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TURKEY'S NATIVE WOOD SPECIES: PHYSICAL AND MECHANICAL CHARACTERIZATION AND SURFACE ROUGHNESS OF ROWAN (*SORBUS AUCUPARIA* L.)

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ABSTRACT

This article aims to familiarize wood expert outside Turkey eith the wood of Rowan by comparing its physical and mechanical properties with some of the world's more recognized hardwood species. The sample trees were harvested from, a mixed oak-hornbeam-rowan stand, north-western part of Turkey. Conventional destructive methods were followed on small clean specimens. Rowan wood's air dry (801 $kg.m^{-3}$), oven dry (737 $kg.m^{-3}$) and basic (635 $kg.m^{-3}$) densities were determined. Fiber saturation point was calculated to be 23.79%; volumetric shrinkage and swelling were found as 15.048% and 18.465%; MOR, MOE, compression strength parallel to grain, impact bending, tensile strength parallel and perpendicular to grain, shear strength, cleavage strength, Janka hardness values (parallel and perpendicular to grain) and surface roughness (Ra) value were determined as 115.571 $N.mm^{-2}$, 9843.857 $N.mm^{-2}$, 55.027 $N.mm^{-2}$, 14.849 $J.cm^{-2}$, 120.71 $N.mm^{-2}$, 6.187 $N.mm^{-2}$, 12.792 $N.mm^{-2}$, 0.941 $N.mm^{-2}$, 1.416 and 1.159 kN, 7.239 (μm) respectively. Four main roughness parameters, mean arithmetic deviation of profile (Ra), mean peak-to-valley height (Rz), root mean square roughness (Rq), and maximum roughness (Ry) were used to evaluate the surface characteristics of the specimens.

KEY WORDS: Sorbus aucuparia, Rowan, wood properties, density, surface roughness

INTRODUCTION

The genus Sorbus is a genus of about 100-200 species of trees and shrubs in the subfamily Maloideae of the Rose family Rosaceae. *Sorbus aucuparia* is known as rowan or mountain ash. The name "rowan" is derived from the Old Norse name for the tree, *raun* or *rogn*. Linguists believe that the Norse name is ultimately derived from a proto-Germanic word **raudnian* meaning "getting red" and which referred to the red foliage and red berries in the autumn (Price 2007).

European Rowan (*Sorbus aucuparia*),the best-known species of the genus Sorbus, is native to most of Europe except for the far south, and northern Asia. In the south of its range in the Mediterranean region it is confined to high altitudes in mountains. Rowan is very tolerant of cold and is often found at high altitude on mountains; it occurs at up to 1.000 m altitude in the UK, and up to 2.000 m in France. It is native Britain and Ireland, south and east part of Europe from Iceland to Spain, Macedonia and the Caucasus, it is also found North Africa and Asia Minor. It has received many alternative names, the most frequent one is "Mountain Ash" (Raspe et al. 2000, Yaltırık and Efe 2000). In Turkey, Rowan is found primarily in the north and northwest Anatolia as small groups in angiosperm mixed forests (Yaltırık and Efe 2000). It is a small to medium-sized deciduous tree typically growing 8 –20 m heigth (rarely 20 m and exceptionally 28 m) and can live over 100 years. It is very tolerant of a wide range of soil conditions.The bark is a smooth, silvery grey in young trees, becoming scaly pale grey-brown and occasionally fissured on old trees. (Anonymous 1996, Yaltırık and Efe 2000).

Rowan timber is extremely hard and dense and has a dark, purplish brown heartwood surrounded by a pale, yellowish brown sapwood. Rowan has a strong, flexible, close-grained, yellow-grey wood, which was once widely used for making tool handles, small carved objects, plough-pins, small parts in tools, spinning wheels and wagons, mallet heads, platters, bowls, pegs for tethering animals, cartwheels, poles, hoops for barrels, household utensils, general woodcraft, churn staves, tackle for watermills, rough basketwork, etc. If large enough it provided excellent planks and beams. It was used by the hill people to make long bows, instead of the yew and ash so often used by lowland people for this purpose. Rowan was also used for different purposes: wands, magical spears, talisman inscribed with runes and other meaningful patterns. (Sachsse et al. 1988, Rameau et al. 1989).

Literature review has shown that there is not any detailed and original previous research reporting important wood properties (i.e. mechanical properties, FSP, basic density) of this species. A strong relationship is well known with wood properties and the quality of wood.Thus, these properties are classically used to select wood for the particular applications (Haygreen and Bowyer 1996). Rowan (*Sorbus aucuparia* L.) is not widely used because its properties and potential uses are not well known.Besides it has limited natural stands in Turkey.There are many lesser-known wood species, sometimes with similar properties to those well-known species, which are less exploited and used because of a lack of knowledge regarding their properties. Thus, further research to determine their properties and possible end uses is likely to be beneficial to the forest industry. "The rowan-tree (*Sorbus aucuparia* L.) shows potential to occupy a more important position in forestry in the future - especially with respect to the re-afforestation of areas prejudiced by air pollution in uplands. In these areas the rowan-tree will not only serve as a pioneer species, but also will increasingly deliver useful trunk wood grades, therefore the technologically important wood properties for this species are of interest" (Sachsse et al. 1988).

The aim of this study was to fulfill the gap in research and to facilitate optimal utilization fields of this species. Further research to determine the properties and suitable end uses of this lesser known species is likely to be beneficial.

MATERIAL AND METHODS

The sample trees used for the present study were harvested from a mixed oak-hornbeam-rowan stand in the Kastamonu Forest Enterprises, north-western part of Turkey. The experimental area is located at an average altitude of 1250 m. The mean annual precipitation of experimental area is about 700 mm/year, the yearly average temperature is 9.6°C, and prevailing wind direction is north. Soil is sandy-clay. (All climatic data obtained from Kastamonu meteorology station located very close to experimental area)

20 by 20m^2 five plots were chosen randomly from the experimental area. Breast height diameters ($d_{1.30}$) of Rowan (*Sorbus aucuparia* L.) trees were measured for every plot, and the arithmetic mean values were calculated. The arithmetic mean tree was felled as sample tree. To avoid errors during sampling, extreme cases were taken into account such as excessively knotty trees and the presence of reaction wood or slope grain (ISO 4471, 1982). Tab. 1 shows the properties of sample trees.

Tab. 1: Properties of sample trees

Tree no	Age of tree	Diameter of tree $d_{1.30}$ (cm)	Height of tree (m)	Green branch (m)	Dead branch (m)	Altitude (m)	Slope (%)	Direction
1	140	30	25.4	12.2	4.5	1250	63	N
2	164	35	26.5	14.3	2.8	1250	65	N
3	125	26	23.6	10.2	3.9	1250	53	N
4	118	25	21.7	11.8	4.3	1250	58	N
5	164	35	25.7	12.9	5.6	1250	64	N

Determination of Density, Sorption, FSP and MMC

Five different sampling heights (0.30, 1.30, 3.30, 5.30, and 7.30m) were chosen through the stems and one disk 10 cm in thickness was removed at each height. From each disk, a sample of 3 cm width from bark to bark was cut. This sample was then cut into a strip 2 cm thick. Air-dry and oven dry densities (D_{m12}, D_{m0}) (ISO 3131, 1975), shrinking [(tangential, radial, longitudinal, volumetric) (β (t,r,l,v))] (ISO 4469, 1981) and swelling [(tangential, radial, longitudinal, volumetric) (α (t,r,l,v))] (ISO 4859, 1982) of the wood were determined according to Turkish Standards using wood specimens of 2x2x3 cm (along the grain).

Fiber saturation point (FSP) was calculated by the following equation (Bozkurt and Göker 1987).

$$FSP = \beta v / D_b \ (\%) \quad (1)$$

Where βv is the volumetric shrinkage (%) and D_b is the density value in volume ($g.cm^{-3}$).

Maximum moisture content (MMC) was calculated by the following equation:

$$M_{max} = (1.5 - D_b) / (1.5x \ D_b) \ (\%) \quad (2)$$

D_b is the density value (D_b) in volume (wood basic density). The basic density was determined by the gravimetric method (Haygreen and Bowyer 1996).

$$D_b = M_0/Vg \quad (3)$$

Where D is the basic density of wood ($g.cm^{-3}$), Vg is the green volume of the specimen (cm^3), and M_0 is the dry-matter weight of the specimen (g). Percentage of the cell wall and porosity were calculated by the following equations (Bozkurt and Göker 1987).

$$Vc = Do/Dc \times 100 \quad (4)$$
$$V_H = 100 - Vc$$

Where Vc is percentage of the cell wall (%), Do is oven dry density ($g.cm^{-3}$), Dc is oven dry density of the cell wall (1.5 $g.cm^{-3}$) and V_H is percentage of the porosity.

Measurement of strength Properties

Sections of 1.5m were cut from the 2-4 m height of trees to obtain samples for strength properties. Boards which are 8 cm in thickness sawn and sawdust immediately removed from surfaces then boards stored in an unheated room for air drying (ISO 3129, 1975).

Following the air-drying process, small and clear specimens were cut from the boards according (ISO) to determine compression strength parallel to grain ($\sigma c//$) (ISO 3787, 1976), bending strength (MOR) (ISO 3133, 1975), modulus of elasticity in bending (MOE) (ISO 3349, 1975), Janka-hardness [(parallel, perpendicular to grain) (Hj(//,⊥))] (ISO 3350, 1975), impact bending strength (σi) (ISO 3348, 1975), tension strength parallel ($\sigma t_{//}$) and perpendicular to grain ($\sigma t\perp$) (ISO 3345, 3346; 1975), shear strength (τ_{aB}) (ISO 3347, 1976) and cleavage strength (σs) (ASTM D 143, 1994). The specimens were then conditioned at 20±2°C with 65% relative humidity according to ISO 554. After acclimatization, mechanical properties of the Rowan wood were determined.

At the end of experiments, moisture contents (M) of specimens were measured according to ISO 3130 (1975) and the moisture content of specimen in which moisture content deviated from 12% determined. Strength values were corrected (transformed to 12% moisture content) using the following strength conversion equation:

$$\delta_{12} = \delta_m * [\, 1 + \alpha\, (M_2 - 12)\,] \quad (5)$$

Where δ_{12} = strength at 12 percent moisture content ($N.mm^{-2}$), δ_m = strength at moisture content deviated from 12 percent ($N.mm^{-2}$), α = constant value showing relationship between strength and moisture content (α=0.05, 0.04, 0.02, 0.025, 0.015, 0.04 and 0.025 for $\sigma c//$, MOR, MOE, σi, σt and Hj respectively) M_2= moisture content during test (%).

To better understand completely the quality of the species, quality values which are calculated based upon a relationship between strength and density should be determined. Static, specific and dynamic quality values (I, I_s, I_d) were calculated by the equations below:

$$I = \delta_{B\,12} / D_{12} \times 100$$
$$I_s = \delta_{B12} / (D_{12})^2 \times 100 \quad (6)$$
$$I_d = a / (D_{12})^2$$

$\delta_{B\,12}$ is the compression strength parallel to grain in 12% moisture content ($N.mm^{-2}$) and D_{12} is the air-dry (12%) density ($g.cm^{-3}$), a: impact work (work arising by impact bending) (Bozkurt and Göker 1987).

Measurement of Surface Roughness

Surface roughness of the samples was measured on hardness test samples. Samples were finished by a fixed-knife planer with a feed speed of 1 m.s^{-1}. The bias angle of the knife was 45° for the sample. If the wood pieces are sawn so that the annual rings are at least in 45° angle to the surface the deformations will be smaller, the hardness of the surface will be stronger and the "general looks" after heat treatment is better.

Surface roughness of the samples was measured by using a profilometer (Mitutoyo Surftest SJ-301). The surface roughness of the samples was measured with the profile method using a stylus device standard. The measuring speed, pin diameter, and pin top angle of the tool were 10 mm.min^{-1}, 4 µm, and 90°, respectively. The points of roughness measurement were randomly marked on the surface of the samples. Measurements were made in the direction perpendicular to the fiber of the samples.

Three roughness parameters, mean arithmetic deviation of profile (Ra), mean peak-to-valley height (Rz), and maximum roughness (Ry) were commonly used in previous studies to evaluate surface characteristics of wood and wood composites including veneer (Stombo 1963). Ra is the average distance from the profile to the mean line over the length of assessment. Rq is the square root of the arithmetic mean of the squares of profile deviations from the mean line. Rz can be calculated from the peak-to-valley values of five equal lengths within the profile while maximum roughness (Ry) is the distance between peak and valley points of the profile which can be used as an indicator of the maximum defect height within the assessed profile (Mummery 1993). Therefore, such parameters which are characterized by (ISO 4287, 1997) and (DIN 4768, 1990) were recorded.

Specification of this parameter is described by Hiziroglu (1996) and Hiziroglu and Graham (1998). Roughness values were measured with a sensitivity of 0.5 µm. The length of scanning line (Lt) was 15 mm and the cutoff was λ= 2.5 mm. The measuring force of the scanning arm on the surfaces was 4 mN (0.4 g), which did not put any significant damage on the surface according to Mitutoyo Surftest SJ-301 user manual. Measurements were performed at room temperature and the pin was calibrated before the tests.

RESULTS AND DISCUSSION

Descriptive statistics were given for air-dry, oven-dry and basic density values (Tab. 2) and for shrinkage, swelling, fiber saturation point and maximum moisture content of Rowan wood (Tab. 3).

Tab. 2: Descriptive statistics for basic, air-dry and oven-dry density values (kg.m^{-3})

Property	Arithmetic mean (x)	Standard deviation (SD)	Variance (V)	Coefficient of variation (CV)	Minimum value (Min.)	Maximum value (Max.)	Sample size (N)
D_{m12}	801	0.071	0.005	8.868	578	961	100
D_{m0}	737	0.059	0.003	7.957	550	828	100
D_b	635	0.054	0.003	8.487	496	798	100

Tab. 3: Shrinkage, swelling, FSP and MMC of Sorbus aucuparia L.

Properties		x	SD	V	CV	Min.	Max.	N
β	βt	8.351	0.982	0.965	11.76	6.09	11.46	100
	βr	6.211	0.767	0.588	12.34	4.176	7.917	100
	βl	0.377	0.094	0.009	24.8	0.220	0.716	100
	βv	15.048	1.523	2.320	10.121	11.318	19.327	100
α	αt	11.400	1.957	3.831	17.17	7.16	15.03	100
	αr	6.474	1.274	1.623	19.68	3.673	12.070	100
	αl	0.553	0.141	0.020	25.47	0.272	0.902	100
	αv	18.465	2.638	6.957	14.285	11.724	23.083	100
FSP		23.79	2.616	6.845	11	17.96	29.63	100
MMC		91.834	13.509	182.49	14.71	58.674	134.99	100

The cell wall percentage and porosity were calculated as 42.47%, and 57.53%, respectively.

Descriptive statistics for the strength, hardness and quality factors of Rowan wood were given in Tab. 4 and for surface roughness values in Tab. 5.

The surface roughness values (Ra, Ry, Rz, Rq) of Turkish Hazel (*Corylus colurna* L.) was found as 10.398 µm, 86.176 µm, 66.380 µm and 13.226 µm respectively. Rowan (*Sorbus aucuparia* L.) had lower surface roughness values compared to Turkish Hazel (*Corylus colurna* L.) (Sevim Korkut et al. 2008).

Various factors can affect surface roughness such as annual ring width, differences between juvenile and mature wood, density, differences between early and late wood and cell structures. Increase in smoothness or decrease in roughness is very important for many applications of solid wood. In addition, losses occurring in the planning machine are reduced and high quality surfaces are attained. Also, the wooden materials with rough surface requires much more sanding process compared to one with smooth surface, which leads to decrease in thickness of material and, therefore, increase the losses due to the sanding process (Dündar et al. 2008, Sevim Korkut et al. 2008).

The wood of Rowan grown in the middle Black Sea district is hard, very tough and heavy, similar to the wood of European Hophornbeam (*Ostrya carpinifolia*), making it difficult to work with. This is as expected from the remarkably high Janka hardness value, however this is preferable for use as flooring raw material.

The disparate size of different wood cells in the hardwoods results in heterogeneous compressive deformation. During compression, large vessels cause smaller surrounding cells to be deformed more than in regions without vessels, increasing the energy absorbed. However, vessels that are too close together initiate kink banding at low loads and less energy is absorbed. The different morphologies of hardwoods are probably responsible for the variation in resistance between species (Hepworth et al. 2002). As a reference basis, the results were also compared to published values for some other species of which have similar anatomical properties in the same or other families (Tab. 6).

Tab. 4: Strength (N.mm^{-2} , J.cm^{-2}), Janka hardness (kN), static, specific and dynamic quality values of Sorbus aucuparia L.

Property:		x	SD	V	CV	Min.	Max.	N
MOR		115.571	14.802	219.101	12.807	67.946	152.095	100
MOE		9843.857	1659.307	2753300.3	16.856	6492.839	14471.45	100
$\sigma c_{//}$		55.027	6.972	48.607	12.67	39.175	86.928	100
$\sigma t_{//}$		120.71	32.380	1048.500	26.824	58.707	200.93	100
$\sigma t_{\perp}$		6.187	1.169	1.366	18.89	3.779	8.875	100
σi		14.849	3.603	12.981	24.263	9.050	22.197	100
τ_{aB}		12.792	0.782	0.612	6.117	10.008	14.244	100
σs		0.941	0.174	0.030	18.46	0.574	1.378	100
Hj	Crossection	2.593	0.340	0.115	13.10	1.568	3.300	100
	Tangential	1.416	0.149	0.022	10.50	1.093	1.847	100
	Radial	1.159	0.136	0.019	11.77	0.875	1.527	100
I		6.916	1.160	1.345	16.77	4.74	11.47	100
I_s		8.807	2.176	4.735	24.71	5.587	16.480	100
I_d		1.916	0.548	0.301	28.62	1.005	2.966	100

Tab. 5: Surface Roughness (μm) values of Sorbus aucuparia L.

Property:	x	SD	V	CV	Min.	Max.	N
Ra	7.239	0.966	0.932	13.34	4.21	10.26	100
Ry	93.787	19.480	379.480	20.770	30.04	143	100
Rz	60.635	13.285	176.5	21.91	26.46	86.97	100
Rq	9.828	1.769	3.128	18	5.3	15.73	100

The variations of wood properties in the same species arise from different factors, such as genetics, growth conditions and ecological factors. In particular, altitude, soil and climate are the most influential ecological factors. In addition tree age, sample size, ring properties (e.g. ring width, ring orientation), and the test procedure also affect test results (Haygreen and Bowyer 1996). As most of these factors (except test procedure) were different in the reference

Tab. 6: Comparison of physical and mechanical properties of Sorbus aucuparia L. with other tree species

Species	Properties															Ref.
	D_{m0} (g.cm^{-3})	D_b (g.cm^{-3})	β_v (%)	α_v (%)	FSP (%)	MOR (N.mm^{-2})	MOE (N.mm^{-2})	σc// (N.mm^{-2})	σt⊥ (N.mm^{-2})	$\sigma t_{//}$ (N.mm^{-2})	σi (J.cm^{-2})	τ_{aB} (N.mm^{-2})	σs (N.mm^{-2})	Hardness (kN)		
														//	⊥	
S. aucuparia	0.737	0.635	15.048	18.465	23.79	115.571	9843.857	55.027	6.187	120.71	14.849	12.792	0.941	1.416	1.159	
S. aucuparia	0.570					84.220		40.473		97.671	6.415					(Sachsse et al., 1988)
O.carpinifolia	0.854	0.671	23.02	24.9	34.21	131.5	11501.06	66.94	7.11	105.5	18.66	24.505	1.132	6.89	5.63	(Korkut&Guller,2008)
Carpinus betulus	0.790		18.8			160	15260-16200	48.3-82		135	8-12			4.80	4.04	(Bozkurt&Erdin,1997; Goker et al.,1999; Aydin &Yardimci, 2007)
Ostrya ssp.	0.760	0.630	18.6		29.52*	91.7	7929	58.61			24.62	12.342	1.00			(Alden, 1995)
Liquidambar orientalis Mill.	0.680	0.468	16.12			78	6234.8	38.27					0.7			(Bozkurt et al., 1990)
Alnus glutinosa	0.454	0.399	12.62	13.78	32.87	77.53	8611.81	41.48		76.3	5.7			2.83**	1.47**	(Guller&Ay,2001; Korkut&Guller,2008)
Fagus orientalis	0.645	0.538	16.21	17.84	30.13	83.3***-110	12829.3	61.7***	7.14	131.6	9.5	9.9	0.74	6.9	4.99	(Bektas et al., 2001,2002)
Robinia pseudoacacia L.	0.720		11.7			136	11270	73		136		13	0.62			(Goker&As, 1995)
Nothofagus menziesii	445-650					79-124	13000***	33-63								(Olson, 2003)
Betula pendula	0.610		13.7			144	16180	51							2.2-4.9	(Bozkurt&Erdin,1998)
Betula lutea		0.55	16.8		30.55*	114.5	13858.5	56.33	6.34		14				5.6	(Anonymus,1987; Haygreen&Bowyer,1996)
Quercus dschorochensis K. Koch.	0.681		17.37			128		57		112		10	0.117			(Berkel&Göker, 1974; Goker et al.,1999; Aydin &Yardimci, 2007)
Ceratonia siliqua L.	0.810		12.4			122	11458.35	67					1.207	1.077		(Göker et al., 1999)

*: Calculated value, **: Brinell hardness,***:Mean value for different regions (Some reference values from different unit system converted to same unit system)

(Sachsse et al. 1988), it is difficult to explain the different density findings for the same species. However, additionally tree age difference, sample preparation could be one of effective factors. Sachsse et al. found wood density separately for hearth wood and sap wood and calculated mean density on equal sample size but, we did not separate sample as hearth wood, sap wood or together considering the material usage in practice. Our hearth wood ratio might be higher than the other study.Wood density is accepted as a good indicator of mechanical properties (Anon. 1987). The existence of a strong relationship between wood density and strength has been demonstrated by several investigators (Kollmann and Côte 1968, Pernestal et al. 1995, Hernandez 2007). Since *Sorbus aucuparia* grown in Turkey has highest density value among all of the species (Tab. 6) higher strength values were normally expected. But, although the density values of beech (*Fagus* ssp.) and birch (*Betula* ssp.) are lower than *Rowan*, they have closer or higher strength values (Tab. 6). Differences of mechanical properties should be explained by both density and presence of extractives (Hernandez 2007). Therefore, extractive contents and chemical composition of Rowan should be investigated.

Hardwoods can be classified as low (I_s<6), fair (6<I_s<7) and good (7<I_s) quality according to their static quality value (I_s). Limit values for the classification change depend on density and hardness of species. In this case, values given in the parenthesis suitable for *Sorbus aucuparia* as density and hardness. According to this classification, *Sorbus aucuparia* has a good quality wood. Furthermore, dense hardwoods, such as *Sorbus*, can be classified as low, fair and good quality according to the value of dynamic quality (Id) also. Id <1 is low quality, 1< Id <2 is fair quality and 2<Id is good quality wood. According to this classification, it can be said that the Rowan has a fair impact quality (Kollmann and Côte 1968).

The higher the density of the wood, the more it will tend to shrink (Haygreen and Bowyer 1996). When comparing the shrinkage and swelling of *Sorbus aucuparia* to other species (Tab. 5) higher values were accepted normal as a result of high density.

CONCLUSION

The General characteristics of *Sorbus*, summarized from literature, and information on swelling and shrinkage, quality and strength properties of *Sorbus aucuparia* obtained from this study, together with other reported data (i.e.Sachsse 1988), provide a basis for more efficient utilization of these species.

Consequently *Sorbus aucuparia* wood is suitable raw material for walking sticks, turnery, carving, firewood, bow, tool handles, novelties, levers, mallet heads, bawl, platter, splitting wedges, canes, carpentry, wooden wares, and especially flooring material. But, it is well known that growing stock of a species is a restrictive factor to determine the preference of forest product industry. Due to a low growing stock of this species in Turkey, it is not possible to excessively use it especially in the flooring industry for the present. However, forest enterprise should give more attention to *Sorbus aucuparia* wood which has the potential to be a valuable wood source in specific plantations.

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