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LONGITUDINAL VARIATION IN SELECTED WOOD PROPERTIES OF ORIENTAL BEECH AND CAUCASIAN FIR

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In memoriam of Dr. Thomas C. MANNES

ABSTRACT

In this study, several wood properties were investigated along with the longitudinal direction for oriental beech and caucasian fir trees grown in Turkey. Wood density, compression strength parallel to grain, chemical characteristics (holocelluose, celluose, lignin), fiber dimensions (fiber length, fiber width, fiber lumen width, fiber cell wall thickness) were measured from the sapwood of the discs taken at the stem heights of 1,30; 6,30 and 12,30 meters. Both wood species showed clear trends in wood properties along longitudinal direction. For both wood species, the highest values in density, compression strength, volumetric shrinkage and swelling were at 1,30 m stem height, and the investigated parameters decreased along with the stem height, while longitudinal shrinkage and swelling percentage increased. The highest cellulose content was found at 1,30 m stem height, and the highest lignin content was found at 12,30 m stem height for both wood species. The longest fibers and the thickest fiber walls were determined at 1,30 m stem height in both wood species. These results clearly indicated that stem height greatly affected the investigated wood properties for both wood species.

Keywords: *Abies nordmanniana*, *Fagus orientalis*, longitudinal variation, stem height, wood properties.

INTRODUCTION

The importance of variability in wood properties within tree has often been emphasized in the literature. Zobel and van Buijtenen (1989), the most important reference on this subject, explained in detail the changes in a number of wood properties both radial (from the center to the bark) and longitudinal (from the base to the top) direction in the tree. Lachenbruch *et al.* (2011) reported that the anatomical, chemical, physical and mechanical properties of wood vary considerably between plant parts (such as main stems, branches and roots) and within any plant part. Many publications describe the various longitudinal variation patterns within trees. The recent work of Kiaei and Farsi (2016) for Persian silk wood (*Albizzia julibrissin*) illustrated wood density, modulus of elasticity and modulus of rupture in bending decreased from base to top with height, and Longui *et al.* (2016) for *Astronium graveolens* showed specific gravity was higher at the base of tree and shear parallel to grain did not vary in analyzed heights.

When the publications are examined, it is seen that there are more studies in conifers than hardwoods. Machado and Cruz (2005) determined a decreasing tendency of mechanical properties (bending strength, modulus of elasticity parallel to grain, compression strength parallel to grain, tension strength perpendicular to grain) of maritime pine because of the growing presence of juvenile wood. Molteberg and Høibø (2006) found that fiber width decreased, while basic density and fiber length of norway spruce increased with increasing height in the tree. Cato *et al.* (2006) stated that wood from

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the crown in *Pinus radiata* has a lower density because of a decrease in cell wall thickness. Antony *et al.* (2010) reported specific gravity of *Pinus taeda*, decreased in a nonlinear trend with tree height. A decreased trend of wood density, shrinkage and swelling (tangential and volumetric) along the stem height for *Larix decidua* trees was reported by Ay *et al.* (2012). Moreover, mature norway spruce trunkwood had higher hydraulic efficieny and bending stiffness than juvenile wood from the tree top, while both wood types had similar ring densities (Rosner and Karlsson 2011, Rosner 2013).

In contrast to these findings, Lukašek *et al.* (2012) working on grand fir determined that the vertical position did not obviously affect the size of the shrinkage. Regarding the vertical variation in wood properties of hardwoods, Rueda and Williamson (1992) studied the vertical variation in the radial increase in specific gravity of *Ochroma pyramidale*, and observed a linear increase with radial distance at any given height. Poplar and eucalyptus species are among the most studied tree species in angiosperms. For example, Kord *et al.* (2010) found that within tree wood density and shrinkage values of *Populus euramericana* decreased along the stem, from the base to the upwards at 5%, 25%, 50%, and 75% of total tree height. Contrary to the usual trend, Githiomi and Kariuki (2010) reported that basic density of *Eucalyptus grandis* decreased from base to breast height and then increased a maximum at 60% height point.

The literature contains many references to the longitudinal variation (from the base to the top) of several wood properties in conifers and hardwoods. No information is available about the variation of physical, mechanical and chemical wood properties of oriental beech and caucasian fir naturally grown in Turkey. However, oriental beech is used in various places in the Turkish forest products industry (Bozkurt and Erdin 1997) and caucasian fir constitutes 81% of the forest tree seeds exported by the Forest Trees Seeds and Tree Breeding Research Directorate in Turkey (Karasahin *et al*. 2002). It is also important for end user to know how the wood properties of these species have economic importance vary at different heights in the tree. Nevertheless, information about the longitudinal variation of physical, mechanical, and chemical properties for oriental beech and caucasian fir grown in Turkey is still lacking. To use these tree species more effectively in the forest product industry, the wood properties mentioned above need to be determined.

The objective of this study was to examine the variation of wood density, compression strength parallel to grain, chemical characteristics (holocelluose, celluose, lignin), fiber dimensions (fiber length, fiber width, fiber lumen width, fiber cell wall thickness) along longitudinal position of oriental beech and caucasian fir stems. These wood properties along the stem height were also evaluated.

MATERIALS AND METHODS

Trees and test samples

Wood samples of oriental beech (*Fagus orientalis* Lipsky.) and caucasian fir (*Abies nordmanniana* (Stev.) Spach.) were obtained from the forest stands located between 40˚55'03'-41˚04'43" N latitude and 38˚23'33"-41˚45'46" E longitude in the Black Sea region of Turkey. The trees of both species were randomly selected to represent other trees in the stands with similar diameters at breast height and with similar tree heights. Characteristics of the test tree are indicated in Table 1. The six trees felled using destructive method and total tree height measured. Discs are 15 cm height were cut at 1,30 m; 6,30 m and 12,30 m avoiding branches and defects. After, from the discs, heartwood was removed and 20 mm wide strips were cut from sapwood using band saw. Small clear specimens with dimensions of 20 × 20 × 30 mm (radial × tangential × longitudinal) were then cut from these strips using circular saw (Figure 1). The specimens were then conditioned a conditioning room at 20ºC temperature and 65% relative humidity until average moisture content reaches 12% (ISO 554, 1976).

Table 1. Characteristics of the test tree.

Species	Tree No	Diameter at breast height (cm)	Total tree height (m)	Cambial age at breast height
Oriental beech	1	31,0	22,0	49
	2	30,0	22,6	50
	3	33,2	23,3	53
Caucasian fir	1	23,0	20,0	40
	2	24,0	21,5	38
	3	23,5	21,0	39

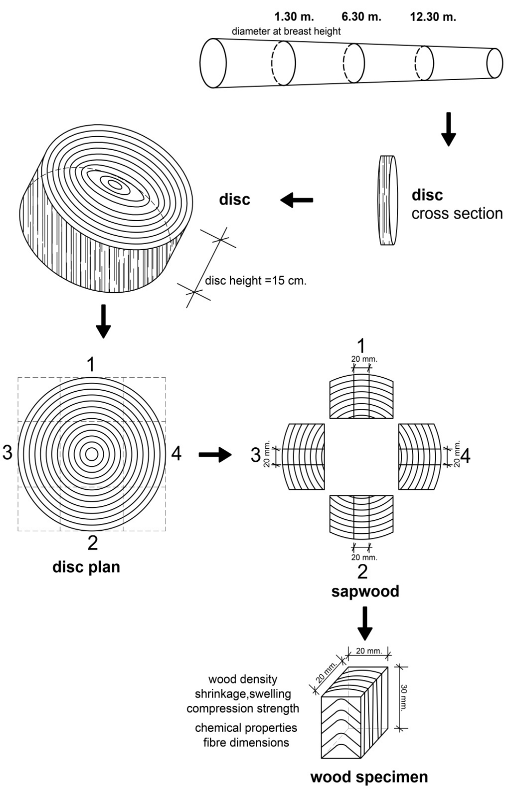

Figure 1. Tree sampling and position of wood samples in the tree.

Wood density, shrinkage, swelling measurements and compression strength test

Air-dry density (D_{12}), shrinkage percentage [tangential (β_t, %), radial (β_r, %), longitudinal (β_l, %), volumetric shrinkage percentage (β_v, %)], swelling percentage [tangential (α_t, %), radial (α_r, %), longitudinal (α_l, %), and volumetric swelling percentage (α_v, %)] of the wood were determined according to the ISO 3131 (1975), ISO 4469 (1981), ISO 4858 (1982), ISO 4859 (1982), ISO 4860 (1982), respectively. Weight and volume of wood specimens with 12% moisture were measured.

Air-dry density was calculated the ratio of air dry mass to air dry volume. Weight and dimension of wood specimens with oven dry (0% moisture content) and green condition (above the fiber saturation point) were measured. Shrinkage percentage was calculated the ratio of decrease in dimension to green dimension, and swelling percentage was calculated the ratio of increase in dimension to green dimension. Volumetric shrinkage and swelling percentages were calculated by summing the tangential, radial and longitudinal shrinkage and swelling percentages (Bektas and Guler 2001). Compression strength parallel to the grain (*CS*) was determined on universal testing machine and according to the principles of ISO 3787 (1976). Thirty measurements were performed to determine the experiments belonging to each group.

Chemical analyses

The determination of the wood cell composition was carried out according to TAPPI Test Methods: Sampling and Preparing Wood for Analysis (TAPPI standard 2012), Solvent Extractives of Wood and Pulp (TAPPI standard 2007) and Acid-Insoluble Lignin in Wood and Pulp (TAPPI standard 2011). To determine the holocellulose content of the wood, Wise's Chloride method was used. In this method, pre-extracted wood particles were reacted with acidified sodium chloride (pH 4) at 70-80°C for 3-5 hours (Wise *et al*. 1946). Kürschner-Hoffner's approach, in which wood particles are directly treated with nitric acid in ethyl alcohol mixture, was used for to determine the cellulose content (Browning 1967, Fengel and Wegener 1989).

Fiber measurements

For fiber dimension determinations, the wood samples without bark were chipped by hand. As using in the industrial purposes, all parts of wood were chipped as if there was no difference between earlywood and latewood. Then, about 3-4 grams small slivers were macerated with 60 ml glacial acetic acid/hydrogen peroxide solution (v/v) in an oven at 60°C for 12 hours (Tavares *et al*. 2011). After completion of the maceration, the delignified fibers were washed by distilled water, filtrated and then placed in a small flask with distilled water. To disintegrate fiber bundles, the suspension was gently mixed by a magnetic stirrer to avoid fiber breaking and then the fiber suspension was filtrated again. Fiber suspension was consisted of largely tracheids, and less rays and epithelial cells for caucasian fir but only tracheid cells were measured. On the other hand, for oriental beech samples, fiber suspension with vessel elements, fibers, rays and longitudinal parenchyma had a more complex system than the former one but only fibers were selected and measured. Finally, three slides were prepared for each measurement and the images of the slides under a calibrated light microscope (PROJECTINA 4014 Forensic Microscope) were recorded by a semiprofessional camera (Akita DC-200C model 3.3 mega pixel digital camera). The measurements of fiber dimensions from the light microscope images were performed by the help of a digital analyze program (Digimizer).

Statistical analysis

Analysis of variance (ANOVA) for all wood properties was performed the basis of the 95% confidence interval. Significant differences among stem heights were determined by Duncan's homogeneity groups. Statistical analysis was performed using the SPSS 22.0 version.

RESULTS AND DISCUSSION

Wood density, shrinkage and swelling values

The mean and standard deviation values for each stem height, and summary of variance analysis for air dry density, compression strength, shrinkage and swelling of oriental beech and caucasian fir are given in Table 2 and Table 3.

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Table 2. Air dry density, compression strength, shrinkage and swelling values of wood specimens.

Wood Properties	Unit	Oriental beech			Caucasian fir		
		Stem height (m)					
		1,30	6,30	12,30	1,30	6,30	12,30
D_{12}	kg/m^3	730 (20)^{a*}	690 (10)^b	650 (40)^c	400 (30)^x	370 (10)^y	350 (20)^z
CS	MPa	59,26 (5,12)^a	55,34 (5,79)^b	54,06 (5,90)^b	39,82 (1,86)^x	38,55 (5,57)^x	33,02 (3,88)^y
β_t	%	11,11 (0,40)^a	10,58 (0,92)^b	10,31 (0,74)^b	8,01 (0,31)^x	7,67 (0,16)^y	6,96 (0,12)^z
β_r	%	5,49 (0,31)^a	5,13 (0,53)^b	4,68 (0,27)^c	4,00 (0,24)^x	3,75 (0,12)^y	3,37 (0,11)^z
β_l	%	0,30 (0,05)^b	0,32 (0,05)^{ab}	0,34 (0,05)^a	0,27 (0,03)^z	0,32 (0,06)^y	0,35 (0,08)^x
β_v	%	16,90 (0,65)^a	16,04 (1,32)^b	15,33 (0,87)^c	12,28 (0,59)^x	11,74 (1,03)^y	10,68 (0,51)^z
α_t	%	13,96 (0,50)^a	11,92 (0,60)^b	11,31 (0,65)^c	8,33 (0,72)^x	7,98 (0,73)^y	7,39 (0,29)^z
α_r	%	6,12 (0,74)^a	5,69 (0,47)^b	5,57 (0,34)^b	4,02 (0,36)^x	3,74 (0,33)^y	3,48 (0,22)^z
α_l	%	0,31 (0,03)^c	0,33 (0,02)^b	0,35 (0,03)^a	0,34 (0,06)^y	0,39 (0,08)^x	0,44 (0,07)^x
α_v	%	20,40 (1,05)^a	17,95 (0,79)^b	17,23 (0,71)^c	12,69 (0,88)^x	12,11 (0,85)^y	11,31 (0,35)^z

* Values in parentheses are standard deviations.

Different letters (a-c) and (x-z) within a line indicate significant differences between heights at 95% confidence level.

Table 3. Summary of variance analysis for air dry density, compression strength, shrinkage and swelling values

Wood properties	Significant level (*P*)	
	Oriental beech	Caucasian fir
D_{12}	0,000	0,000
CS	0,002	0,000
β_t	0,000	0,000
β_r	0,000	0,000
β_l	0,023	0,000
β_v	0,000	0,000
α_t	0,000	0,000
α_r	0,000	0,000
α_l	0,000	0,001
α_v	0,000	0,000

The results show that the lowest and highest air dry density for oriental beech and caucasian fir were found to be 650-730 and 350-400 kg/m^3, respectively. Wood density values of oriental beech and caucasian fir are stated to be as 690-770 kg/m^3 by Topaloglu *et al.* (2016), and 420 kg/m^3 by Usta (2004), respectively. Wood density is one of the most important physical properties of wood (Wiedenhoeft and Miller 2005), and it is related to other wood properties such as strength, stiffness and efficiency in use (Saranpää 2003). Lachenbruch and McCulloh (2014) reviewed wood density is correlated with hydraulic and mechanical performance of woody plants, and is also related to hydraulic safety in the living tree (Rosner 2013). Analyses of variance showed that there was a significant difference (P<0,05) among the stem heights, and air dry density decreased with increasing stem height for both wood species. Similar results were reported for *Pinus sylvestris*, *Betula pendula* and *Betula pubescens* by Repola (2006), for *Tectona grandis* Izekor *et al.* (2010), for *Corylus colurna* by Zeidler (2012), for *Abies alba* by Rodrigo *et al.* (2013), for *Pinus taeda* by Yu *et al.* (2014), for *Albizza julibrissin* by Kiaei and Farsi (2016), and for *Neolamarckia cadamba* by Mahmud *et al*. (2017). In contrast, Molteberg and Høibø (2006) reported an increase of basic density with vertical position in the norway spruce trees. Moreover, in a given cambial age for norway spruce, Jyske *et al.* (2008) found wood density increased with increasing tree height. Chowdhury *et al.* (2007) also observed no significant differences among heights (butt, centre, and crown) of *Casuarina equisetifolia* even though the density decreased by a small amount from butt to crown. Machado *et al.* (2014), working with 35-49 years old blackwood in Portugal, reported an increase in wood density with the height level especially from the 35% to the 65% tree height.

In the study, overall shrinkage and swelling percentage decreased from 1,30 m to 12,30 m except for longitudinal shrinkage and swelling percentage for both wood species. The highest volumetric shrinkage and swelling percentage were 16,90% and 20,40% for oriental beech, 12,28% and 12,69% for caucasian fir at 1,30 m, respectively. Contrary to this declining trend, longitudinal shrinkage and swelling percentage increased from 1,30 m to 12,30 m, reaching a maximum of 0,34% for oriental beech and 0,35% for caucasian fir. ANOVA (Duncan test, $P<0,05$) confirmed the statistically significant difference among stem heights for both wood species (Table 3). Kiaei (2011) found volumetric shrinkage and volumetric swelling of *Zelcova carpinifolia* grown in Iran decreased along longitudinal direction from the base to the top stem height. Similarly, Kord *et al.* (2010) reported that within tree longitudinal, radial, tangential, and volumetric shrinkage of *Populus euramericana* decreased along the stem from the base to the upwards. Rodrigo *et al.* (2013) reported a downward trend in volumetric shrinkage of *Abies alba* from the base to the crown. For 27 year-old *Pinus radiata* trees in New Zealand, Wang *et al.* (2008) reported that the longitudinal shrinkage decreased with the stem height, but tangential and radial shrinkage did not show a clear trend along the stem height. Moreover, Ay *et al.* (2012) found the shrinkage and swelling percentage (tangential and volumetric) of *Larix decidua* reached maximum values at 9 m in height, and then drop towards to 18 m. Also, longitudinal shrinkage and swelling percentage do not have a clear trend in vertical direction. Chowdhury *et al.* (2007) studied physical properties of 25 year-old *Casuarina equisetifolia* at three different heights (butt, centre, and crown). They found that radial and longitudinal shrinkage did not vary significantly with increasing tree height, but tangential shrinkage did vary significantly and crown wood had greater shrinkage than wood from the other two heights. Contrary to these findings, the insignificant of vertical position on shrinkage values (tangential, radial, and volumetric) of grand fir was reported by Lukašek *et al.* (2012).

Compression strength parallel to grain

Compression strength parallel to grain values of the specimens and summary of variance analysis are given in Table 2 and Table 3. The highest compression strength was found to be 59,26 MPa at 1,30 m for oriental beech, and the lowest compression strength was found to be 33,02 MPa at 12,30 m for caucasian fir, while there was no difference between the other two stem heights. This pattern showed that there was a decreased trend from at 1,30 m to 12,30 m in compression strength for both of wood species. Machado and Cruz (2005) observed a decrease from stem butt to top in compression strength of maritime pine depending on distance to the pith, emphasizing the strong influence of juvenile wood. As reported by Zobel and van Buijtenen (1989), the top logs contain mainly juvenile wood, which has low specific gravity and strength, butt logs from the same tree consist predominantly of mature wood. Also, Izekor *et al.* (2010) observed a decreasing trend from base to top in compression strength of *Tectona grandis* wood. In contrast to these findings, Kiaei (2011) found that the longitudinal direction has no effect on compression strength parallel to the grain of *Zelcova carpinifolia* grown in Iran, and Machado *et al.* (2014) reported that the compression strength of blackwood grown in Portugal did not vary with tree stem height (5%, 35% and 65% of tree height). Density is the most important physical characteristic determining the compression strength of a wood sample, and a significant correlation between density and compression strength exists (Gindl and Teischinger 2002). Moreover, there are more material distributed internal stresses in dense wood, so the mechanical properties of wood are also increasing (Baar *et al.* 2015). In the present study, a declining trend from at 1,30 m to 12,30 m in density and compression strength for both wood species can be related to above mentioned correlation.

Chemical properties

Wood chemical components (holocellulose, cellulose and lignin) are summarized in Table 4.

Table 4. Chemical properties of wood specimens

Chemical properties	Unit	Oriental beech			Caucasian fir		
		Stem height (m)					
		1,30	6,30	12,30	1,30	6,30	12,30
Holocellulose	%	75,55 $(0,02)^{b*}$	75,28 $(0,39)^{c}$	76,41 $(0,09)^{a}$	75,38 $(0,40)^{y}$	76,73 $(0,63)^{x}$	77,04 $(0,08)^{x}$
Cellulose	%	54,30 $(0,25)^{a}$	52,69 $(0,19)^{b}$	51,26 $(0,17)^{c}$	64,57 $(0,44)^{x}$	64,65 $(0,24)^{x}$	63,01 $(0,53)^{y}$
Lignin	%	20,28 $(0,07)^{c}$	20,94 $(0,16)^{b}$	21,52 $(0,21)^{a}$	28,15 $(0,14)^{z}$	28,49 $(0,09)^{y}$	29,53 $(0,19)^{x}$

[*] Values in parentheses are standard deviations.
Different letters (a-c) and (x-z) within a line indicate significant differences between heights at 95% confidence level.

Analysis of variance showed that there were significant differences (P<0,05: P<0,01) among the stem heights for both wood species (Table 6). Hemicellulose, cellulose and lignin are the constituent polymers of wood, and are responsible for most of the physical, chemical and strength properties of wood and wood products (Pandey 1999). The lowest holocellulose content of oriental beech and caucasian fir was 75,28% at 6,30 m and 75,38% at 1,30 m, respectively. While the holocellulose content of oriental beech increased from 6,30 m to 12,30 m stem height, the holocellulose content of caucasian fir increased from 1,30 m to 12,30 m stem height. Campbell *et al.* (2007) found that the holocellulose content in both varieties of lodgepole pine increased to about 20-30% stem height, they stated that this increase is possibly related to the higher percentage of hemicellulose in the juvenile wood in the top of the tree. The lignin content showed an increasing trend with increasing stem height, reached highest amounts at 12,30 m in both wood species. Campbell *et al.* (2007) observed the lignin content in both varieties of lodgepole pine increased from 0% to 20% stem height and then remained stable at higher stem heights. They stated that the increase in lignin with stem height is possibly related to higher percentage of juvenile wood in the upper stem. Moreover, Zobel and Sprague (2012) stated that juvenile wood is comprised nearest the pith at all heights in the tree and the tops of trees, regardless of tree age, have mainly juvenile wood. In contrast to the increasing trend in holocellulose and lignin content, cellulose content of oriental beech and caucasian fir decreased from 54,30% at 1,30 m to 51,26% at 12,30 m and 64,57% at 1,30 m to 63,01% at 12,30 m stem height, respectively. A decrease in the alpha-cellulose content of *latifolia*, which is the variety of lodgepole pine, was reported by Campbell *et al.* (2007). Furthermore, they concluded that the decrease in alpha-cellulose with stem height is associated with an increase in juvenile wood, an increase in hemicellulose, and a decrease in specific gravity. In the present study, the decrease in wood density and compression strength with increasing of stem height for both wood species can be related to the decrease in cellulose content with stem height. As known, cellulose is the main chemical component (Neagu *et al.* 2006), and one of the function of the cellulose is to provide the required strength in plant cells (Khalil *et al.* 2015). Moreover, Bergander and Salmén (2002) concluded that the elastic properties in the longitudinal direction of the cell wall are almost only determined by the elastic constants of cellulose.

Fiber dimensions

Fiber dimensions of oriental beech and caucasian fir are shown in Table 5. Significant differences were observed in fiber dimensions among stem heights (Table 6).

Table 5. Fiber dimensions of wood specimens.

Fiber dimensions	Unit	Oriental beech			Caucasian fir		
		Stem height (m)					
		1,30	6,30	12,30	1,30	6,30	12,30
Fiber length	mm	1,02 (0,19)[a*]	0,96 (0,15)[ab]	0,93 (0,19)[b]	2,67 (0,35)[x]	2,31 (0,58)[y]	2,47 (0,58)[xy]
Fiber width	µm	21,08 (5,64)[a]	17,10 (3,55)[b]	20,45 (3,49)[a]	33,88 (8,24)[y]	36,95 (7,40)[x]	35,92 (8,13)[x]
Fiber lumen width	µm	8,27 (2,78)[b]	7,05 (2,15)[c]	12,00 (2,73)[a]	20,47 (5,60)[z]	24,90 (6,76)[y]	27,17 (6,09)[x]
Fiber wall thickness	µm	6,40 (2,50)[a]	5,03 (1,90)[b]	4,23 (1,97)[c]	6,71 (2,19)[x]	6,03 (1,81)[y]	4,37 (1,75)[z]

[*] Values in parentheses are standard deviations.
Different letters (a-c) and (x-z) within a line indicate significant differences between heights at 95% confidence level.

Table 6. Summary of variance analysis for chemical properties and fiber dimensions.

Wood properties	Significant level (*P*)	
	Oriental beech	Caucasian fir
Holocellulose	0,000	0,000
Cellulose	0,000	0,000
Lignin	0,000	0,000
Fiber length	0,029	0,028
Fiber width	0,000	0,002
Fiber lumen width	0,000	0,000
Fiber wall thickness	0,000	0,000

As shown in Table 5, the fiber length was found to be 0,93-1,02 mm and 2,31-2,67 mm for oriental beech and caucasian fir, respectively. As known, fiber length is a valuable determinant of paper strength, and hardwood fibers are significantly shorter than softwood tracheids (Shmulsky and Jones 2011). Fiber length slightly decreased from 1,30 m to 12,30 m along with the stem height for both of wood species. The decrease of wood fiber length to the top was described for *Eucalyptus globulus* by Jorge *et al.* (2000), who found a small decrease in wood fiber length from base to top. Tavares *et al.* (2011) also found a slight decrease in fiber length of *Acacia melanoxylon*, from 0,97 mm to 0,91 mm at 5% and 65% of total tree height, respectively. Bhat *et al.* (2007) observed that there was a small increase in fiber length of *Eucalyptus grandis* from stump level to 25% of tree height level and then a decrease towards the top. The decrease in fiber length with stem height is because the tree top of an old tree consists basically of juvenile wood which has shorter fibers (Zobel and van Buijtenen 1989). In contrast to our findings, Gominho *et al.* (2015) found that fiber length of unbleached *Eucalyptus globulus* pulps increased from 827 µm at 0% to 877 µm at 50% height levels. Moreover, Molteberg and Høibø (2006) observed that fiber length of *Picea abies* increased with increasing height in the tree, and concluded to be closely related to cambium age. Adamopoulos *et al.* (2010) reported that cambium age and growth rate are principal factors affecting wood properties, mainly cell dimensions and density in both gymnosperm and angiosperm species. There is also a direct relationship between fiber morphology and paper properties (Azeez *et al.* 2016).

The fiber width initially decreased from 21,08 µm at 1,30 m to 17,10 µm at 6,30 m, and then increased to 20,45 µm at 12,30 m stem height for oriental beech. The fiber width of caucasian fir showed a general increasing trend from 33,88 µm to 35,92 µm. Gominho *et al.* (2015) found that fiber width of unbleached *Eucalyptus globulus* pulps decreased from 19 µm at 0% to 17 µm at 50% height levels. For oriental beech, the fiber lumen width first decreased from 8,27 µm at 1,30 m to 7,05 µm at 6,30 m and then strongly increased to 12,00 µm at 12,30 m. For caucasian fir, the fiber lumen width strongly increased from 20,47 µm at 1,30 m to 27,17 µm at 12,30 m. The fiber wall thickness decreased from 6,40 µm at 1,30 m to 4,23 µm at 12,30 m and from 6,71 µm at 1,30 m to 4,37 µm at 12,30 m stem height for oriental beech and caucasian fir, respectively. Molteberg and Høibø (2006) observed the fiber width of *Picea abies* decreased with increasing height in the tree, fiber wall thickness was not affected by tree height.

In present study, for both wood species the decreasing trend in density with increasing stem height could possibly be related to the decrease in fiber wall thickness. Moreover, Cato *et al.* (2006) reported that wood at the crown had a lower density due to reduced cell wall thickness at the crown of the tree. The decrease in density, compression strength, fiber length, fiber wall thickness, and the increase in longitudinal shrinkage and lignin content for both wood species indicate the presence of juvenile wood. As reported by Langum *et al.* (2009), the main factors lead to less strength, decreasing stiffness, and increasing longitudinal shrinkage are low density, short fibers, thinner cell walls, and higher microfibril angles in juvenile wood. Wood properties vary at different heights in the tree because the proportion of juvenile wood increases largely from the base to the top (Zobel and van Buijtenen 1989). Especially, the determining of the wood properties of the butt and top logs of commercial timber species is an important issue for wood users. Therefore, juvenile and mature wood need to be studied separately to better understand the changes of wood properties with the height in the tree.

CONCLUSIONS

In this study the longitudinal variation of several wood properties of oriental beech and caucasian fir stems was investigated. Wood density, compression strength, shrinkage and swelling percentage except for longitudinal shrinkage and swelling percentage decreased clearly from 1,30 m to 12,30 m stem height and the difference among stem heights was significant for both wood species. The content of lignin increased while the content of cellulose decreased along the stem height in both wood species. Significant differences were observed along the stem height in fiber dimensions of both wood species. Fiber wall thickness strongly decreased along the stem height in both wood species. An understanding of longitudinal variation in wood properties is important for forest product industries because it provides the differentiation of raw material in the production phase. This obtained information could be useful to wood users of beech used in the production of bentwood furniture, veneer, plywood, and fir used in the production of wooden panels, joinery, and plywood in forest products.

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LIST OF ABBREVIATIONS

N	North
E	East
D_{12}	Air-dry density
β_t	Tangential shrinkage percentage
β_r	Radial shrinkage percentage
β_l	Longitudinal shrinkage percentage
β_v	Volumetric shrinkage percentage
α_t	Tangential swelling percentage
α_r	Radial swelling percentage
α_l	Longitudinal swelling percentage
α_v	Volumetric swelling percentage
ISO	International Organization for Standardization
CS	Compression strength parallel to the grain
TAPPI	Technical Association of the Pulp and Paper Industry
P	Significant level