coefficient of white poplar heartwoods' with age*

The coefficient of elasticity of sapwood is minimum 68.5 in 55 annual ring and maximum 72.0 in 45 annual ring with an average of 69.82±1.54 (n=4) in all annual ring groups (*Fig. 11*). The elasticity coefficient of the sapwood is higher and a more homogenous distribution than that of heartwood and is within the range of 2nd group with a density above 0.50. It is understood that the sapwood elasticity coefficient has the predicted value (70) for the softwood woods and that the heartwood has a similar value. As a result, it has been shown that the physical properties of the papers to be obtained from white poplar wood raw material will be good and close to the softwood wood. When compared with the elasticity coefficients of hardwood species, the white poplar wood was found to have a value higher than all hardwood species except *Acer platanoides* L. (*Table 2*) (Durmaz and Ates, 2016).

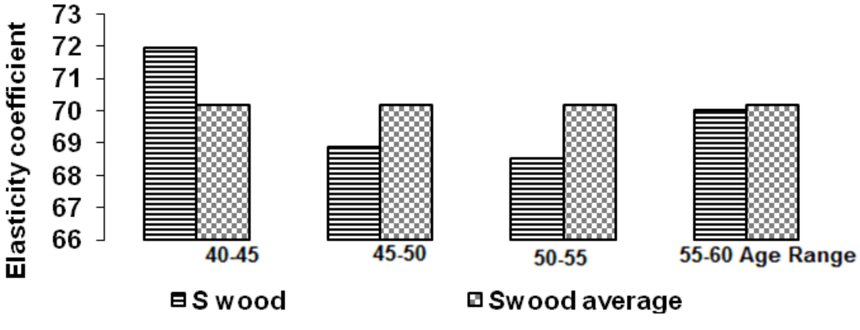

Figure 11. *Distribution of the Elasticity coefficient of the white poplar sapwoods' with age*

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Runkel ratio is calculated by division of double cell wall thickness by the width of lumen. Any ratio lower than 1 indicates that the raw material has fibers with wide lumens and thin cell walls which means that the raw material has desirable properties. At the same time, such a ratio would also indicate that the physical resistance properties of the paper to be produced will be very positive and hence the raw material is suitable for paper production (Eroglu, 1980). The values obtained for the heartwood age groups of this ratio gave a minimum less than 0.4 at 5 years and 15 years and maximum more than 0.5 in the 20 years. Given an average above 0.51±0.07 (n=8), the heartwood is suitable for pulp production (*Fig. 12*) (Eroglu, 1980; Syed et al., 2016).

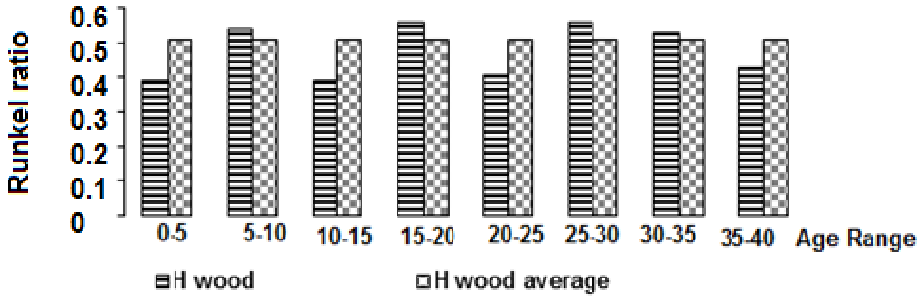

Figure 12. *Distribution the Runkel ratio of the white poplar heartwoods' with age*

For sapwood age groups, the Runkel ratio was minimum 0.39 at 45 years ring and 0.46 at 60 years ring. With an average ratio of 0.4±0.03 (n=4), the Runkel ratio was lower than in sapwood age groups which indicates that the sapwood is suitable for pulp production. It indicated a more homogenous distribution *(Fig. 13*).

It is determined that the Runkel ratio of heartwood is higher than the value of sapwood. The fact that the wood fiber length is higher than that of the sapwood is the main cause of the positive difference in Runkel ratios. According to the results of white poplar's heartwood and sapwood, it can be said that white poplar wood has a thin cell wall and a sufficient length of fiber, and hence is suitable for pulp production.

The Runkel ratio of the white poplar is similar to that of heartwood and sapwood of *R. pseudoacacia, Populus nigra* (*Table 2*) (Ozdemir et al., 2015; Alkan et al., 2015). It indicates positive resistance and durability properties, except for tear strength.

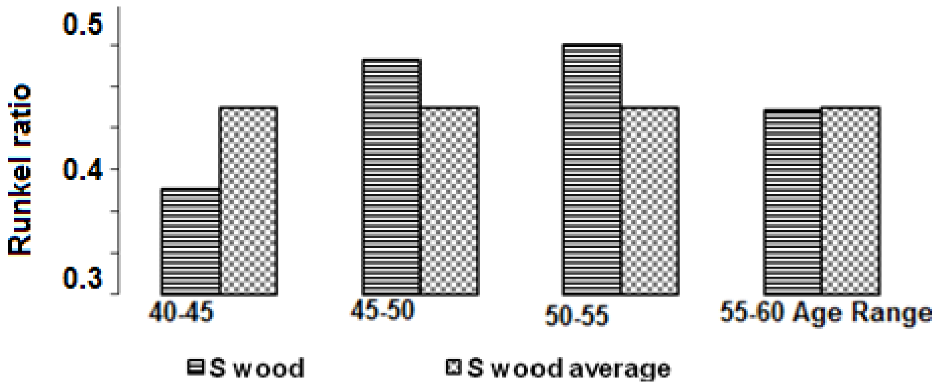

Figure 13. *Distribution of the Runkel ratio of the white poplar sapwoods' with age*

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Muhlstep ratio is related to the cell wall thickness in paper which is calculated as 100 times of the proportion of cell wall area to cross sectional area of fiber and which affects tear and breaking strength of paper. In the heartwood age groups, the Muhlstep ratio was determined minimum 48.2 in first 5 years ring and maximum 56.4 in 20 years ring with an average of 56.4 (*Fig. 14*).

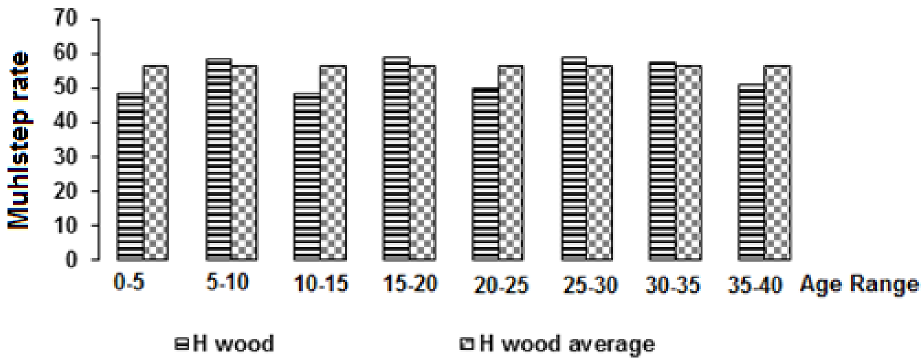

Figure 14. *Distribution of the Muhlstep ratio of the white poplar heartwoods' with age*

In the sapwood age groups, the Muhlstep ratio was found between 48.3 in 45 years ring and 53.1 in 50-55 years ring with an average of 50.8 which translates into good suitability for pulp production. The results show that the muhlstep ratio of heartwood of white poplar is higher than that of sapwood and that both woods are suitable for paper production (*Fig. 15*). Based on muhlstep ratio averages of sapwood (50.8±2.16; n=4) that is more homogenous than heartwood (56.4±4.81; n=8), the white poplar wood has higher values than *Populus tremula* and *Acer platanoides* L. and lower values than others (*Table 2*) (Durmaz and Ates, 2016; Alkan et al., 2003).

According to some researchers, this index indicates that use of clones is more suitable in board and corrugated board production rather than paper. Another aspect of papermaking would be blending of long fiber pulp with white poplar. Anothers, these ratios indicate that white poplar would be more suitable for corrugated board production. Another area of use would be blending in long fiber pulp that contains white poplar.

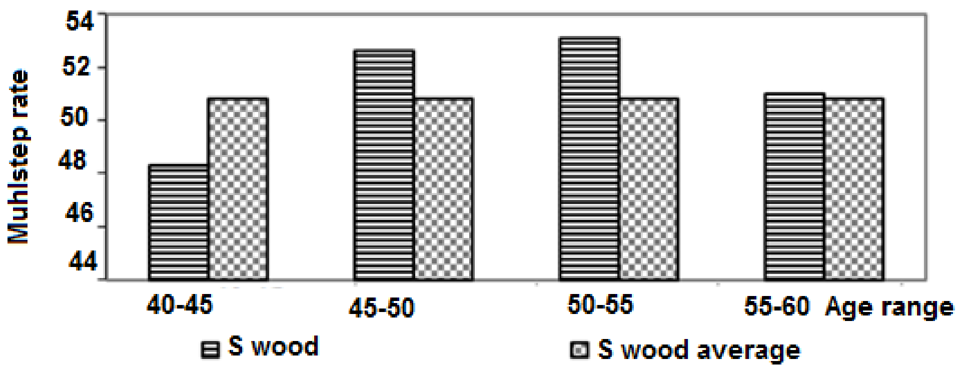

Figure 15. *Distribution of the Muhlstep ratio of the white poplar sapwoods' with age*

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The rigidity coefficient is defined as 100 times of the proportion of cell wall thickness to the fiber diameter and a low rigidity coefficient positively affects the breaking and tears strengths (Bektaş et al., 1999). In the heartwood age groups, the rigidity coefficient was calculated 14.0- 17.9 at 5-20 years' rings and 30 years rings with an average of 16.07±1.77 (n=8) (*Fig. 16*). It was determined that the ratio of the heartwood is lower than other hardwoods species (*Table 2*).

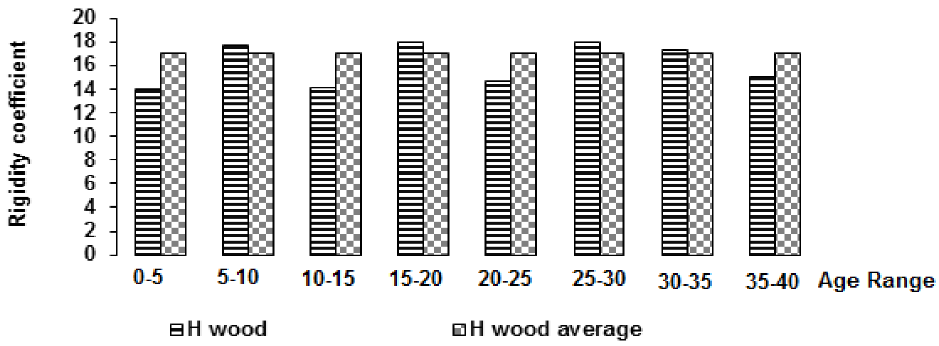

Figure 16. *Distribution of the rigidity coefficient of the white poplar heartwoods' with age*

In the sapwood age groups, the rigidity coefficient was calculated minimum 14.0 at 45 years ring and maximum 15.8 at 55 years ring with an average of 15.09±0.77 n=4 (*Fig. 17*). It was observed that the rigidity coefficient of the sapwood is higher than that or heartwood. It was also determined that the rigidity coefficient of the heartwood is higher than that of *Populus tremula* and that of sapwood is higher than those of *Populus tremula* and *Acer platanoides* L. (*Table 2*).

Figure 17. *Distribution the rigidity of the white poplar sapwoods' with age*

A high coefficient indicates low resistance properties. Ates et al. (2008) confirmed this view in a study on the resistance properties obtained from *P. elongota* (which has a rigidity coefficient of 27.6) through different chemical pulping method. This view is also supported by the fact that the coefficient that shows inverse proportion to rigidity (17.8) elasticity (65) values reflects similar rigidity properties with the elasticity resistance properties of higher limit of second class (Ates et al., 2008).

Given that there is an inverse proportional relationship between the rigidity coefficient (16.07±1.77; n=8) and elasticity (67.84±3.54; n=8) of heartwood and between rigidity coefficient (15.09±0.77; n=4) and elasticity (69.82±1.54; n=4) of

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sapwood of white poplar. The rigidity coefficient of heartwood is larger than that of sapwood, but it has a heterogenous distribution. These woods correspond to second elasticity class, as identified in theoretical calculations, and will yield lower resistence properties. Rigidity coefficient are lower the other hardwoods (Alkan et al., 2015; Durmaz and Ates, 2016; Huş et al., 1995; Ozdemir et al., 2015; Tank, 1971).

The F factor stands for flexibility of the paper and in heartwood annual ring groups, the factor was determined with an average of 236.7±28.01 n=8 (*Fig. 18*).

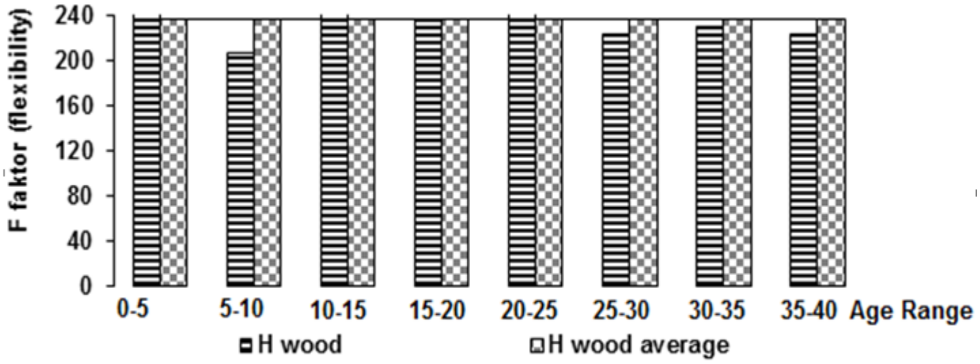

Figure 18. *Distribution of the F coefficient of the white poplar heartwoods' with age*

F factor (flexibility) indicates the flexibility of the papers to be obtained from the fibers. In sapwood, this factor was found minimum 219 at 55 years ring and maximum 242.3 at 50 years ring with and average of (229±12.50; n=4). The F factor average of heartwood (236.7±28.01; n=8) is higher by 3.3% and it has a more homogenous distribution than that of sapwood (229±12.50; n=4) (*Fig. 19*). It was observed that these results of the sample were higher than that of *Fagus orientalis* and *A. platanoides* lower than others (*Table 2*) (Akgul and Tozluoglu, 2009; Tank, 1971; Durmaz and Ates, 2016).

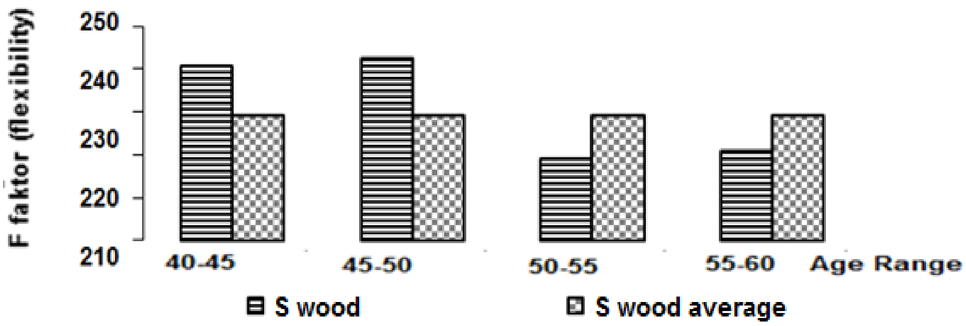

Figure 19. *Distribution of the F factory of the white poplar sapwoods with age*

The papers obtained from this type of fibers present high flexibility (Akgul and Tozluoglu, 2009). It can be used as the intermediate paper for corrugated board and newspaper, due to low bleaching expenses required due to its light color, in blends with other long fibers for office papers.

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Conclusions

The fiber dimensions and relationships between fiber dimension of heartwood and sapwood of white poplar were examined separately for each wood sample by the five-year rings groups with a specific view to fiber morphology to evaluate their suitability for use in pulp production.

1. An inverse correlation was determined between the fiber length of heartwood and its age. Although the fiber length of the sapwood is generally high, it has been found that the fiber length of the white poplar heartwood with 40-year-old annual rings is higher than that of sapwood.
2. Depending on the age of the heartwood, the change in fiber width was found to be high in the formation process of the heartwood and then it was equal to the average value in the last annually rings.
3. The sapwood also showed a polynomial correlation which reaches slightly higher than the average at the earlier years and then reduces to the minimum levels and reaches its maximum level in the process.
4. Although there is a polynomial relationship between the cell wall thickness and age of the heartwood, a linear relationship was determined in the sapwood.
5. The heartwood with high felting ratio has been found to have high tear strength.
6. The flexibility coefficients of sapwood and heartwood have the anticipated values for softwood. It can be stated that the physical properties of the papers obtained from white poplar wood would be similar to those of softwood papers.
7. The Runkel ratios of heartwood and sapwood of white poplar were found be suitable for pulp production due to positive resistance and durability properties, except for tear strength.
8. The Muhlstep ratio indicates that white poplar would be more suitable for corrugated board production. Another area of use would be blending in long fiber pulps that contain white poplar.

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