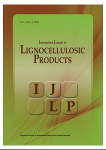

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Variability in wood properties of promising willow clones

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Abstract

The objective of the article is to investigate the variability in growth and wood properties of the willow clones. The growth and wood traits of four year old 21 clones willow clones were investigated. Analysis of variance showed that willow clones differed significantly for all the studied growth and wood traits. Among the growth parameters the maximum heritability value was shown by height which was 0.92 (92%) and minimum of 0.59 (59%) was recorded for wood and bark percentage. The mean value of specific gravity is 0.76 (Heritability 0.69) and mean value of fiber length is 1.41 mm and value of heritability factor is 0.77. The value of heritability factor is high for alcohol-benzene extractive content (heritability value= 0.73). Wide range of variability was seen for all the physico-chemical characteristics of wood of promising willow clones. The values for phenotypic and genotypic coefficients of variability, heritability, genetic advance and genetic gain ranged between 2.51-35.63, 2.09-30.49, 24-92, 0.03-31.20 and 3.95-53.73%, respectively.

***Keywords*:** Chemical composition, Heritability, Physical properties, Variability, Willow clones.

1. Introduction

The genus *Salix*, encompass around 400 species (Mabberley, 1997) of deciduous trees and shrubs, found primarily on moist soils in cold and temperate regions of the Northern Hemisphere. The remarkable characteristics that promote the cultivation of this species are their adaptation to thrive in flooding environments, easy vegetative propagation and fast growth. It also offers great opportunities both for wood and biomass production and for environmental protection. Willows are used for firewood, poles, wicker products, and wood for utensils. Although willow cultivation has never reached industrial size, it is reasonable to believe that it is quantitatively large and economically profitable throughout Europe. In other parts of the world, the cultivation is even more widespread. In the Parana Delta in Argentina the world's largest Willow plantations cover more than 50000 ha (Paiero, 2007).

During the last three decades, oil crisis, agricultural surpluses and global climate change enhanced the interest in short-rotation forestry (SRF). The study on the biomass production of birch (*Betula pendula* Reth), maple (*Acer pseudoplatanus* L.), poplar (*Populus trichocarpa* x *deltoides*-Hoogverst) and willow (*Salix viminalis*) growing under short-rotation (SR) management systems were compared after a 4 years period. Survival rates after 4 years were 75.8%, 95.8%, 86.3% and 97.6%, for birch, maple, poplar and willow, respectively. The mean actual biomass production for these four species amounted to 2.6, 1.2, 3.5 and 3.4 tDM ha^{-1} yr^{-1}, respectively. The growth of poplar and willow, birch can be considered as a very interesting alternative for the establishment of Short rotation plantations (Vande Walle et al., 2007).

The genus salix having potential to grow as short rotation coppice tree crop and the plantation of fast growing clones can supplement the increasing demand of lignocelluloses material. The development of willow as short rotation coppice was started in Sweden, and a number of plantations were established, on both good and poor soils. However, many of these plantations failed because of using low yielding varieties, poor weed control, frost damages and lack of fertilizer application. In spite of this, willow is still the most important arable crop for bioenergy production, planted in approximately 16000 hectares (Larsson, 2004).

The wood of willow is soft, light and tough. The willow sawn timber is suitable for joinery, decorative, common furniture, pulp and paper, fibre board, particle board and packaging. The anatomical features, physical characteristics and mechanical properties of willow wood allow its use for sports goods, carved wood and tool handles (Leclercq, 1997).

Improvement work in willows is now being directed towards the introduction and development of wide range of species and clones of diverse genetic origin. In order to assess adaptation or to have desirable attributes, an intensive nursery evaluation of initially screened clones has been undertaken. Increasing the range of genetic material available for intra and inter specific hybridization at this stage is considered to be the best method of producing improved willows. Further, these clones are transplanted for on field performance testing for growth and wood characteristics. Various workers have reported that the genetic makeup can influence the physical and chemical properties of wood (DeBell et al., 1998;

Peszlen, 1998; Matyas and Peszlen, 1997). The aim of present study is to determine the variability of chemical composition, moisture content, wood specific gravity and fibre length in promising willow clones.

2. Materials and Methods

The present investigation was carried out on the experimental plantation of willow clones. The experimental site lies in the mid hill zone of Himachal Pradesh with an elevation of 1250 m above mean sea level. It is located at 30° 51′ N latitude and 76° 11′ E longitude. The best performing 21 clones from worldwide distribution areas were collected from National Bureau of Plant Genetic Resources, New Delhi and planted in the campus area of Dr. YS Parmar University of Horticulture & Forestry in the year 2006. The physico-chemical characteristics of these clones were investigated in the year 2010. Three trees were selected from each clone and with the help of chisel two wood samples (1x3x3 cm) were taken at breast height. In total wood samples were taken from 63 trees. The details of clones are presented in Table 1.

Table 1. Details of clonal material.

Sr. No.	Clone name	Species/hybrid	Source country (Plant material procured)	Origin/Developed
1.	Kashmiri willow	*Salix alba* cv Coerulea	UK	UK
2.	NZ-1002	*S. matsudana x S. alba*	New Zealand	USA
3.	NZ-1140	*S. matsudana x S. alba*	UK	UK
4.	NZ-1179	*S. matsudana x S. Alba*	UK	UK
5.	NZ-1184	*S. matsudana x S. Alba*	New Zealand	New Zealand
6.	J-795	*S. matsudana x S. alba*	UK	China
7.	J-799	*S. matsudana x S. alba*	UK	China
8.	084/03	*S. alba*	Turkey	Turkey
9.	131/25	*S. babylonica x S. alba*	UK	Argentina
10.	212/03	*S.matsudana x S. caprea*	UK	China
11.	V-99	*S. caprea x S. rubens*	Croatia	Croatia
12.	V-311	*S. matsudana*	Croatia	Croatia
13.	U-11841	*S. alba*	Finland	Finland
14.	PN-227	*S. matsudana*	New Zealand	New Zealand
15.	PN-721	*S. matsudana x S. Alba*	New Zealand	New Zealand
16.	PN-733	*S. nigra*	New Zealand	USA
17.	MB-368	*S. alba*	Croatia	Croatia
18.	SI-63-007	*S. alba*	Italy	S. Italy
19.	SEI 63-016	*S. jessoensis*	Italy	Japan
20.	SI-64-17	*S. alba*	Italy	S. Italy
21.	J-172	*S. babylonica x S. alba x S. matsudana*	UK	China

The chemical composition of wood: water-soluble extractives, alcohol benzene extractives, Klason -lignin content and holocellulose content were determined by employing the TAPPI standard methods T207cm-99, T204cm-97, T222om-11 and T249cn-00 respectively (Anonymous, 2007). The fibre length was determined by macerating the savings of wood in Jeffery's fluid (10% chromic acid and 10% nitric acid) for 48 hours (Pandey et al., 1968) after which the samples were thoroughly washed, stained with safranine and teased on 10% glycerin. The measurements were made with the help of ocular micrometer, standardized with the help of stage micrometer. Specific gravity was determined by maximum moisture content method (Smith, 1954). Five centimeter long samples of wood were taken at the base of each section. The green weight of the samples was recorded at maximum moisture level. The samples were then oven dried at 102 ± 1 °C until a constant weight was attained. The specific gravity was calculated as per the formulae given below:

$$\text{Specific gravity} = \frac{1}{\frac{Mm - Mo}{Mo} + \frac{1}{GS}} \quad (1)$$

where, Mm is fresh/green weight of the sample having maximum moisture, Mo is oven dried constant weight of the sample and GS is average density of wood substance a constant, having value 1.53.

The statistical analysis for each character was carried out as mean values, coefficient of variation, (ANOVA) as described by Panse and Sukhatme (1978) and Chandel (1984). The design used was Randomized Block Design. Broad sense heritability was calculated as per Burton and DeVane (1953) and Johnson et al. (1955).

$$H = (Vg/Vp) \times 100 \quad (2)$$

where, H is heritability (broad sense), Vp is phenotypic variance and Vg is Genotypic variance.

Phenotypic and genotypic coefficients of variability were worked out by the formula suggested by Burton and DeVane (1953).

$$PCV (\%) = \sqrt{(Vp/\bar{x}} \times 100 \quad (3)$$
$$GCV (\%) = \sqrt{(Vg/\bar{x}} \times 100 \quad (4)$$

where, PCV is phenotypic coefficient of variation, GCV is genotypic coefficient of variation and $\bar{X}$ is population mean of the characters.

The expected genetic advance at five percent selection intensity was calculated by the formula suggested by Lush (1940) and further used by Burton and DeVane (1953) and Johnson *et al.* (1955).

$$\text{Genetic advance} = (Vg/Vp) \times \sqrt{Vp} \times K \quad (5)$$

where, Vg is genotypic variance, Vp is phenotypic variance, K is selected differential at 5% selection intensity. The value of K is 2.06 (Allard, 1960).

3. Results and Discussion

The moisture content of the wood samples has shown significant variation among promising willow clones (Table 2). The moisture content ranged from 58.83 to 110.49 per cent. El-Baha et al. (2002) obtained maximum moisture content of 119.32% *Leucaena leucocephala* and Nicholls et al. (2003) reported maximum moisture content of 149.7% in *Tsuga heterophylla.*

Table 2. Mean, range and coefficient of variation (CV) of physical properties of wood of four year old willow clones.

Property	Mean (All values)	Range	CV	F value
Moisture content (%)	80.90	58.83-110.49	17.12	20.62
Specific gravity (g/cm^3)	0.76	0.74-0.81	2.47	7.698
Fiber length (mm)	1.41	0.96-1.93	24.18	5.588

The analysis of variance shows significant differences among the clones for specific gravity and fibre length (Table 2). The mean value of wood specific gravity is 0.76. The specific gravity show narrow range of variability (min 0.74, max 0.81, CV 2.47). This study is congruous with the study carried out by Monteoliva et al. (2005), who reported significant difference in the specific gravity among different willow clones and wood density variations between 0.36 g/cm^3 and 0.455 g/cm^3.

This variation is due to varied accumulation of phenols and other extractives. The variation in specific gravity of wood has been reported by Wittman et al. (2006) in *Hevea spruceana* and *Tabebuia barbata*, Verma et al. (2001) in hybrids of *Eucalyptus citriodora* and *E. torelliana,* Dhillon and Sidhu (2007) in Poplars, Kumar et al. (2005) in *Dalbergia sissoo.*

The mean value of fiber length is 1.14 mm. Fiber length varies significantly among willow clones (minimum 0.96 mm, maximum 1.93 mm and coefficient of variation 24.18). The analysis of variance show significant difference among the clones. Monteoliva et al. (2005) reported that fiber length varies between 873.1 µm and 1142.1 µm among clones. Various workers reported fiber length of 0.99 mm

(Goyal et al., 1999) and 0.886 mm (Alvarez and Tjeerdsma, 1995) in poplar wood. Yuezhong et al. (2004) and El-Baha (2002) also observed significant variations in the fibre length of poplar varieties and *Leucaena leucocephala respectively.* The fiber length determine whether the quality of raw material is suitable for specific use in paper industry and it also has impact on paper characteristics such as strength , optical property and surface quality. For pulp and paper production species with higher fiber length are preferred since a better net is achieved, resulting in higher resistance of the paper.

The chemical composition of analysed clones is presented in Table 3. The table shows mean values, range of cold water, hot water, alcohol- benzene soluble extractives, lignin and holocellulose content, determined for individual clone. The major constituents of wood tissue in wood samples of willow clones show relatively high variation of alcohol benzene extractive (min 2.73%, max 7.10%, CV 35.94%) followed by cold water (min 3.33%, max 7.67%, CV 27.89%), hot water extractives (min 5.33%, max 11.33%, CV 28.79%), lignin content (min 19.10%, max 26.33%, CV 13.14%) and holocellulose content (min 64.27%, max 79.33%, CV 8.16%). It is significant to note that the results of analysis of chemical composition differ significantly interclonaly. This variation is due to the varied level of accumulation of extractives in different promising willow clones studied.

Table 3. Mean, range and coefficient of variation (CV) of chemical composition of wood of four year old willow clones.

Chemical composition (%)	Mean (All values)	Range	CV	F value
Cold water extractives	5.58	3.33- 7.67	27.89	2.199
Hot water extractives	7.72	5.33- 11.33	28.79	3.43
Alcohol-benzene extractives	4.02	2.73- 7.10	35.94	8.554
Lignin	22.52	19.10- 26.33	13.14	3.431
Holocellulose	72.52	64.27- 79.33	8.16	2.782

The mean value of cold water and hot water soluble extractive content for all the clones are 5.58% and 7.72% respectively. Alcohol-benzene solubility of wood is an important character representing extractives present in wood which affect the pulping quality. The mean value of alcohol-benzene soluble extractives for all the clones is 4.02% (min 2.73%, max 7.10%). In earlier research of willow clones, the mean value of alcohol benzene extractive contents ranged between 2.1-4.0% (Mistui et al. 2010). The variation in chemical composition of willow (*Salix viminalis*) and Virginia mallow (*Sida hermaphrodita*) have been reported by Stolarski et al. (2006). The similar variation is also reported by Morais et al. (2005) in *Pinus oocarpa*. Regarding lignin content, it can be concluded that the assessed mean value of all the clones (22.52%) ranges within the limit of this species, considering that this is a young unextracted wood (four year). The values of lignin content ranged from 19.10 to 26.33% among different clones. Szczukowski et al. (2002) reported the average value of 13.79% lignin content in willow wood and Mitsui et al. (2010) stated that lignin content ranged from 27.0–32.3% in willow clones. The lignin content varies among species, individual and within plant (Bleam and Harkin, 1975). The possible reason for variation in cell wall constituents can be assigned to the varied production of dry matter.

The holocellulose content is ideal for fiber manufacture and pulp yield. The mean value of holocellulose content is 72.52%. The holocellulose content varies from 64.27-79.30 per cent among the clones. Szczukowski et al. (2002) reported 73.96% holocellulose content in stems of salix species cut every three years. Mitsui et al. (2010) found that holocellulose content ranged from 78.9 to 81.2% in willow clones. Szczukowski et al. (2008) has reported variation in lignin and Holocellulose contents of *Salix viminalis* and its cross with *S. purpurea*. Kumar (2000) while working on *Dalbergia sissoo* and Bleam and Harkin (1975) in *Eucalyptus* hybrid also reported the similar findings.

The genetic parameters for a particular trait are important tool to predict the amount of gain expected from genetic material (Foster and Shaw, 1988, Kumar, 2007). The estimate of genetic parameters such as variance (Both genotypic and phenotypic), broad sense heritability, genetic gain and genetic advance for wood characteristics are presented in Table 4. Heritability values express the proportion of variation in clones which is attributed by the genetic differences among the clones. The broad sense heritability of moisture content, specific gravity and fibre length was 0.87, 0.69, and 0.74, which indicate that these traits are least influenced by the environment and are is under strong genetic control. These findings are in conformity with those reported by Kumar (2007), Hunde et al. (2007), Bo-xin et al. (2006), Zhang-qi (2006) and Missio et al. (2004). However, in contrast the heritability of tree height and diameter tended increase with tree age in *Pinus radiata* (Wu et al., 2007) and in *Quercus acutissina* (Toda et al., 1994). The specific gravity is heritable and the differences between clones are due to the genetic makeup of the clones (Sahri et al., 2001). Moteoliva et al. (2005) reported that estimate of h^2 =0.65 was obtained for wood basic density in willow clones. In other studies Peszlen (1998) found a heritability of 0.51 for wood basic density in poplar clones. Sykes et al. (2006) have also reported that fiber length is genetically controlled and is not under influence of environmental fluctuation. The environment in combination with genetic variability also plays an important role in the alteration of fiber length as has shown by Hunde et al. (2007). Yanchuk (1984) suggested that the effect of clones is 60% of phenotypic variation of fibre length and its value can be influenced to a significant extent.

Regarding chemical composition of wood the heritability ranged from 0.24 (Cold water extractives) to 0.73 (alcohol–benzene extractives). The high value of heritability for alcohol-benzene extractive content, indicating that alcohol –benzene extractive content of salix wood is under high genetic control. The genetic advance indicates the average improvement in offsprings over the parents. In the present study genetic advance was higher for moisture content (31.20%) and lowest for specific gravity (0.031). The genetic gain was higher for alcohol-benzene benzene extractive contents (53.73%) followed by moisture content (38.51%) and fibre length (31.20). The phenotypic (35.63%) and genotypic (30.49%) coefficients of variability showed highest values for alcohol- benzene extractives, whereas the lowest values were observed in specific gravity, respectively.

Table 4. Estimates of heritability, genetic advance, genetic gain and variability for wood traits of four year old willow clones.

Property	Heritability	Genetic advance	Genetic Gain (%)	Variability (%)	
				PCV	GCV
Moisture content (%)	0.87	31.20	38.57	21.47	20.05
Specific gravity (g/cm^3)	0.69	0.03	3.95	2.51	2.09
Fibre length (mm)	0.74	0.45	31.91	20.56	17.73
Cold water extractives (%)	0.24	0.77	13.80	27.48	13.55
Hot water extractives (%)	0.46	2.13	27.59	29.19	19.78
Alcohol-benzene xtractives(%)	0.73	2.16	53.73	35.63	30.49
Lignin content (%)	0.45	2.76	12.26	13.33	8.90
Holocellulose content (%)	0.38	4.64	6.43	8.24	5.07

PCV: Phenotypic coefficient of variation,
GCV: Genotypic coefficient of variation.

4. Conclusions

This article presents the study results of chemical and physical wood properties of 4 years old willow clones. The aim of the study was to study the variability in wood properties among different willow clones. The analysis of physical wood properties and chemical composition of wood (moisture content, specific gravity, fibre length, cold water, hot water, alcohol-benzene extractives, lignin and holocellulose content) show significant difference among clones and high value of heritability for alcohol benzene extractives.

Due to considerable amount of variability in wood characteristics, willow is likely to be grown for a specified end use. From the results obtained by analysis of variance for wood specific gravity and fibre length, it can be concluded that these characteristics are under considerable genetic control. In view of the multipurpose role of willow, the possibility of increasing cultivation area to provide raw material for paper industry require a deep knowledge of genetics. Since the willow is an economically viable and productive species, it is necessary to extend the research to definition of the dependence of physical and chemical characteristics with indicator of plant growth and development. This is also important in order to be able to affect the holocellulose content, specific gravity and fibre length which significantly enhance diverse utilization of this species. The value of heritability factor is high for alcohol benzene extractive contents (0.73).

References

Allard R.W. 1960. Principles of Plant Breeding. John Wiley and Sons, Inc., New York.

Alvarez R.S., Tjeerdsma B.F. 1995. Organosolv pulping of poplar wood from short rotation intensive culture plantations. Wood Fib. Sci. 27(4): 395-401

Anonymous, 2007. Tappi Test methods. Tappi press, Atlanta, USA.

Bleam R.D., Harkin, M.J. 1975. Lignin of hardwood growing on Southern Pine Sites. Wood Sci. 8: 122-129.

Bo-xin, H., Lin-feng, Ge-fei, Y., Xin-hua, Zh., Shen-mian, T. 2006. Result on geographical provenance trial at young *Fokienia hodginsii* stand in Hunan. Forest. Res., 19: 21-26.

Burton, G.W., DeVane, E.W. 1953. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. Agro. J., 4: 78-81.

Chandel, S.R.S. 1984. A Handbook of Agricultural Statistics. Achal Prakashan Mandi, Kanpur, 565p.

DeBell, J.D., Gartner, B.L., DeBell, D.S. 1998. Fibre length in young hybrid *Populus* stems grown at extremely different rates. Can. J. For. Res. 28: 603-608.

Dhillon, G.P.S., Sidhu, D.S., 2007. Genetic variation in wood specific gravity in Poplar (*Populus deltoides* Bartr.) from two locations in Punjab. Ind. J. Forest., 30: 5-7.

El-Baha, A.M. 2002. Biomass yield, chemical analysis, specific gravity and fiber length *Leucaena leucocephala* of trees planted in sandy soil at different ages and spacing. Alex. J. Agri. Res. 47: 215-222.

Foster, G.S., Shaw, D.V. 1988. Using clonal replicates to explore genetic variation in perennial plant species. Theor. Appl. Genet., 76: 788-794.

Goyal, G.C., Fisher, J.J., Krohn, M.J., Packood, R.E., Olson, J.R. 1999. Variability in pulping and fiber characteristics of hybrid poplar trees due to their genetic zakeup, environmental factors, and tree age. TAPPI 82: 144-147.

Hunde, T., Gizachew, B., Harwood Ch. 2007. Genetic variation in survival and growth of *Eucalyptus globulus* Ssp. *globulus* in Ethiopia. Aust. Forest. 70: 48-52.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955. Estimate of genetic and environmental variability in soybean. Agron. J., 47: 314-318.

Kumar, A. 2007. Growth performance and variability in different clones of Gmelina arborea (ROXB.). Silv. Genet., 56: 32-36

Kumar, R. 2000. Evaluation of candidate plus trees of *Dalbergia sissoo* Roxb. for physic-chemical characteristic of wood. M.Sc. Thesis, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), 64p.

Kumar, R., Sharma, K.R., Gupta, L.M. 2005. Variation in physico-chemical characteristics of wood of candidate plus trees of Shisham (*Dalbergia sissoo* Roxb.). Ind. Forest., 131: 1012-1023.

Larsson, S. 2004. Salix. Sveriges Utsadesforenings Tidskrift. 114: 129-132.

Leclercq, A. 1997. Wood quality of white willow. Biotechnol. Agron. Soc. Environ. 1: 59-64.

Lush, J.L. 1940. Intera-site correlation and segregation of offspring on corn as a method of estimating heritability characters. In: Proc. American Society of Animal Product. 33: 292-301.

Mabberley, D.J. 1997. The Plant Book. Cambridge University Press #2: Cambridge.

Matyes, C., Peszlem, I. 1997. Effect of age on selected wood quality traits on popular clones. Silva. Gen. 46 (2, 3): 64-72.

Missio, R.F., dos Santos Dias L.A.n., de Moraes M.L.T., de Resende, M.D.V. 2004. Selection of *Pinus caribaea* var. *bahamensis* progenies based on the predicted genetic value. Crop Breed. Appl. Biotech. 4: 399-407.

Mitsui Y., Seto, S., Nishio, M., Minato, K., Ishizawa, K., Satoh, S. 2010. Willow clones with high biomass yield in short rotation coppice in the southern region of Tohoku district (Japan). Biom. Bioenerg., 34: 467-473.

Monteoliva, S., Senisterra, G., Marquina, J.L., Marlats, R.M., Ciocchini G.R. 2005. Clones de sauce, longitud de fibras en su madera. Rev. FCA UNCuyo, Tomo XXXIV. 2: 49–56.

Morais S.r.A.n.L.d., Nascimento E.A.d., Melo D.r.C.d. 2005. Chemical analysis of *Pinus oocarpa* wood part I-quantification of macromolecular components and volatile extractives. Revista Arvore. 29: 461-470.

Nicholls, D.L., Brackley, A.M. and Allen, T. 2003. Moisture distributions in western hemlock lumber from trees harvested near Sitka, Alaska. Research Note Pacific Northwest Research Station, USDA Forest Service, (PNW-RN-530): 8.

Paiero, P. 2007. Willows in forestry, agriculture and environmental protection. Annali Accademia Italiana di Scienze Forestali. 56: 1-100.

Pandey, S.C., Puri, G.S., Singh, J.Sh. 1968. Research methods in plant ecology. Asia Pub. House, Bombay, New York.

Panse, V.G., Sukhatme P.V. 1978. Statistical Methods for Agricultural Workers, ICAR, New Delhi.

Peszlen, I. 1998. Variation in specific gravity and mechanical properties of poplar clones. Drevarsky Vyskum. 43: 1-17.

Sahri, M.H., Nor Rahmat, A.J., Siti Rafedah, A.K., Kadir, R. 2001. Growth and wood quality of four plantation dipterocarp species from Malaysia. Proceedings of 6th Round Table Conference on Dipterocarps, Bangalore, February 8-12, 1999: 199-210.

Smith, D.M. 1954. Maximum moisture content for determining specific gravity of small wood sample. Forest Products Laboratory. USDA. Forest Service Rep, FPL-2014ocr, 10p.

Stolarski, M., Wroblewska, H., Szczukowski, S., Tworkowski, J., Kwiatkowski, J., Cichy, W. 2006. Biomass of willow and Virginia mallow as a potential stock material for industry. Fragm. Agron., 29: 277-289.

Sykes R., Li B., Isik F., Kadla J., Chang H.-M. 2006. Genetic variation and genotype by environment interactions of juvenile wood chemical properties in *Pinus taeda* L. Ann. For. Sci. 63: 897-904.

Szczukowski, S., Pradzynski W., Waliszewska B. and Wojech R. 2008. Chemical composition and heat of combustion of new varieties of *Salix* genus. Ann. Warsaw Univ. Life Sci, Forestry and Wood Technology (66): 101-106.

Szczukowski, S., Tworkowski, J., Klasa, A., Stolarski, M. 2002. Productivity and chemical composition of wood tissues of short rotation willow coppice cultivated on arable land. Rostlinna Vyroba 48: 413-417.

Toda, T., Nighimura K., Tajima M. 1994. Genetic variation of tree height, DBH, bark thickness and number of fissures of the characters among 12 families in the test plantation of *Quercus acutissina*. Bulletin of the National Forest Tree Breeding Center, 12: 1-26.

Vande Walle, I., Van Camp, N., Van de Casteele, L., Verheyen, K., Lemeur, R. 2007. Short-rotation forestry of birch, maple, poplar and willow in Flanders (Belgium) I-Biomass production after 4 years of tree growth. Biom. Energy., 31: 267-275.

Verma, S.K., Sharma V.K., Bagchi S.K. 2001. Variation in specific gravity of wood in segregating F2 and F3 populations of *E. citriodora* Hook. x *E. torelliana* F.V. Muell. hybrids. Ind. For. 127(4): 450-456

Wittmann, F., Schongart, J., Parolin, P., Worbes, M., Piedade M.T.F., Junk W.J. 2006. Wood specific gravity of trees in Amazonian white water forests in relation to flooding. IAWA J., 27: 255-266.

Wu, H.X., Powell, M.B., Yang, J.L., Ivkovic, M., McRae, T.A. 2007. Efficiency of early selection for rotation-aged wood quality traits in radiata pine. Ann. For. Sci. 64: 1-9.

Yanchuk, A.D., Dancik, B.P., Micko, M.M. 1984. Variation and heritability of wood density and fibre length of trembling aspen in Alberts Canada. Silv. Genet., 33: 11-16.

Yuezhong J., Guiyan, W., Leichang, L., Suping, Y., Ling, M. 2004. Studies on pulp-oriented cultivation techniques of poplar wood. Scientia Silvae Sinicae, 40: 123-130.

Zhang-qi, Y. 2006. Selection of superior families in seed orchards of Masson pine. J. Fujian College of Forest., 26: 45-48.