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THE SUITABILITY OF RADIATA PINE WOOD FOR PAPERMAKING

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Abstract:
The aim of this research is to determine morphological properties of fibers of Radiata pine wood exotically grown in Turkey and suitability of these properties for pulping. The test trees were collected from Kaynarca (Adapazarı-Turkey) growing region. The fiber lengths, fiber diameters, lumen diameters and cell wall thicknesses of Radiata pine fibers were measured. Using these data, felting power, flexibility coefficient, Rigidity coefficient, Runkel index, Muhlstep classification and F ratio from morphological properties of wood fibers were calculated and the effects of these values on several properties of paper were investigated. These values were compared with the values belonging to other places. According to the results, it can be deduced that radiata pine is suitable raw material for papermaking.

Key words: *fiber morphology; morphological ratios; Radiata pine.*

INTRODUCTION

Fundamental tracheid morphological characteristics such as wall thickness, length and diameter are important factors in determining pulp fiber quality and paper performance (Schimleck and Evans 2004). Radiata pine is the dominant forest plantation species for the sawmill industry in Australia, New Zealand, Chile and several other countries. Breeding programs in radiata pine have been conducted in Australia since the early 1950s (Wu *et al*. 2007).

The natural range of radiata pine is mainly through the southern hemisphere. The species is cultivated on a commercial scale in New Zealand, Australia, Chile, South Africa, Spain, France, Argentina, Greece, and India, and a variety of radiata pine is also reported to be grown in Guadeloupe Island and Mexico. The tree prefers to grow on slopes, in coarse soils, usually sandy loams, and is often found in pure stands or with Monterey cypress, Gowen cypress, and Coast live oak (Entrican *et al.* 1951). The wood of radiata pine is remarkably versatile and is used for both structural- and appearance-grade wood products and pulp (Kininmonth and Whitehouse 1991). Also, the wood chemistry of radiata pine can vary greatly from tree to tree depending on genetic makeup, age, and growing environment (Kibblewhite *et al*. 2002). On the other hand, knowledge of the factors that influence wood and fiber characteristics is vital for improving the quality of timber (Sarén *et al.* 2004).

Entrican (1929), Roller et al. (1997) and Benjamin (1923) determined that radiata pine is quite suitable for papermaking through various processes. Göksel (1983) also showed that radiata pine exotically grown in Bandırma (Turkey) is suitable for papermaking using sulphate method. Even though Pinus radiata is not used extensively in pulp production in the northern hemisphere, it is indeed widely used in kraft pulp production in the southern hemisphere. It is still the main raw material for softwood market pulp in Chile, Brazil, Australia, and New Zealand (Giacomozzi and Joutsimo 2015).

In short, the growth of radiata pine has huge importance for Turkey since its first plantation in Turkey during 1960s. Therefore, using of radiata pine in the Turkish pulp and paper industry as a raw material should be understood more clearly. Thus, this study was aimed to determine the morphological properties of radiata pine and consequently to contribute for the pulp industry of Turkey by increasing available information about this tree, and to compare these morphological properties with those of radiata pines in other continents.

MATERIAL AND METHOD

Determination of test area and trees

The radiata pine (*Pinus radiata* D.Don.) trees were selected from the district of Kaynarca (Adapazarı) where the pine is one of the best growing regions in Turkey. The test area was determined in this district by following Turkish standard (TS) 4176/1984. According to this standard, firstly, at least 3 different test sites are determined from the research stand at 20×20m dimensions. Then, the average breast height diameters of the trees in these areas were measured. At the end, sufficient numbers of equal trees to each test site were selected from the trees corresponding to the average diameter.

The characterizations of the site and test trees were shown in Table 1. Also, soil in depths of 40-60cm, where the pine species is grown, is a clay-loam type soil and it is consisted of 2.6 % $CaCO_3$, 36% silt, 47% clay, 17% sand.

Table 1

General characteristics of the selected test trees and the test region

Tree age at the breast height (year)	Mean diameter at the breast height (cm)	MH[a] (m)	Exposure	Altitude (m)	Slope (%)	MAR[b] (mm)	MAT[c] (°C)
20	23	16	south	40	10	794.4	24

[a]Mean height of trees, [b]Mean annual rainfall, [c]Mean annual temperature.

Early, the four trial areas (20x20m^2) in this region were determined. Later, fourteen trees were selected from the site. They had breast height diameters in the range of 16 - 31cm and they were cut from distances of ± 0, 0.5, 1 and 1.5 cm standard deviations of mean diameters as two trees for each test area.

Preparation of microscopic sections

Firstly, 1m long end matched log sections were prepared by cutting at heights of between 2.3-4.30m from the base for the each tree. The cross sections of 1m - long green logs were cut into 2cm - thick lumbers from their North and South directions. Specimens to be evaluated in this study were prepared from these lumbers (1×1×2cm).

Since the microscopic sections are easily obtained, these specimens were boiled in water untill they sank into water and then, they were kept in mixture of ethyl alcohol (50%)+ Glycerol (50%) for 3-5min. Microscopic sections were obtained among 10-30μ - thickness in the directions of cross, radial and tangential to measure the morphological properties of radiata pine. These sections were stained with safranin for distinguishing the contrast between cell walls and lumens, and the lignin's color was also converted to red.

Finally, microscopic sections were cleaned by 50-, 70- and 99% alcohol three times for 3-5min to extract the water into sections. These also were treated with alcohol (60%)+Xylene (40%), alcohol (40%)+Xylene (60%), alcohol (20%)+ Xylene (80%), and Xylene (100%) for 5 minutes to extract alcohol from specimens. Then, sections were placed on microscope slide, and the Canadian balsam was dropped on them.

Anatomical characterization of the fibers Maceration

The material was macerated using the Franklin method (Normand 1972). The wood chips were cut with a scalpel and placed in test tubes in a solution of 1:1 acetic acid and oxygenated water of 30 volumes. The samples were dried in a stove at oven for approximately 1 week. The disaggregated particles were washed in water, stained with aqueous safranin at 1% for 3min, dehydrated with alcohol at 96% and xylol. Subsequently, the fibers were dried, placed on slides and fixed with Canada balsam.

Determination of the morphological properties

The morphologic properties were measured with the microscope. The fiber diameters, lumen diameters and cell wall thicknesses of both early wood and late wood were measured in radial and tangential directions on the cross-sections of specimens. To measure fiber lengths of specimens (0.5mm thickness and 2cm long in parallel to grain), Jeffrey's method was applied (Richard 1986). In this method, specimens were immersed into Jeffrey's solution until they were defibered and later, fiber lengths were measured with the Reichert microscope after they were washed with distilled water.

Determination of important criteria in papermaking

Important criteria in papermaking can be determined using following six equations (Tank 1980, Kırcı 2000, Eroğlu and Usta 1987):

$$Felting\ power: Fiber\ length \div Fiber\ diameter \quad (1)$$

$$Elasticity\ coefficient\ (\%): Lumen\ diameter \div Fiber\ diameter \times 100 \quad (2)$$

$$Rigidity\ coefficient\ (\%): Cell\ wall\ thickness \div Fiber\ diameter \times 100 \quad (3)$$

$$Runkel\ index: Cell\ wall\ thickness \times 2 \div Lumen\ Diameter \quad (4)$$

$$Muhlstep\ classification\ (\%): Cell\ wall\ field \div Fiber\ field\ in\ cross-section \times 100 \quad (5)$$

$$F\ ratio\ (\%): Fiber\ length\ \div Cell\ wall\ thickness\ \times 100 \qquad (6)$$

In these calculations, average values obtained from measurements in radial and tangential directions were used.

RESULTS AND DISCUSSION

The results of fiber lengths, fiber diameters, lumen diameter and cell wall thickness measurements were shown in Table 2. These values were used to calculate the felting power, elasticity coefficient, rigidity coefficient, Runkel index, Muhlstep classification and F ratio of radiata pine.

Table 2

The results of statistical analysis for morphological properties of radiata pine

Properties	Number of sample	Mean	Standard deviation	Coefficient of variation	Range
Fiber length (mm)	1000	2.57	1.4256	55.47	2.32
Fiber diameter (μm)	200	31.69	3.6658	11.57	26.11
Lumen diameter (μm)	200	19.18	2.2948	11.96	22.4
Cell wall thickness (μm)	200	6.24	2.0912	33.51	8.92

In Table 3, the some values of fiber dimensions were compared with those of radiata pine and some conifers.

Table 3

The some calculated values of Turkish radiata pine and the some other conifers

Tree species	FP[a]	EC[b](%)	RC[c](%)	RI[d]	MC[e](%)	F[f](%)
Pinus radiata (This study)	81.00	60.52	19.69	0.66	63.36	411.85
Pinus radiata(Giacomozzi and Joutsimo 2015)	63.61	74.99	12.51	0.35	63.36	508.72
Pinus brutia (Bektaş 1997)	110.00	62.31	18.15	0.58	61.20	606.70
Pinus nigra (Bektaş 1997)	86.10	60.00	20.00	0.67	63.99	430.52
Pinus silvestris (Tank 1980)	92.00	83.15	8.42	0.20	30.84	-
Abies nordmanniana (Tank 1980)	96.98	72.36	13.82	0.38	47.63	701.81
Picea orientalis (Erdin 1985)	104.40	66.70	16.70	0.54	73.25	312.32
Cedrus libani (Erdin 1985)	90.74	78.50	11.29	0.58	39.42	410.34

[a]Felting power, [b]Elasticity coefficient (75%>EC (I. Group): The most suitable in papermaking; 75%>EC%>50% (II. Group): Suitable in papermaking; 50%>EC%>30% (III. Group): a little suitable in papermaking; EC%<30% (IV. Group): Unsuitable in papermaking (Tank 1980, Das *et al*. 1999), [c]Rigidity coefficient, [d]Runkel index, [e]Muhlstep classification, [f]*F* ratio.

The criteria which were determined to be suitable in papermaking and calculated based-upon relationships between morphologic properties of wood fibers were explained as follows:

Felting power (FP)

In woods, one of the main criteria determined to be suitable in papermaking is felting power formulated in equation (1). This value positively affects durability, breaking, tearing, burst and double folding strengths of paper, and it is required to be over 70 for conifers. Probably, an important characteristic of fibers is their fiber length because it contributes to paper strength (Eroğlu and Usta 1987).

Average felting power of radiata pine is found to be 81 as shown in Table 3. Radiata pine has lower felting power (81.0) than other trees when felting power of radiata pine is compared with the other trees in the same table. This value, however, is higher than 63.61 determined to radiata pine by Göksel (1983). Despite this low values of radiata pine, the average felting power value (72.31) of radiata pine is higher than felting value of 70 required in the standard above and is suitable in papermaking. On the other hand, this is not the only values used to determine the suitability of a fiber for papermaking for a tree. This result was confirmed for especially conifers by Tank (1980).

Elasticity coefficient (EC)

Elasticity coefficient (EC) is one of the principal criteria for determination of woods suitability in papermaking and is classified into four groups, which is shown in Table 3, and it is formulated in equation (2).

The EC (60.52%) of radiata pine places it in group 2^{nd} in Table 3. Another research found that EC of radiata pine is 74.9% (Göksel 1983) and this is higher than 60.52%. However, both of EC values are suitable in papermaking.

The elasticity coefficients of other trees are listed in Table 3 and these are in the same range with the EC of radiata pine. Especially, elasticity coefficient (66.70%) of eastern spruce the main conifer used for papermaking in Turkey is similar to the average EC (66.76%) of radiata pine. As a result, radiata pine can be used in papermaking according to elasticity coefficients.

Rigidity coefficient (RC)

A rigidity coefficient given in equation (3) depends on the physical and chemical properties of the fiber wall material as a measure of fiber conformability (Jang and Seth 1998). The physical properties of paper decrease with increasing rigidity coefficient (RC). Increase of this coefficient also negatively affects the breaking, tear, burst and double folding strengths of paper.

The RC of radiata pine is 19.69% and it also was calculated 12.51% for the same specie grown in Bergama (Turkey) region by Göksel (1983). In Table 3, the average of these values is 16.10% which is similar to other species such as, eastern spruce (16.70%). It can be said that radiata pine is much suitable in papermaking according to rigidity coefficient, when compared with other tree species in the Table 3. It has also stated that radiata pine is suitable for printing and pressing papers. Depending on the desired paper properties, furnishes can be optimized by blending according to the pulps' rigidity coefficient and keeping the proportion with a low coefficient as high as practicable and a high resistance reflects a relatively high fiber wall thickness, and thus generally poorer pulp strength properties (Law *et al*. 1999).

Runkel index (RI)

The Runkel index (RI) equals double fiber wall thickness divided by the diameter of the lumen (Eq. 4). RI can be used to determine the suitability of fiber cell wall in papermaking. It refers to the cells having thicker walls which are reported unsuitable for papermaking. When RI is 1, indicating cell with medium wall thickness, that are acceptable for papermaking. However, the most suitable fiber in papermaking is fibers having RI ratio lower than 1. The tearing, burst and breaking strengths of paper is positively affected (Eroğlu and Usta 1987).

Although Göksel (1983) previously reported the Runkel index of radiata pine as 0.35, it was found to be 0.66 as shown in Table 3. Nevertheless, the both figures are lower than 1, indicating thin walled cells which are suitable for papermaking. In addition, RI value (0.66) of radiata pine is higher than that of the other trees in Table 3, excluding that of crimean pine (0.67). However, the average RI (0.51) of radiata pine is suitable for papermaking.

Muhlstep classification

The Muhlsteph ratio equals the cross-sectional area of the fiber wall material divided by the fiber's total cross-sectional area (Eq. 5). It is used for characterizing wood density, with high values considered as less desirable for papermaking (Eroğlu and Usta 1987).

Muhlstep classification has shown the effect of cell wall thickness on the physical properties of paper. It also except to be quite low in papermaking. Because, fibers having thin walls can be easily pressed in papermaking, hence positively affect both density and strength properties of resultant paper as reported by other researches (Tank 1980).

Muhlstep classification of radiata pine was found to be 63.36%, which was similar to the finding of Göksel (1983) (64.39%) in 1983. Both figures are noted to be higher than that of other trees seen in Table 3, especially the value (73.25%) of eastern spruce was higher than that of others. It was shown that fibers of radiata pine are less suitable for paper production. Nevertheless, Scotch pine has the most suitable value for papermaking in Table 3 because of thin cell wall and lower value of Muhlstep classification (30.84%).

F ratio

The high value of F ratio formulated in equation (6) shows that the suitability of fibers for papermaking which will have quite elastic structure (Kırcı 2000, Ekhuemelo and Udo 2016). And the fiber flexibility is also a pulp property that plays an important role in the manufacture of paper (Rusu *et al.* 2011).

The F of radiata pine is 411.85% that is higher than those of eastern spruce (312.32%) and Lebanon cedar (410.34%) and lower than those of other species given in Table 4. It can be said that radiata pine is generally suitable for production of paper in F ratios (411.85% and 508.72%) are shown in Table 3.

At the same time, the findings of this study were compared with those of other studies in order to assess fully. So, some important criteria for the papermaking of Turkish radiata pine were compared with the calculated values of the continentals as shown in Table 4.

Table 4

Comparison of the important criteria for papermaking of Turkish radiata with those of the continents(*)

Tree species	Felting power	Elasticity coefficient (%)	Rigidity coefficient (%)	Runkel index	F ratio (%)
Pinus radiata (Turkey)	81.00	60.52	19.69	0.66	412
Pinus radiata (Asia)	61.88	82.18	8.91	0.22	694
Pinus radiata (Europe)	82.50	-	17.50	-	471
Pinus radiata (America)	-	78.35	10.31	0.26	-
Pinus radiata (Oceania)	123.46	185.89	19.11	0.21	646
Pinus radiata (Africa)	69.23	-	10.77	-	643

(*)The literatures used to calculate the values in this table: (Kibblewhite and Hamilton 1984, Salvo *et al*. 2004, Louppe *et al*. 2008, Komulainen 2012, Fakhrian 2014).

When Table 4 is examined, it can be seen that the highest radiate pine values are obtained from measurements of the Oceania continental. This is closely related to the ratio of fiber length to fiber diameters (FL/FD). The FL/FD values of Turkey, Asia, Europe, America, Oceania and Africa's radiate pine are 82, 83, 62, 75, 123 and 69, respectively. In here, it can be said that, due to the ages of the test trees, the ecological and climatic factors and the soil texture, the values calculated for the radiata pine differ from each other. When the limit values discussed above of the criteria shown in Table 4 are taken into consideration, it appears that the values of *Pinus radiata* located in the table met all of the mentioned limits.

Relationships between the fiber structure of wood and the physical properties of paper

It is well know that there is a strong relationship between the strengths of paper and morphologic structures of wood (Bektaş *et al*. 1999). The relationships between the physical properties of papers and fibers of woods were compared in Table 5.

Table 5

Relationships between the morphological properties of fiber cells and the physical properties of paper

Relationships (Dadswell and Watson 1961)	Burst strength	Tearing strength	Double folding strength	Paper density
with increasing the fiber length	+	++	+	–
with increasing the cell wall thickness	–	+	– –	– –
with decreasing the cell wall thickness	+	–	++	++
with increasing the fiber length / fiber diameter			+	
with increasing the spiral grain	– –	+	+	–

+Porousite air permeability, the capacity of water holding and volumness are opposite ratio with density; +it had been determined that it has a positive effect; ++There is certainly positive effect; –it had been determined that it has a negative effect; – –There is certainly negative effect.

It was understood that the increasing fiber length and decreasing cell wall thickness has considerable effect on the physical properties of paper presented in Table 5. It also can be seen in Table 5 that the burst, tearing and double folding strengths of paper increase with increasing fiber length, and also tearing strength increase with increasing cell wall thickness. On the other hand, the burst and double folding strengths have increased with decreasing cell wall thickness.

CONCLUSIONS

In this study suitability of the fiber dimensions of *Pinus radiata* were investigated as raw materials for papermaking and fiber dimensions of *Pinus radiata* were compared with some other species.

As a result, it has been clearly understood that the morphological texture of radiata pine exotically grown in Turkey is quite suitable for papermaking. Newsprint made from radiata pine possesses excellent printing properties which, rather than strength, are the most important criteria. In addition, radiata pine pulps make their full contribution to the burst and folding strengths of a paper. The papers required to have a high tearing strength can be produced by blending the pulp of radiata pine with other pulp having longer fibers listed in Table 5.

Thereby, radiata pine is one of the most important species in the world, especially for paper industries in New Zealand, Australia, Chile, and South Africa, Spain, France, Argentina, Greece, India, Guadeloupe Island and Mexico. It can be also inevitable raw material for paper industry in Turkey.

The paper industry of Turkey has needed the long-fiber raw material for papermaking from softwoods. Because fiber length correlates with strength increment, softwood pulps produced from long-fibers are generally stronger than hardwood pulps, thus, the plantation of radiata pine should be resumed again in order to supply for supplying long-fiber raw material for a high strength paper production in Turkey.

REFERENCES

Bektaş İ (1997) The physical and mechanical properties of calabrian pine (*Pinus brutia* Ten.) and their variations according to regions. PhD Thesis, Istanbul University, Turkey.

Bektaş İ, Tutuş A, Eroğlu H (1999) A study of the suitability of *Pinus brutia* Ten. for pulp and paper manufacture. Turk J of Agric and For 23(3):589-599.

Benjamin LR (1923) The Manufacture of pulp and paper from Australian woods. Melbourne Inst Sci and Ind Bull 25 pp. 92.

Dadswell H, Watson AJ (1961) Influence of the morphology of wood pulp fibers on paper properties. Tec Section of the British Paper and Board Makers Association, London.

Das S, Cresson T, Couture R (1999) New pulp characterization from drainage, fiber flexibility & RBA. Proceeding of 85th Annual Meeting Jan 1 PAPTAC, Montreal (CA), pp. A345-A347.

Ekhuemelo DO, Udo AM (2016) Investigation of variations in the fibre characteristics of *Moringa oleifera* (Lam) stem for pulp and paper production. International Journal of Science and Technology 5(1):19-25.

Entrican A (1929) Paper Pulp from New Zealand-grown woods. NZJ of S&T Vol XI, New Zealand.

Entrican A, Ward WC, Reid JS (1951) The physical and mechanical properties of the principal indigenous woods of New Zealand. New Zealand Forest Service, Wellington (NZ).

Erdin N (1985) Studies on the anatomical structure and density of Lebanon cedar (*Cedrus Libani* A.Ric.). M. T. Press House Istanbul, Turkey.

Eroğlu H, Usta M (1987) Researches on evaluation of woods of S*alix alba* L. in paper industry. TUBITAK-Press Ankara, Turkey.

Fakhrian A (2014) Investigation the properties of radiata pine wood kraft pulp and paper. Iranian journal of wood and paper science research 4(45):678-690.

Giacomozzi DE, Joutsimo O (2015) Drying temperature and hornification of industrial never-dried *Pinus radiata* pulps. 1. Strength, Optical, and water wolding properties. BioResources 10(3):5791-5808.

Göksel E (1983) The tests on obtaining of sulphite cellulose from woods of fast growing pine trees species. The J of Ul Fac of For 33(2):22-32.

Jang HF, Seth RS (1998) Characterization of the collapse behaviour of papermaking fibers using confocal microscopy. TAPPI J 81(5):167-172.

Kırcı H (2000) Textbook of pulping industry. KTU University Press Trabzon, Turkey.

Kibblewhite RP, Evans R, Riddell MJC (2002) Sampling criteria and interrelationships involving tree age and wood and pulp-fibre properties in 50 individual *Radiata Pine* trees [online]. Proc 56th Appita Annual Conference, Rotorua (New Zealand), pp. 25-36.

Kibblewhite RP, Hamilton KA (1984) Fibre cross-section dimensions of undried and dried *Radiata pine* kraft pulps. NZ J of Forst Sci 14(3):319-330.

Kininmonth JA, Whitehouse LJ (1991) Properties and uses of radiata pine: Wood properties (Vol. 1). New Zealand Ministry of Forestry, Forest Research Institute, Rotorua (NZ).

Komulainen P (2012) Fiber and Pulp Characteristics for Papermaking: Basics of wood, pulp and paper. Online at: http://www.slideshare.net/Peeke/fiber-and-pulp-characteristics-for-papermaking-51877512

Law KN, Lanouette R, Valade JL (1999) Influence of mixtures of hardwood species on CTMP. Proc of 85th Annual Meeting PAPTAC, Montreal (CA), pp. B29-B36.

Louppe D, Oteng-Amoako AA, Brink M (Editors) (2008) Plant Resources of Tropical Africa 7(I). Timbers I. Backhuys Publishers. Wageningen (NL).

Normand D (1972) Manuel d'identification des bois commerciaux (Commercial Wood Manual Identification). Centre Technique Forestier Tropical Vol 1, Nogent-sur-Marne (FR).

Richard SD (1986) Fiber length measurement systems: A review and modification of an existing method. J Wood & Fiber Sci 18(2):276-287.

Rusu M, Mörseburg K, Gregersen Ø, Yamakawa A, Liukkonen S (2011) Relation between fiber flexibility and cross sectional properties. BioResources 6:641-655.

Salvo L, Ananías R, Cloutier A (2004) Influencia de la estructura anatómica en la permeabilidad especifica transversal al gas del *Pinus radiata* (Influence of the anatomical structure in the transverse specific gas permeability of radiata pine). Maderas Ciencia y tecno 6(1):33-44.

Sarén MP, Serimaa R, Andersson S, Saranpaa P, Keckes J, Fratzl P (2004) Effect of growth rate on mean microfibril angle and cross-sectional shape of tracheids of Norway spruce. Trees - Structure and Function 18(3):354-362.

Schimleck LR, Evans R (2004) Estimation of *Pinus radiata* D. Don tracheid morphological characteristics by near infrared spectroscopy. Holzforschung 58:66-73.

Tank T (1980) Cellulose and fiber technology. Istanbul University Press, İstanbul (Turkey).

Wu HX, Eldridge KG, Matheson AC, Powell MP, McRae TA, Butcher TB, Johnson IG (2007) Achievement in forest tree improvement in Australia and New Zealand. VIII. Successful introduction and breeding of *Radiata pine* to Australia. Australian Forestry 70:215-225.