

STUDIES ON PHYSICO-CHEMICAL CHARACTERISTICS OF WOOD OF PROMISING WILLOW CLONES

Thesis

by

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*Submitted in partial fulfilment of the requirements
for the degree of*

**MASTER OF SCIENCE
in
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(FOREST PRODUCTS)**



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Willow Clones

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CERTIFICATE-I

This is to certify that the thesis entitled, “**Studies on physico-chemical characteristics of wood of promising willow clones**”, submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE in FORESTRY (FOREST PRODUCTS)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) is a record of bonafide research work carried out by **Mr. Aloyce M. Kilemwa (F-2008-11-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation has been fully acknowledged.

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This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, “**Studies on physico-chemical characteristics of wood of promising willow clones**”, submitted to Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) by **Mr. Aloyce M. Kilemwa (F-2008-11-M)**, in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE in FORESTRY (FOREST PRODUCTS)**.

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ABBREVIATIONS USED

AGB	=	aboveground biomass
d.o.b	=	diameter over bark
d.u.b.	=	diameter over bark
d.b.h.	=	diameter at breast height
C	=	carbon
cm	=	centimeter
C.V.	=	coefficient of variance
°C	=	degree Celsius
Dr.	=	Doctor
etc.	=	etcetera
g	=	gram
g/cm ³	=	gram per cubic centimeter
ha	=	hectare
H.P.	=	Himachal Pradesh
in.	=	inch
m, m ³	=	meter, cubic meter
ml	=	milliliter
mm	=	millimeter
pp.	=	pages
%	=	percent
RBD	=	random block design
S.D.	=	standard deviation
SG	=	specific gravity
v	=	volume

Chapter-1

INTRODUCTION

The issue of potential wood supply is becoming increasingly important in the light of rapidly growing demand for wood in the world. To meet both the increasing needs of the wood-processing industry as well as the needs of the bioenergy sector and policy targets for bioenergy consumption more woody biomass needs to be mobilized on a sustainable basis. Data about potential wood supply and its availability in the world is however scarce or imprecise. According to FAO (2005), there were 140 million hectares of forest plantations globally, of which 78 percent were for productive purposes. According to the Global Planted Forest Thematic Study (Del Lungo *et. al.* 2006), the global planted forest area was estimated at 271 million hectares, of which 76 percent was for productive purpose.

In 1995 it was estimated that 124 million hectares of forest plantations (3.5 per cent of forest area) yielded more than 22 per cent of industrial roundwood production and by 2010, between 31 and 34 per cent, by 2020 up to 46 per cent, and by 2050 up to 64 per cent, depending upon the forest plantation production scenario and extrapolation of industrial roundwood consumption. In 2005 the global industrial roundwood produced was 1.8 billion m³ (FAO, 2005) with some variations between estimates. The wood for industrial use available from planted forests in 2005, calculated as the sum of pulp/fiber and wood products, was 1.2 billion m³.

The variety of uses to which wood products are put indicates how, and to what extent, wood is a basic material for larger, better housed, more literate populations with rising incomes. A high cost supply of wood would mean not only more expensive housing, but often a shift to other materials, which would have to be imported. In some uses, such as

printing and writing, there is little alternative material. It is also important to recognize the uses for which the wood produced from fast-growing plantations would be suitable. However, the variety of fast-growing species available can provide material well suited to the full range of pulp products required and for the manufacture of fibreboard and particle board - the fastest growing wood products.

The United Nations' Food and Agricultural Organization (FAO) World Symposium on 'Man-Made Forests and Their Industrial Importance', Canberra, Australia, 1967 established a global recognition of the potential importance of planted forests. Although primarily driven by the need for a sustainable supply of industrial roundwood, the social and environmental dimensions of planted forests were also emphasized (FAO, 1967). Planted forests have an important role in providing economic and social benefits in eradicating poverty in developing countries and in industrialized countries where marginalized groups and indigenous peoples have previously been excluded from the benefits of development processes (Anonymous, 2004).

Another aspect of species selection on which further work is needed is tree breeding to improve the performance and properties of selected species. Interest in the possibilities of tree breeding in these respects has grown in the developing countries in the past few years, but has not so far been translated into much concrete action in the form of research, except in a very few countries. It is highly desirable that more research on breeding should be put in hand, though specialized staff will in many instances need to be supplied by outside agencies.

The need to extend our knowledge of the utilization properties of many quick-growing species and to improve the utilization of them, both through developing alternative uses and through improved methods of utilization, is rapidly becoming more acute. With regard to the first, a considerable knowledge is already available for some plantation species

now in wide use, but for many of the potential species little appears to be known. More research is also needed into the effects of different sites and different ages, rates of growth and tending practices on timber properties.

The genetic programmes concerning willows investigate how to maintain their wide range of adaptability to different environmental conditions, while simultaneously improving wood quality, specifically wood density and fibre length. Knowledge of the genetic and environmental variation present in forest stands allows the development of adequate strategies for the selection of superior genotypes. A higher variability also permits a higher gain obtained by selection. Before expanding the cultivation area of willows, it is necessary to assess if values of wood characteristics are maintained in new environments. It is known that site influences growth in height, diameter, and yield of plantations, but the impacts of site on wood quality has not been well studied (Monteoliva *et. al.*, 2002). Tree breeding is only one of several processes that can be employed to manipulate wood properties. As these will form the background to any breeding programme, they must be mentioned briefly at this point. One example will suffice to indicate the general role of each process. Management practice regulates wood properties in many ways - through species selection, through changing growing conditions as determined by the sites selected for each species, and through many other decisions such as those regulating the ages of rotations (Nicholls, 1965).

Because of the rapidly changing demands of technology, improvements of only fundamental wood properties are likely to prove worth while. For many species, other selection criteria have priority; wood properties should be included primarily to ensure that they are not affected adversely. Alternatively, the main objective may be to reduce within-tree variability in some fundamental property; this would contribute to easier and more efficient harvesting and manufacture and could ultimately prove to be the greatest contribution for wood quality

improvement. However, properties fundamental to one industry may be of little concern to another (Smith, 1965).

In recent years, a diverse modern forest industries sector has been encouraged to adapt to the use of the “new wood” from planted forests. The range of industrial products from planted forests include: lumber, plywood and veneer, reconstituted panels, modular components, pulp and paper, and increasingly bioenergy. Scientific research and development, particularly in genetic improvement and forest industries processing have revolutionized the productivities and the end use options for planted forests. Application of biotechnology has substantially improved site-species matching, growth, yields and financial benefits for planted forest investors, particularly in fast-growing and short-rotation crops. The development of forest industries technology has resulted in increasing end use options for raw materials from planted forests, improved efficiencies and reduction in the cost of wood based industries (Sutton, 2003; Millennium Ecosystem Assessment, 2005).

Willows, sallows, and osiers form 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. Most species are known as willow, but some narrow-leaved shrub species are called *osier*, and some broader-leaved species are referred to as *sallow* (derived from the Latin word *salix*, willow). Some willows (particularly arctic and alpine species) are low-growing or creeping shrubs; for example the Dwarf Willow (*Salix herbacea*) rarely exceeds 6 cm (2 in.) in height, though spreading widely across the ground.

Species of the genus *Salix* (willows) have among their advantages three remarkable characteristics that promote their cultivation. One of them is their adaptation to thrive in flooding environments, and the other two advantages are their easy vegetative propagation and fast growth.

With many species and varieties, it 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).

Forest expansion, including short rotation plantation on agriculture land offers a huge opportunity to increase potential wood supply in world as well. However, policy and land owners' decisions have to be made how to best use the available arable land. Wood production is an option, but it has to be weighed against other land uses such as food production, nature conservation, or planting other energy crops than trees. Woody residues from agriculture also can contribute to increase wood supply, in particular for energy generation. Much of these residues are probably already used for energy. Effective systems to collect these residues and systems to process (or burn) this material are current restriction to utilize its potential.

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* Roth), maple (*Acer pseudoplatanus* L.- Tintigny), poplar (*Populus trichocarpa* x *deltoides*-Hoogverst) and willow (*Salix viminalis*-Orm) growing under a 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 SR plantations (Inge *et al.* 2007).

Ericsson *et al.* (2006) reported that bioenergy is recognized as the most important renewable energy source in Poland in several national policy documents. This has spurred an increased interest in energy crops, particularly willow, due to the large areas of arable land in Poland. Their calculations show that growing willow can indeed be an economically viable alternative to wheat and barley. At the current Polish price of wood chips (about 33 PLN/MWh or 7.5€/MWh), the viability of willow is similar to that of barley given their assumptions on yields, etc. Wheat is the most viable crop of the three crops studied. Willow, however, is more profitable than both wheat and barley assuming a wood chip price of 50 PLN/MWh (11€/MWh), which better represents the price in Europe as a whole. Despite good viability, willow is unlikely to be adopted by great numbers of farmers without active support mechanisms and long term stability of the status of energy crops in Polish and the EU common agricultural policy.

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).

Short-rotation woody crops (SRWC) along with other woody biomass feedstocks will play a significant role in a more secure and sustainable energy future for the United States and around the world. In temperate regions, shrub willows are being developed as a SRWC because of their potential for high biomass production in short time periods, ease of vegetative propagation, broad genetic base, and ability to resprout after multiple harvests. With only 6 percent of the current U.S. energy consumption met by renewable sources the accelerated

development of willow biomass and other renewable energy sources is critical to address concerns of energy security and environmental impacts associated with fossil fuels (Keoleian and Volk, 2005).

Begley *et al.* (2009) reported that seven straight *Salix viminalis* genotypes with different levels of rust (*Melampasora eptez*) susceptibility were grown as mono plots as well as being incorporated into a range of mixtures. It was concluded that the current commercial practice in many parts of Europe of planting mixtures as a disease control strategy will only be effective if there is sufficient genetic diversity between the *Salix* genotypes incorporated into mixtures. Castellano *et. al.* (2009) estimated the technically available woody biomass from forests and willow biomass crops within a 40 km radius of Tupper Lake New York using a Geographic Information System. They found that there were approximately 215,300 odt of forest biomass technically available annually around Tupper Lake from 211,500 ha of timberland. There were 781 ha of technically available agricultural land in that area so willow biomass production would be minimal.

Industrial roundwood from planted forests is being recognized as a renewable resource and an energy efficient and environmentally friendly raw material for construction when compared to alternative products such as steel, aluminum, concrete and plastic (Sutton, 2003). Planted forests can make significant positive contributions to rural economies through primary and secondary industry development, employment and development of rural infrastructure. Trees are increasingly being planted to support agricultural production systems, community livelihoods, poverty alleviation, and food security (FAO, 2006).

Improvement work in willows is now being directed towards the introduction and development of wide range of species and clones of diverse genetic origin. New introductions from Europe, New Zealand, United States of America, China, Japan, Turkey, etc. have been made

recently and more are planned. 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.

The present investigations entitled “**Studies on physico-chemical characteristics of wood of promising willow clones**” were undertaken with the following objectives:

- i To study variation in holocellulose, lignin and other extraneous contents in the wood of various Willow clones.
- ii. To study variation in wood characteristics (specific gravity, fibre length, moisture content, etc) in various Willow clones.

Chapter-2

REVIEW OF LITERATURE

This chapter reviews the relevant literature pertaining to studies on physico-chemical characteristics of wood of promising willow clones. For the sake of convenience, the review has been discussed under the following three heads.

- 2.1 Growth parameters
- 2.2 Physical wood characteristics
- 2.3 Chemical properties
- 2.4 Variability and correlation studies

2.1 GROWTH PARAMETERS

Cheon *et al.* (2009) surveyed growth and branch characteristics of 35 half-sib families in a seedling seed orchard of *Quercus acutissima* at ages 10 and 12. The averages of height and DBH (diameter at breast height), at age 12 were 9.96 m and 14.50 cm, respectively. Families of 075 and 052 showed superior height growth and 0511 and 0517 were inferior ones. For DBH growth, 075 and 0413 were best families and 0725 and 0511 were inferior families.

Jaffirin and Kelvin (2009) reported that plantation trial plots of Kapur Paji (*Dryobalanops lanceolata*) were established at four different locations and at different time, namely, Sibuga Forest Reserve, Kimanis Research Plot, Segaliud Lokan Forest Reserve and Gum Gum Forest Reserve. The trial plot at Gum Gum Forest Reserve reached the mean height of 16.77 m and mean diameter at breast height (DBH) of 13.56 cm, at the age of 12 years. Whereas the trial plot at Segaliud lokan Forest Reserve attained the mean height of 18.52 m and mean DBH of 19.99 cm, at the age of 13 years. The mean height and mean DBH of trial plot at Kimanis at the age of 39 years is 30.74 m and 53.64 cm respectively. As

for the trial plot at Sibuga, the mean height and mean DBH at the age of 48 years is 31.14 m and 45.97 cm respectively. It shows that growth performance of the trial plot at Kimanis is better than the trial plot at Sibuga.

Himmapan *et al.* (2009) evaluated a nine year old *Azadirachta indica* provenance trial of comprising 24 provenances from 9 regions (countries) in the world. The field trial was established in 1997 in Kanchanaburi province in a randomized complete block design with 4 blocks and 25 trees per plot. Survival rate, height (H), diameter at breast height (DBH), stem form and number of stems were recorded. The results showed that the mean of all characters were significantly different at regional levels. Provenances within region also showed significant differences for most traits. Averages of survival, height, diameter at breast height (DBH), total basal area, number of stems and the score of stem form of the Neem plantation were 77.7 per cent, 5.6 meters, 8.1 centimeter, 1,020 cm², 1.8 stem and 4.1, respectively. The provenances from Annur-India and Khao Luang- Thailand showed highest survival percentages (98 per cent and 95 per cent, respectively), whereas provenance Ban Nong Hoi-Thailand performed best for stem form (6.2). Provenance Ban Nong Rong-Thailand showed the highest total basal area (1,885 cm²). Most of the seed sources showed moderate score in stem form. Provenance Tung Luang presented the lowest growth performance.

Hussain *et al.* (2009) reported that New Zealand is subject to summer and autumn droughts that limit pasture growth. The planting of willow (*Salix*) and poplar (*Populus*) trees is one option used to provide green fodder during drought. However, there is a wide concern that such an option can reduce the overall understorey pasture growth. They evaluated the comparative establishment and growth of densely planted young willow and poplar and their effects on understorey pasture growth. Two experiments were established for 2 years in Palmerston North and

Masterton, North Island, New Zealand. Willow and poplar survival rates were similar ($P>0.05$) after 2 years of establishment (100 vs. 90.5 per cent, respectively). However, willow grew faster than poplar in height (1.90 vs. 1.35 m), stem diameter (43.5 vs. 32.6 mm), canopy diameter (69 vs. 34 cm) and number of shoots (8.7 vs. 2.3) at the age of 2 years.

Kwon *et al.* (2007) investigated growth performances of 12 provenances originated from Southeast US in Wanju, Korea. Pitch-loblolly hybrid pine (*Pinus rigida* x *P. taeda*) was planted as comparisons. Analyses of variance for all the growth performances (height, D.B.H), at the age of 30 were significantly different among provenances. Volume growth of loblolly pine was 1.3 times higher than pitch-loblolly hybrid pine. Growth performances of southern provenances were generally better than those of other provenances. Averages of height, D.B.H. and volume growth were 15.6 m, 25.0 cm and 0.369 m³, respectively. Worcester Mass., Greene Ga. and Berkeley S.C. provenances were proved to be superior provenances; especially average individual tree volume growth of them was over 0.4 m³. A range of slenderness ratio was from 54.4 per cent to 70.4 per cent (average 64.6 per cent). It means that diameter growth was better than height growth in Wanju test plantation.

Bauch *et al.* (2006) reported that due to over-exploitation in the past, native conifer species in many tropical countries are hardly available anymore for wood utilization. In the last decades Costa Rica has undertaken considerable efforts to study the silvicultural characteristics of the native species of the family Podocarpaceae, in particular *Podocarpus oleifolius* var. *macrostachyus* (Parl.) Buchholz and Gray, in order to evaluate its suitability for cultivation in mixed plantations with preference for native species. They selected wood characteristics of old-growth trees from the Cordillera de Talamanca (approximately 2,700 m a.s.l.), Costa Rica. Tracheids occupy 93 per cent of total volume; average tracheid length is 4 mm, wall thickness ranges 2.5-4.5 (-6.5) micro m throughout the annual increment. Cellular UV microspectrophotometry reveals that

the compound middle lamella (CML) and S2 layer are characterized by a higher absorbance than is commonly observed in e.g. Pinaceae, and with a distinct gradient from S1 to S3.

Zeng *et al.* (2006) studied selected some clones of Chinese fir (*Cunninghamia lanceolata*) with fast growth and superior timber properties through excellent provenances, population and individual trees. There were significant differences among those clones in terms of diameter at breast height (dbh), height, individual volume, wood basal density and fibre length, and broad heritability. The average dbh, height, individual volume and wood basal density of those selected clones were 16.8 cm, 11.0 m, 0.1331 m³, and 0.3193 g/cm³ respectively, in 12-year-old trees.

Hosseini and Afra (2005) reported that *Paulownia fortunei* is one of the exotic trees which have been successfully growing in the Gorgan region of Iran, for 25 years ago. The 8-year-old Paulownia trees have produced 100 per cent juvenile wood, in which the fibre length of the first and eighth annual rings was measured as 0.800 and 1.11 mm, respectively. The post-cambial growth of fibre length starts from the sixth annual ring. Fibre diameter and thickness were 31.00 and 4.14 in the first annual ring, and 33.18 and 5.18 micrometers in the eighth annual ring, respectively.

Kumar *et al.* (2005) conducted study on variation in physico-chemical characteristics of wood of candidate plus trees (CPTs) of Sissoo (*Dalbergia sissoo*). Among different CPTs of *Dalbergia sissoo*, significant differences were noticed for all the characters except for holocellulose contents. The maximum height and diameter were recorded in Khajjian-1 (43.00 m and 116.50 cm, respectively) whereas, the minimum height was observed in Dhaulakuan-1 (15.00 m) and diameter in Dhartatoh-3 (17.30 cm).

Esteves *et al.* (2005) said that in maritime pine (*Pinus pinaster* Ait.), heartwood represents a substantial part of the tree stem at final

harvest age (80 years) corresponding to 42 per cent at the base of the stem wood diameter and decreasing upward. The rate of heartwood formation was estimated at 0.35 rings/year, beginning at 18 years of age.

Mahdavi *et al.* (2004) cut cross sectional disks at breast height from three 17-year-old trees of *Eucalyptus camaldulensis* grown in Pasand research station in Mazandaran province. Ring width, wood density, and fibre dimension were measured for each two rings from pith to the bark. Cross sectional growth rate and wood production for the trees were measured at 11.1 mm and 12.3 m³/ha./year respectively.

Toghraei *et al.* (2003) sampled twelve trees (10-22 years old) from different areas in Kerman Province, Iran, to analyse the physical, chemical and anatomical characteristics of saxaul [*Haloxylon* sp.] woods. Growth periodicity of wood was determined to be 3-4 rings per year.

Labrecque and Teodorescu (2003) undertook a study on two species of Willow, *Salix discolor* and *S. viminalis* under short rotation intensive culture on two abandoned farm land sites: sandy site (S1) and clay site (S2) with fertilization (T1) and no fertilization (T0) treatment. The objectives of the experiment were to compare the growth performance and nutrient exported by willow species planted on marginal site with different soil characteristics and to assess the impact of fertilization with waste water sludge on yields during a second rotation cycle. The results showed that willow height, diameter and above ground biomass were greater for *S. viminalis* than for *S. discolor* on all fertilized plots.

Saini *et al.* (2002) studied the effect of stem cutting diameter on growth and survival of *Salix* clones in nursery under shallow water, Tarai conditions of Pantnagar. Maximum collar diameter (2.07 cm, 2.18 cm) were recorded in S1 clone and D4 diameter class, respectively, whereas, maximum heights (258 cm, 233 cm) were observed in S3 clone and D4 diameter class, respectively.

Tunctaner (2002) studied the growth performance and wood properties on 53 willow (*Salix* sp.) clones selected from natural populations occurring in Turkey. The different characteristics of the willow clones, along with check- poplar clone I-214, such as diameter, height, volume, volume increment, basic density, dry matter, holocellulose production, calorific value, ash content and nitrogen and protein values were estimated on the basis of nursery performance. Some of willow clones showed better growth performance than poplar clone I-214.

Cox *et al.* (2001) assessed the growth and wood quality of four dipterocarp species (*Shorea acuminata*, *S. ovalis*, *S. leprosula* and *Dryobalanops aromatica*). The trees were randomly selected from a taungya plantation that was established in Kenaboi Negeri Sembilan, Peninsular Malaysia. The xylem growth of *S. leprosula* and *D. aromatica* was measured using dendrometer bands and from the measurements, it is concluded that both *S. leprosula* and *D. aromatica* grew continuously during the one year study period. The annual diameter growth increment was 15.3 and 14.0 mm for *D. aromatica* and *S. leprosula*, respectively.

Pan *et al.* (1998) studied genetic variation on fibre length in willow (*Salix*) nursery stock of different hybrids and clones and found significant differences in fibre length of clones at saplings stage. There were also significant differences in diameter and fibre length/diameter among different ages off same clone.

2.2 PHYSICAL WOOD CHARACTERISTICS

Nguyen *et al.* (2009) examined growth, specific gravity, and wood fiber length of *Acacia mangium*, *Acacia auriculiformis*, *Acacia* hybrid clones, and combinations, which were planted in a trial forest in Bavi, Vietnam. Superiority of hybrids over their parents ranged from 36.3 per cent to 41.6 per cent for diameter, from 6.9 per cent to 20.7 per cent for specific gravity, and from 6.1 per cent to 12.8 per cent for wood fiber length. Wood fiber length was initially 0.5-0.6 mm near the pith and then

increased slowly, finally reaching 1.0-1.2 mm near the bark. The specific gravity of *Acacia* increased from 0.49-0.58 near the pith to 0.63-0.74 near the bark. From a relative distance of 30 per cent from the pith, the specific gravity increased slightly and seemed to be stable.

Agbontalor (2008) reported that specific gravity (SG) of wood has not been adequately reported to be a factor directly or indirectly influencing its selection for incorporation into or retention in some of the agroforestry systems. The specific gravity of twelve wood species that top the priority ranking of respondents in Akinyele and Ido Local Government Areas (LGAs), Oyo State, Nigeria, where the predominant type of agroforestry system practiced is that of scattered trees in croplands, were evaluated and found to range between 0.42 and 0.85 with eleven of the species having values >0.60.

Alberto and Elvir (2008) reported that carbon fixation could be the base of international payment for environmental services mechanisms. The accumulation and growth of aerial biomass as well as the carbon fixation associated to this growth has to be measured in 36,139.78 hectares of natural forests of *Pinus oocarpa*, the most frequent tree in Honduras, in Cabanas, Santa Ana y Opatoro in the Department of La Paz. A forest survey was done to collect the information on tree distribution in diameter at breast height and tree densities. The specific gravity of wood was 0.55.

Ximenes *et al.* (2008) reported that a significant factor influencing the contribution of wood products to carbon (C) storage is the proportion of the aboveground tree biomass (AGB) recovered in commercial logs at harvest. They examined the proportion of AGB in logs and residues during the harvest of radiata pine (*Pinus radiata*), cypress pine (*Callitris columellaris*), blackbutt (*Eucalyptus pilularis*), spotted gum (*Corymbia maculata*) [*Eucalyptus maculata*] and messmate (*E. obliqua*) in Australia. Messmate and spotted gum showed the highest variation in stem

diameter and height. The mean moisture content of the wood of the different species ranged from 35 to 50 per cent. Messmate and radiata pine logs had the highest moisture content (48 and 50 per cent, respectively).

Tang (2007) said that White ash (*Fraxinus*) wood is a strong and elastic timber used for furniture, tool handles, and sporting goods such as baseball bats. The shrinkage and swelling properties of white ash wood were analysed with the use of drying and absorbing moisture methods. The changes in sizes in three dimensions with wood moisture content were preliminarily detected, and were then compared with other three varieties. The results showed that the basic density of the white ash wood is 0.73 g/cm³.

Dhillon and Sidhu (2007) measured specific gravity of wood samples collected at breast height of Poplars planted at two locations of Punjab viz. central plain region (Ludhiana) and semi-arid region (Bathinda). Significant differences among clones were noticed at both the locations. Specific gravity ranged from 0.403 to 0.475 in central plain region and from 0.356 to 0.436 in semi-arid region was noticed.

Mani and Parthasarathy (2007) reported the basic wood specific gravity of 41 tree species determined by oven-dry weight by volume which ranged from 0.46 to 0.92 g cm⁻³ for inland sites and 0.47 to 0.89 g cm⁻³ for the coastal sites tropical dry evergreen forests of peninsular India.

Venkaiah *et al.* (2006) evaluated twenty clones of *Populus deltoides* for wood characteristics at the end of 9th year. Clone '5-18' (0.427) showed the maximum specific gravity and clone 'C-181' recorded the minimum value (0.333). The longest fibres were found in the clone 'IC' (1.236 mm), closely followed by 'A-238' (1.222 mm), the shortest fibre were recorded in '6-17' (0.952 mm).

Zeng *et al.* (2006) selected some clones of Chinese fir (*Cunninghamia lanceolata*) with fast growth and superior timber properties through excellent provenances, population and individual trees. There were significant differences among these clones in terms of wood basal density and fibre length. The average wood basal density and fibre length of these selected clones were 0.3193 g/cm³ and 3317 micro m, respectively, in 12 year old trees.

Islam *et al.* (2006) reported that mango (*Mangifera indica*) and raintree (*Albizia saman* [*Samanea saman*]) are very common species in Bangladesh. The wood of these two species are cheap and widely used. The physical properties of wood e.g., moisture content, density, shrinkage etc. are very important in selecting a species for particular end uses. From the study, the moisture contents of *M. indica* and *A. saman* wood were 73.82 per cent and 90.03 per cent, respectively. The density of *M. indica* and *A. saman* woods at air dry and oven dry conditions were 0.48 & 0.54 g/cm³ and 0.42 & 0.47 gm/cm³, respectively.

Sykes *et al.* (2006) studied genetic variation and genotype by environment interaction (G x E) in several juvenile wood traits of 11-year-old loblolly pine trees (*Pinus taeda*) in four sites in South Carolina, USA. Wafer thin (200 micro m) samples from juvenile (ring 3) and transition (ring 8) wood of 12 mm increment cores were analysed. Transition wood had longer fibre (1.98 mm), and higher coarseness (0.34), but shorter fibres than juvenile wood (fibre length 1.4 mm and coarseness 0.28). Hosseini (2006) reported that the mean fibre length of three beech trees (*Fagus orientalis* [*F. sylvatica*]) at the lower and higher points (1 per cent and 75 per cent tree height) of the stem at an intermediate altitude (500-1000 m) in the Caspian forests in Sari region, Iran, were 1.36 and 1.22 mm respectively, close to the values in three trees at high altitude (1000-1500 m), that were found to be 1.39 and 1.36 mm. The mean fibre lengths of the whole stem, using the stem formula, were 1.31 and 1.38 mm at

intermediate and high altitudes, respectively, which were very close to each other.

Molteberg and Hoibo (2006) investigated important wood, pulp and fibre properties on small wood samples from two Rumanian, one German and one Norwegian provenance of Norway spruce (*Picea abies*) grown in Sorkedalen, Norway. Several samples were collected from inside each single tree, both in radial and transverse directions in the stem. Data were collected from a total of 59 trees, each 28 years of age. All investigated properties showed close relationship to ring number (RN) (cambium age). For basic density, a fast decline was first observed when moving from pith to bark and a minimum value was found around RN 5-8, and then followed by an increase. Basic density and fibre length increased with increasing height in the tree. Basic density and fibre length decreased with increasing DBH. Height to crown had a positive effect on basic density.

Ren *et al.* (2006) studied the effects of different plant densities (1000, 500 and 250 trees/ha) on the anatomical properties of *Populus x xiaohei* in Shuozhou County, Shanxi Province, China. Results showed that the planting densities had certain effects on the radial variation of fibre properties. An initial rapid and then gentle increase was observed on fibre length from pith to outer layer.

Xu *et al.* (2006) investigated fibre morphology and anatomical structure of sandlive willow (*Salix psammophila* C. Wang et Ch. Y. Yang). Results from light microscopy (LM), scanning electron microscopy (SEM), and Kajaani FS200 analysis showed that anatomical features of *S. psammophila* exhibited distinct growth ring boundaries. Fibres make up 60-70 per cent of total cells. Although mean fibre length of *S. psammophila* is 0.52 mm, which is beneficial to pulping and papermaking according to its fine fibre morphology.

Wang *et al.* (2006) determined and analysed key fibre morphological features, fibre length, fibre width, cell wall thickness, ratio of length to width, and ratio of cell wall to lumen of poplar (*Populus deltoides* I-69/55). In the radial variance, from the pith outward, the fibre length, fibre width and ratio of length to width all increased year after year, reaching a maximum at a certain year and then, decreases gradually.

Popovic and Todorovic (2006) conducted study to analyse the macroscopic characteristics of sessile oak (*Quercus petraea*) in the coppice forest of the National Park erdap, Serbia and Montenegro. The characteristics investigated were: percentage of stemwood; growth ring width; thickness and percentage of bark; percentage of sapwood and heartwood; moisture content; and their variation per tree height. The average percentage of stemwood was 55 per cent. Bark thickness decreased per tree height. The average bark thickness of the analysed trees was 9.74 mm, with an average coefficient of variation of 28.42 per cent. For the whole trunk, the area percentage of the bark was 17.6-23.5 per cent. The average percentage of heartwood and sapwood for all the trees studied was 33.1 and 4 per cent, respectively.

Lawrence (2006) devised a new cost-effective method for the determination of moisture content and basic density of wood. The method was based on the relationship between drying rate and moisture content of wood. The reliability of this method ranges from 94.5 to 96 per cent for the moisture content of green wood, 94.6 to 100 per cent for the moisture content of partially air-dried wood and 97.9 to 98.4 per cent for basic density.

Chiu *et al.* (2006) investigated inter-tree and intra-tree variations in green moisture content, green specific gravity, and basic density in stems of red cypress (*Chamaecyparis formosensis* Matsum.) in seventy-five 46 year old plantation trees. In addition, the relationships of growth characteristics and wood properties were explored. The average green

moisture content value among the sampled trees at breast height position was around 147 per cent, and ranged from 102.9 to 208.5 per cent, with a difference of 19.4 per cent. The inter-tree variation in average basic density was around 0.392 g cm^{-3} , and ranged from 0.337 to 0.432 g cm^{-3} , with a difference of 10 per cent. Basic density in sapwood was higher than in heartwood, and that in stems of live crowns was higher than that in basal stems. The average green specific gravity was around 0.963, and ranged from 0.772 to 1.137, with a difference of 11.5 per cent.

Sharma *et al.* (2006) studied variation of shrinkage (radial, tangential, volumetric and longitudinal) and specific gravity with moisture content has been studied in wood of seven year old plantation grown *Simarouba glauca*. The result showed that the standard specific gravity increases with decreasing moisture content. Low value of specific gravity suggests that the timber is light and useful for making toys and other handicraft items by artisans.

Wittmann *et al.* (2006) analyzed wood specific gravity (SG) from wood cores of 180 individuals belonging to 58 common upper canopy tree species of late successional white water (varzea) forests in the Mamiraua Sustainable Development Reserve, Central Amazon Basin (Brazil). The mean specific gravity in the low and high varzea was 0.62 and 0.57 g cm^{-3} , respectively. In the two species that occurred in both forest types (*Hevea spruceana* and *Tabebuia barbata*), specific gravity was significantly lower in the high varzea trees. Fakhrian *et al.* (2005) researched physical, chemical, fibre dimensions, pulp and papermaking characteristics of 4 years old *Alnus glutinosa*. The average of oven dry and critical density and fibre length were measured at 0.396 , 0.368 and 0.875 mm , respectively. Hosseini and Afra (2005) said that *Paulownia fortunei* is one of the exotic trees which have been successfully growing in the Gorgan region of Iran, for 25 years ago. The 8 year old *Paulownia* trees have produced 100 per cent juvenile wood, in which the fibre length of the first and eighth annual rings was measured as 0.800 and 1.11 mm ,

respectively. The post-cambial growth of fibre length starts from the sixth annual ring. Water soluble extractive material obtained was 6.94 per cent, the highest among all solutions. Habibi *et al.* (2005) reported that MDF was produced from Reed (*Phragmites australis*). Reeds are collected from Talabe - Anzalye areas. The anatomical property of Reed such as fibre length was measured as 1.38 mm.

Sharma and Sharma (2005) has observed significant decrease in the wood density from base to top of the *Robinia pseudoacacia* trees managed under high density short rotation system. The wood percentage increased from base to top while bark per cent showed a reverse trend. The planting densities also showed variation in wood and bark percentage.

Monteoliva *et al.* (2005) determined the variability of wood basic density and fibre length in six 13-year-old willow (*Salix*) clones growing under two different site conditions in Argentina. Values of basic density and wood fibre length were obtained and variance analyses were performed considering site and clone as sources of variation. Site influence was significant for basic density, which ranged from 0.364 and 0.455 kg/m³. Clones americano and hybrid cv A 13-44 showed the highest density values in both sites. For fibre length, values of the continental site were significantly higher. For each clone, mean values vary between 837.1 and 1142.1 micro m. The clones americano and 13-44 stand out because of their high density and long fibres.

Pan *et al.* (2005) studied the wood anatomical properties of 24 year old hybrid tulip (*Liriodendron chinense x L. tulipifera*). The results showed an average fibre length of 0.80-1.74 mm. The fibre length from pith to bark increase rapidly, tended to stabilize at the 9th to 11th year growth ring.

Rojas and Villers (2005) reported that in order to consider the wood specific gravity of *Pinus hartwegii* in the La Malinche volcano two methods were used: the traditional one of the maximum moisture content (Smith,

1954) and the empirical method proposed recently; 22 small pieces wood were extracted with a Pressler drill, to which both methods were applied. It was determined that the specific gravity of the wood was 0.496 g/cm^3 . It was demonstrated with a simple correlation that the results of both methods were very close to 1.0. The *Pinus hartwegii* wood is classified as moderately heavy.

Oliveira *et al.* (2005) reported that the specific gravity generally increased in the direction of pith-to-bark, *Eucalyptus* species. Jiang *et al.* (2004) studied fourteen fast growing poplar varieties widely cultivated in Shandong Province, China, for their volume growth, fibre shape, chemical composition and economic indices. The average fibre length and fibre content of the 14 poplar varieties in the 6-year-old stand was 0.863-1.051 mm, which was equivalent to 51.37-58.17 per cent.

Liu *et al.* (2004) observed and analysed the microscopic structure of *Hippophae rhamnoides* by using scanning electron microscope for the first time. Some approaches of quantitative anatomy, micrological image analysis were used to explore the anatomical properties and radial variation regulation of *H. rhamnoides*. Physico-mechanical properties (density, shrinkage ratio, compression (entire) strength perpendicular to grain) were measured by referring to testing methods for physico-mechanical properties of wood. The mean of fibre length was 601.48 micro m. Air-dried density of 0.574 g/cm^3 was medium.

Mahdavi *et al.* (2004) cut cross sectional disks at breast height from three 17-year-old trees of *Eucalyptus camaldulensis* grown in Pasand research station in Mazandaran province. Ring width, wood density, and fibre dimension were measured for each two rings from pith to the bark. Overall fibre length was measured as 758 micrometer. Mean values for the oven dry and basic density were 0.708 g/cm^3 and 0.552 g/cm^3 . The result showed that *E. camaldulensis* is classified as short fibre hardwood. Zhang *et al.* (2003) studied genetic control of growth and wood

properties in 3 year old poplar clones and found that the clonal effects were stronger than growth traits effects on wood density and initial moisture content. They found that the fibre lengths were varying between 0.32-0.44 mm.

Tertuliano *et al.* (2003) conducted research to establish equations to estimate the weight and to determinate the basic specific gravity of marmeleiro wood (*Croton sonderianus*). A total of 40 trees were felled at the Lameirao Experimental Farm, sited in Santa Terezinha, a city of the Brazilian Semi-arid Region (Paraiba State). The wood basic specific gravity, with and without bark, was 0.63 and 0.68 g/cm³, respectively, and the wood moisture content was 24 per cent. Klasnja *et. al.* (2003) investigated the variability in chemical composition, fibre length, and basic wood density (specific gravity) amongst clones. Wood samples were taken from an experimental plantation in a dense 2.5x2.5 m wood, i.e., 1600 trees/ha. The plantation consisted of 127 clones which were selected in the nursery from 11 eastern cottonwood (*P. deltoides* Bartr. section Aigeiros) half-sib progenies. The physical, structural, and chemical characteristics of 40 poplar clones aged four years were investigated in three model trees from each clone. The mean value of the basic wood density was 380 kg/m³ and the mean value of the fibre length was 863 micro m.

Yamamoto *et al.* (2003) evaluated distribution of the moisture content across stem wood at breast height in *Acacia mangium*, *A. auriculiformis* and hybrid *Acacia* trees grown in 3 Asian countries (Malaysia, Vietnam and the Philippines). Moisture contents of the stems of *A. mangium* and hybrid *Acacia* were extremely high not only in sapwood but also in heartwood in most cases. Highest moisture content found in the inner heartwood was 253 per cent for both *A. mangium* and hybrid *Acacia*. In sapwood, the moisture contents were 149 and 154 per cent, respectively. Most trees of these 2 species had wet-heartwood which refers to the higher moisture content of heartwood compared to the surrounding sapwood. The stem wood of *A. auriculiformis* generally

showed a slightly lower moisture content than that of *A. mangium* and hybrid *Acacia*. However, the highest moisture content found in the inner heartwood was 146 per cent in *A. auriculiformis*.

Tharakan *et al.* (2003) reported that woody biomass feedstock produced from willow and hybrid poplar can be converted into bioenergy via thermochemical and biochemical processes. They found a lower amount of variation for specific gravity ($0.33\text{--}0.48\text{ g cm}^{-3}$) and moisture content (49-56 per cent). Willow clones had higher specific gravity and bark percentage compared to hybrid poplar clones.

Nicholls *et al.* (2003) sampled western hemlock (*Tsuga heterophylla*) logs from three trees, ranging in diameter from approximately 10 to 18 inches. Forty-five boards were processed, yielding 225 samples. Sample moisture content ranged from 31.4 to 149.7 per cent (as a percentage of oven-dry wood weight), with a standard deviation of 30.6 per cent. There was no significant moisture variation among sample heights for the three western hemlock trees included in this study. Average moisture content at a given height ranged from about 70 to 85 per cent. Moisture contents of approximately 50 per cent were not uncommon for pith-centred samples, whereas most samples more than 5 inches from the pith were typically at least 100 per cent moisture content. There was considerable variation in overall moisture content among trees, ranging from about 69 to more than 85 per cent. Moisture content variation among butt logs was also considerable, ranging from about 58 to 95 per cent.

Susilawati and Fujisawa (2002) carried out first and second round selection of plus tree candidates of *Eucalyptus pellita* seedling seed orchard (SSO) in Pleihari, South Kalimantan based on growth performance (phenotype). Family performance evaluation in wood properties was based on wood samples collected from progeny test aged 66 months (5 years 6 months). Samples were sorted by diameter class (large, medium and small), and a total of 8 family for each class diameter

were selected, resulting in 24 families for the whole 10 blocks. Wood density and fibre length of *E. pellita* showed high family heritability, which ranged from 0.385 to 0.565 for wood density and 0.155 to 0.569 for fibre length. Estimation of mean values of wood density of total section varied from 0.53 to 0.68. Fibre length of total section varied from 0.76 mm to 1.06 mm.

Cox *et al.* (2001) assessed the growth and wood quality of four dipterocarp species (*Shorea acuminata*, *S. ovalis*, *S. leprosula* and *Dryobalanops aromatica*). The trees were randomly selected from a taungya plantation that was established in Kenaboi Negeri Sembilan, Peninsular Malaysia. A detailed study of *S. ovalis* indicated that mean fibre length was 1035 micro m. The specific gravity ranged from 0.31 (*S. leprosula*) to 0.37 (*S. acuminata*).

Luxmi *et al.* (2001) studied variations in specific gravity and wood anatomy in 10 year old trees of 18 clones of *Populus deltoides*, collected from experimental plantations in Uttaranchal, India. The specific gravity reached maximum at 50 per cent tree height and fibre length at 25 per cent of tree height showing a decreasing trend upwards. At breast height, fibre length and specific gravity increased rapidly up to the 6th year followed by a slower rate of increase up to the 8th year with a tendency to level off. Breast height values of specific gravity and fibre length were highly correlated with whole tree values for these two parameters.

Verma *et al.* (2001) reported the variations observed in the specific gravity of wood in segregating populations of F2 and F3 hybrids of *Eucalyptus citriodora* and *E. torelliana*. These studies were carried out in 10-year-old plants growing in a field trial laid out at New Forest Campus, Dehra Dun, Uttar Pradesh, India. A comparison of specific gravities of wood has been made with parent species involved in hybridization. The range in specific gravity of wood observed was 0.8144-0.8931 in *E.*

citriodora, 0.6279-0.6590 in *E. torelliana* and 0.5170-0.6677 for F2 and F3 recombinants.

Klansja and Kopitovic (1997) studied structural physical characteristics and chemical composition of wood of some white willow clones (*S. alba* L.) of age 13 grown at Poplar Research Institute, Noviasad and found that the average length of wood fibres was above 1 mm except for one clone 79/64/2 whose fibre length was noticed to be 0.9 mm. The nominal wood density was found about 340 kg/m³.

2.3 CHEMICAL PROPERTIES

Ximenes *et al.* (2008) recovered a significant factor influencing the contribution of wood products to carbon (C) storage in the proportion of the aboveground tree biomass (AGB) in commercial logs at harvest. They examined the proportion of AGB in logs and residues during the harvest of radiata pine (*Pinus radiata*), cypress pine (*Callitris columellaris*), blackbutt (*Eucalyptus pilularis*), spotted gum (*Corymbia maculata*) [*Eucalyptus maculata*] and messmate (*E. obliqua*) in Australia. The cellulose concentration of the wood was 56-64 per cent for the hardwoods and 40-52 per cent for the two softwoods. The lignin concentration of the wood was 16-19 per cent for the hardwoods and 25-35 per cent for the two softwoods. The hardwood species could not be distinguished from one another based on the cellulose, hemicellulose and lignin concentration, but within the softwood species, cypress pine and radiata pine formed separate clusters.

Szczukowski *et al.* (2008) carried out investigations on the chemical composition of 3-year old willow (*Salix viminalis*) rods which were created as new, fast-growing cultivars of high potentials for biomass production intended, primarily, for energetic purposes. The *Salix* genus is well known for its ease of crossing and creation of new cultivars and hybrids. The *Salix viminalis* hybrids were characterized by high cellulose content (46-51 per cent), with the exception of the *Salix viminalis* x *S.*

purpurea cross in which about 43 per cent cellulose was determined. The content of lignin ranged from 22.91 to 26.97 per cent and of holocellulose - from about 72 to 78 per cent. New cultivars of bush willows exhibited low concentrations of soluble substances.

Stolarski *et al.* (2006) reported that the productivity of willow (*Salix viminalis*) grown in annual or 4-year cutting cycle and Virginia mallow (*Sida hermaphrodita*) grown in annual cutting cycle was determined in a field trial conducted at the Experimental Station in Tomaszkowo near Olsztyn (Poland). Some properties and chemical composition of chips obtained from the biomass of willow and Virginia mallow were also studied. The highest cellulose content (44.76 per cent) was found in 4-year-old willow stem. The cellulose content of one-year old willow stem was 3 per cent lower and those of Virginia mallow was 5 per cent lower than in willow wood from 4-year cutting cycle. The lignin contents of 4-year willow stems and Virginia mallow biomass were 21.75 and 21.0 per cent, respectively, while one-year willow stems had 23.88 per cent.

Sykes *et al.* (2006) studied genetic variation and genotype by environment interaction (G x E) in several juvenile wood traits of 11-year-old loblolly pine trees (*Pinus taeda*) in four sites in South Carolina, USA. Wafer thin (200 micro m) samples from juvenile (ring 3) and transition (ring 8) wood of 12 mm increment cores were analysed. Transition wood had higher alpha -cellulose content (46.1 per cent), but lower lignin (29.7 per cent) than juvenile wood (cellulose 40.9 per cent and lignin 30.3 per cent).

Bautista Hernandez and Honorato Salazar (2006) carried out the study to determine the chemical composition of four Mexican oak species: *Quercus coccolobifolia*, *Q. durifolia*, *Q. rugosa* and *Q. oleoides*. Samples of sapwood, heartwood and a mixture of sapwood-heartwood were taken from each species and used to determine contents of cellulose, pentosans, lignin, ethanol-benzene extract, hot water extract, ash and tannin. In general, the cellulose content was in the range of 46.18 to 52.94

per cent. The amount of pentosans was from 19.08 to 20.61 per cent. Lignin content was between 20.40 and 23.35 per cent. Extractive content was between 1.02 and 4.83 per cent for ethanol-benzene extract and from 4.35 to 9.07 per cent for hot water extract. Tannin content was between 0.29 and 2.16 per cent for wood.

Adamopoulos *et al.* (2005) determined the variation within the stem of certain chemical properties from the bottom, middle, and top of three mature 35 to 37 year old black locust tree discs. Hot-water extractive content was greater in heartwood than in sapwood, while the reverse occurred for the dichloromethane extractive content. Vertical stem analysis of hot-water extractives showed that they increased in heartwood but decreased in sapwood from the bottom to the top of the stems while the reversal occurred for dichloromethane extractive content of sapwood. At the bottom, lignin content in heartwood (25.73 per cent) was greater than in sapwood (18.13 per cent). Lignin content of heartwood decreased from 25.73 per cent at the bottom to 18.33 per cent at the top, while that of sapwood was 18.13 per cent at the bottom, 21.42 per cent at the middle and 19.64 per cent at the top.

Esteves *et al.* (2005) said that in maritime pine (*Pinus pinaster* Ait.), heartwood represents a substantial part of the tree stem at final harvest age (80 years) corresponding to 42 per cent at the base of the stem wood diameter and decreasing upward. Differences in the chemical composition between heartwood and sapwood were mainly in the extractives, 19.7 per cent and 5.8 per cent, respectively. The lignin content was 23.1 per cent and 24.5 per cent in the heartwood and sapwood, respectively. Fakhrian *et al.* (2005) researched physical, chemical, fibre dimensions, pulp and papermaking characteristics of 4 years old *Alnus glutinosa*. Chemical compositions were obtained 48.5 per cent cellulose, 25.35 per cent lignin, 0.31 per cent ash and 2.36 per cent extractives.

Hosseini and Afra (2005) reported that *Paulownia fortunei* is one of the exotic trees which have been successfully growing in the Gorgan region of Iran, for 25 years ago. Water soluble extractive material obtained was 6.94 per cent, the highest among all solutions. Acetone and acetone + alcohol soluble and extractable materials were 5.05 and 4.88 per cent, respectively. Average lignin content was calculated as 29.77 per cent, which is pretty high and comparable with coniferous lignin content. Cellulose and hemicellulose contents were 45.55 and 24.66 per cent, respectively.

Kumar *et al.* (2005a) conducted study on variation in physico-chemical characteristics of wood of candidate plus trees (CPTs) of *Sissoo* (*Dalbergia sissoo*). Among different CPTs of *Dalbergia sissoo*, significant differences were noticed for all the characters except for holocellulose contents. Chemical properties of sapwood viz., cold water solubility, hot water solubility, alcohol-benzene solubility, lignin content and holocellulose content ranged between 2.25 per cent (1.50)-6.75 per cent (2.60), 3.50 per cent (1.87)-9.15 per cent (3.02), 1.01 per cent (1.00)-7.56 per cent (2.75), 23.90-30.50 per cent and 66.00-76.55 per cent, respectively. Chemical properties of heartwood of *Dalbergia sissoo* CPTs viz., cold water solubility, hot water solubility, alcohol-benzene solubility, lignin content and holocellulose content ranged between 5.25 per cent (2.29)-10.15 per cent (3.19), 9.15 per cent (3.02)-11.55 per cent (3.40), 6.82 per cent (2.61)-10.82 per cent (3.29), 30.50-39.70 per cent and 62.00-70.00 per cent, respectively.

Carballo *et al.* (2005) conducted a study to statistically compare the chemical composition of the wood of *Eucalyptus saligna*, *Corymbia citriodora* [*Eucalyptus citriodora*] and *Eucalyptus pellita* at three heights of commercial bole (25, 55 and 85 per cent) in samples coming from Forestry Companies of Macurije and Guanahacabibes in Pinar del Rio province of Cuba. The wood of *E. citriodora* presented higher contents of cellulose, and lower lignin and extractives, thus considered the most

attractive species, from the chemical point of view, to be used in the of cellulose and paper industry.

Orea *et al.* (2005) studied the chemical composition of the wood of *Eucalyptus saligna* at three height levels of the commercial bole. The samples came from the Forestry Company of Macurijes, Pinar del Rio, Cuba. They determined the contents of cellulose, lignin, hemicellulose, ashes, as well as extractives substances, in different solvents systems using TAPPI Norms. Results showed great differences in the content of extractives substances increasing with the height of the bole, although the lignin increased apparently towards 85 per cent of the height of the commercial bole, due to the influence of the phenolic extractives in the lignin contents. The cellulose showed structural differences with the height of the bole.

Morais *et al.* (2005) established the chemical composition of *Pinus oocarpa* wood cultivated in the Brazilian cerrado. The obtained results were: a-cellulose (59.05 per cent), hemicelluloses A and B (21.22 per cent), lignin (25.18 per cent), dichloromethane extractives (2.78 per cent), ethanol:toluene extractives (4.38 per cent), hot water extractives (4.31 per cent) and ash (1.26 per cent). The cellulose content was high.

Silva *et al.* (2005) studied the chemical composition variation of the *Eucalyptus grandis* wood of four different ages (10, 14, 20 and 25 years), from commercial stands. The samples were removed from three disks taken from the base and top of the first two 3 m logs, from 16 trees (four per age), totaling 48 discs. The mean values of holocellulose, lignin and extractive contents were 69, 27 and 4 per cent, respectively. The extractive and lignin contents increased with age, with greater concentrations near the base. The holocellulose content also decreased with age with greater concentrations in discs removed from the upper parts of the trunk. Mahdavi *et. al.* (2004) cut cross sectional disks at breast height from three 17 year old trees of *E. camaldulensis* grown in

Pasand research station in Mazandaran province. Chemical compositions of the wood consist of cellulose; lignin and extractives (in acetone soluble) were measured at 47.44 per cent, 30.87 per cent and 6.96 per cent, respectively.

Gierlinger *et al.* (2004) studied the extractive content of lignin and the brown-rot decay-resistance against *Coniophora puteana* and *Poria placenta* in larch heartwood from different species and origin (*Larix decidua* var. *decidua*, *L. decidua* var. *sudetica*, *L. kaempferi*, *L. x eurolepis*). The study material consisted of 106 trees from a 39-year old provenance trial in France. The hot water soluble extractives were very variable (from 5.66 per cent to 20.50 per cent of dry weight). In contrast, acetone extractives, the total amount of phenolics and lignin showed significant differences. The concentration of phenolics and lignin was significantly higher in *L. kaempferi* and in *L. x eurolepis* than in *L. decidua*. Liang (2004) determined the extractive content and acid-alkali property of *Acacia mangium* wood were investigated and their relationship was determined. The extractive content in treatments with cold water, hot water, 1 per cent NaOH and benzene alcohol were 4.84, 5.75, 15.98 and 6.09 per cent, respectively.

Fernandez *et al.* (2002) analysed the potential genetic variation in quaking aspen (*Populus tremuloides* Michx.) wood extractives by sampling nine natural clones at breast height. Significant clonal differences were found not only in the levels of total acetone extractives, but also in the levels of sterols-triterpines, steryl esters waxes and triglycerides, all of which are known to contribute to pith formation in pulping and paper making. Sun, *et al.* (2002) conducted treatment of solvent-extracted fast-growing poplar wood with 60 per cent aqueous ethanol in 0.2 M HCL at 75 degrees C for 3 hrs released 16.7 per cent of the original lignin, and 25.5 per cent of the original hemicelluloses. Sun *et al.* (2001) reported that extraction of the dewaxed and partially delignified fast-growing poplar (*Populous* sp.) wood with 1.5, 3.0, 5.0, 7.5 and 8.5 per

cent NaOH at 20 degrees C for 16 hrs was found to solubilize 65.6, 71.6, 73.8, 85.6 and 89.3 per cent of the original hemicelluloses, respectively. Xylans were found to be the predominant hemicellulosic components in the cell walls of fast-growing poplar wood. The 5 isolated hemicellulosic preparations were further characterized by Fourier transform infrared (FT-IR), and carbon-13 magnetic resonance spectroscopy (^{13}C NMR) as well as gel permeation chromatography (GPC).

2.4 VARIABILITY AND CORRELATION STUDIES

Barvidiene and Saulys (2008) presented paper on quantitative and qualitative indices and analysis of regulated streams of southeast Lithuania overgrown with woody plants. The studies carried out in the Neris river basin in the Baltic highland have shown that in the strips of the regulated stream slopes within the study area the most dominant species of trees were common willow (*Salix caprea*) observed in 25 (22.7 per cent) habitats, gray alder (*Alnus incana*) and black alder (*A. glutinosa*) observed in 22 (20.0 per cent) and 16 (14.5 per cent) habitats respectively. Dark-leaved willow (*Salix myrsinifolia*) and common willow (*S. cinerea*) found in 15 (14.3 per cent) and 47 (42.47 per cent) habitats respectively are considered to be the most dominant of all the species of bushes. A particularly strong dependence (correlation coefficients $r=0.91-0.94$) was determined between common woody plants (trees and bushes) and the number of individual species of trees and bushes on the distance of their habitats in regulated stream slopes to the forest.

Kumar (2007) evaluated a clonal trial of *Gmelina arborea* consisting of seventy clones selected from ten geographical locations in four states of northeast India for height, diameter at ground level (DGL) and diameter at breast height (DBH) at the Experimental Station, Rain Forest Research Institute, Jorhat, Assam, India. The performance of all the traits at the age of 24 months showed significant variations between the clones. Broad sense heritability for height, DGL and DBH was 0.31, 0.44 and 0.37 with a genetic gain of 18.1, 24.6 and 30.1 per cent,

respectively. Diameter at breast height (DBH) was determined to be an important trait with maximum genotypic and phenotypic coefficients of variation of 18.6 and 30.4 per cent, respectively.

Wu *et al.* (2007) reported that a total of 360 bark to bark through pith wood strips were sampled at breast height from 180 trees in 30 open pollinated families from two rotation aged genetic trials to study inheritance, age-age genetic correlation, and early selection efficiency for wood quality traits in radiata pine (*Pinus radiata*). Annual ring growth was the largest between ages 2-5 years from pith, and decreased linearly to ages 9-10. Heritability increased from zero near the pith and stabilized at ages 4 or 5 for all four growth and wood quality traits (diameter at breast height (DBH) and density). Age-age genetic correlations were high for the traits studied. The genetic correlation reached 0.8 after age 7 for most traits.

Tesfaye *et al.* (2007) conducted a provenance/progeny trial of *Eucalyptus globulus* subsp. *globulus* at Ilalaa Gojo in the central highlands of Ethiopia to identify superior provenances and establish a breeding population for genetic improvement programmes. Heritabilities for height and dbh were 0.20+or-0.03 and 0.16+or-0.02, respectively. They concluded that there was substantial potential for genetic improvement of *E. globules*. Lawrence (2006) devised a new cost-effective method for the determination of moisture content and basic density of wood. The method was based on the relationship between drying rate and moisture content of wood. The reliability of this method ranges from 94.5 per cent to 96 per cent for the moisture content of green wood, 94.6 per cent to 100 per cent for the moisture content of partially air-dried wood and 97.9 per cent to 98.4 per cent for basic density. There was a strong negative correlation between the reliability of this method and the actual moisture content of a piece of wood.

Chiu *et al.* (2006) investigated inter-tree and intra-tree variations in green moisture content, green specific gravity, and basic density in stems of red cypress (*Chamaecyparis formosensis* Matsum.) in seventy-five 46 year old plantation trees. In addition, the relationships of growth characteristics and wood properties were explored. Average values of the green specific gravity obtained from transition wood were significantly lower than those for the other positions; however, no significant differences existed in different tree height positions. There was a significant negative relationship between the basic density and green moisture content, but a positive relationship between green specific gravity and basic density. The values of green specific gravity increased with an increase in the moisture content.

Hou *et al.* (2006) studied the heredity variability of the height, diameter and volume growth, and the interaction effect between biomass and site, relativity among characters, age and seedling growth of a 4-5 year old *Fokienia hodginsii* forest belonging to 17 geographical provenances and 48 families in Hunan Province, China. Results showed significant differences in the height, diameter and volume growth at mountainous, semi-mountainous and hilly areas. Heritabilities of the height, diameter and volume were 0.5561-0.9034, 0.6303-0.9140, and 0.6701-0.9143, respectively. The genetic gain of 10 superior provenances and 14 families were 16.09-88.70 per cent and 15.19-184.80 per cent, respectively. Mora and Zamudio (2006) investigated narrow sense heritability (h^2), intra-class genetic correlations (Gamma 2IC) and variance components for height, diameter at breast height and stem volume of seven-year-old trees on two progeny trials of *Pinus radiata* planted in southern Chile. The heritability indicated the following values: height, 0.08-0.13; stem diameter, 0-0.13; stem volume, 0-0.09.

Yang (2006) studied the genetic variation of half-sib progeny testing of the clones from three masson pine (*Pinus massoniana*) seed orchards in Guangxi province in China. Results showed that there were

very significant differences among families in terms of growth traits. The heritability of growth traits, the heritability of height, diameter at breast height and individual volume was 0.31-0.72, 0.17-0.69, and 0.29-0.68, respectively.

Bhat and Indira (2005) analysed twenty teak (*Tectona grandis*) clones growing in a 14 year old clonal teak seed orchard at the Arippa and Palappily, Kerala, India, for their relative genetic gain in wood quality parameters, viz. wood density, growth rate (ring width), tissue proportions, fibre wall thickness and vessel size (diameter). The genetic gain was relatively high (12 per cent) in growth rate compared to wood density (1.7 per cent), while it was negligible in the proportion of fibre and parenchyma tissues. The low value of genetic gains indicates lesser coefficients of variation of wood properties displayed by the clones.

Luo *et al.* (2005) conducted a study to analyse the height, diameter at breast height and volume of ten families from 16 year old hybrid larch (*Larix*) progeny testing forests. Results showed that there were abundant variations in these three characters between and within families. The family heritability of height, diameter and volume were 0.741, 0.718 and 0.642, respectively, and their genetic gain was 15.7, 20.8 and 41.5 per cent, respectively.

Mahdavi and Habibi (2005) reported that growing interest in wood and paper consumption in Iranian industries and forest utilization constraints call for alternative approaches on the exploitation trend. The study showed that the branch fibre dimensions have significantly differed compare to trunk. Fibre length increased from crown downward to the stump and also from pith to bark, but there was a significant negative correlation between the variations and tree height.

Kumar and Sharma (2005) reported that *Dalbergia sissoo* is a large multipurpose deciduous tree with a light crown and somewhat crooked bole, and occurs naturally throughout the sub-Himalayan tract from Indus

to Assam, India. The result was the correlation depicting a relationship between the two characters reveals that growth parameters, viz., height, diameter, sapwood percentage, heartwood percentage showed highly significant positive and negative soluble extractives of sapwood, alcohol-benzene extractives of heartwood. The growth parameters also showed highly significant positive and negative genotypic, phenotypic and environmental correlation coefficients as compared to wood extractives. Genotypic correlation coefficients were found to be higher than both phenotypic and environmental correlation coefficients for all physico-chemical characteristics of wood. Rojas and Villers (2005) determined the wood specific gravity of *Pinus hartwegii* in the La Malinche volcano from 22 small pieces wood extracted with a Pressler drill. It was demonstrated with a simple correlation that the results of both methods were very close to 1.0.

Balcorta Martinez and Vargas Hernandez (2005) evaluated the level of phenotypic variation in eight economically important traits, including wood volume, stem straightness and wood density, in a three-years old commercial plantation of melina (*Gmelina arborea* Linn., Roxb.), located in Escarcega, Campeche, Mexico. Results showed that a wide phenotypic variation exists in the plantation, with a coefficient of variation over 20 per cent for six of the eight traits considered, except for wood density and stem straightness, where coefficient of variation was only 8.5 and 5.0 per cent, respectively.

Kumar *et al.* (2005b) studied the variability status in candidate plus trees of *Dalbergia sissoo*. The maximum heritability, genetic advance, genetic gain, phenotypic and genotypic coefficient of variability were recorded in growth parameters as compared to wood extractives.

Missio *et al.* (2004) selected a total of 119 *Pinus caribaea* var. *bahamensis* progenies by mixed models using the estimate of genetic parameters by restricted maximum likelihood estimation for the prediction

of additive genetic values by best linear unbiased prediction. Heritability estimates of 0.12, 0.20 and 0.21 for height, DBH and volume, respectively were found. The trait with greatest variability was the volume, with a genetic variation coefficient of 22.60 per cent, while the genetic variation for height was lower (3.73 per cent). A genetic gain of 14.5 per cent was obtained for DBH.

Susilawati and Fujisawa (2002) carried out first and second round selection of plus tree candidates of *Eucalyptus pellita* seedling seed orchard (SSO) in Pleihari, South Kalimantan based on growth performance (phenotype). Family performance evaluation in wood properties was based on wood samples collected from progeny test aged 66 months (5 years 6 months) old. Wood density and fibre length of *E. pellita* showed high family heritability, which ranged from 0.385 to 0.565 for wood density and 0.155 to 0.569 for fibre length. Luxmi *et al.* (2001) studied variations in specific gravity and wood anatomy in 10 year old trees of 18 clones of *Populus deltoides*, collected from experimental plantations in Uttaranchal, India. Breast height values of specific gravity and fibre length were highly correlated with whole tree values for these two parameters.

Wang Kesheng *et al.* (1996) studied the inheritance and correlation between growth characteristic and quality characteristics of 7 year old poplar (*Populus*) and found relatively high positive correlation between plant height and DBH, fibre length and length width ratio and wood specific gravity and DBH.

Toda *et al.* (1994) reported that year to year correlation in mean tree height and mean diameter at breast height of *Quercus acutissima* as highly significant, within family heritability was estimated at 0-34.4 percent for tree height, 1.8-19.2 percent for DBH, and 8.7-24.9 percent for bark thickness. Heritability of tree height and DBH tended to increase with tree age.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “**Studies on physico-chemical characteristics of wood of promising willow clones**” was carried out in the Department of Forest Products, Nauni, Solan. The data on growth parameters and collection of wood samples was done from the plantation clone under Willow Clones Project of Department of Tree Improvement and Genetic Resources. Laboratory analysis of the collected samples was done in the Department Laboratory of Forest Products, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.).

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 15 km south east of Solan with 30° 51' N latitude and 76° 11' E longitude (survey of India Toposheet no. 55 F/1). The mean maximum and minimum temperature is 25.90°C and 12.30°C, respectively. The highest relative humidity is 85.00 per cent and the lowest is 41.00 per cent. The maximum rainfall is 408 mm; the minimum is 0.00 mm, with an average rainfall of 59.17 mm yearly. The experimental area is situated at the University Campus.

3.1 EXPERIMENTAL DETAILS

Number of clones	=	21
Age of clones	=	4 years
Replications	=	3
Design	=	RBD

3.2 Details of clonal material

Clone name	Scientific name
1. Kashmir willow	<i>Salix alba</i>

2. NZ-1002	<i>S. matsudana</i> x <i>S. alba</i>
3. NZ-1140	<i>S. matsudana</i> x <i>S. alba</i>
4. NZ-1179	<i>S. matsudana</i> x <i>S. alba</i>
5. NZ-1184	<i>S. matsudana</i> x <i>S. alba</i>
6. 795	<i>S. matsudana</i> x <i>S. alba</i>
7. 799	<i>S. matsudana</i> x <i>S. alba</i>
8. 084/03	<i>S. alba</i>
9. 131/25	<i>S. alba</i> x <i>S. babylonica</i>
10. 212/03	<i>S. matsudana</i> x <i>S. caprea</i> x <i>S. matsudana</i>
11. V-99	<i>S. caprea</i> x <i>S. rubens</i>
12. V-311	<i>S. matsudana</i>
13. V-11841	<i>S. alba</i>
14. PN-227	<i>S. matsudana</i>
15. PN-721	<i>S. matsudana</i> x <i>S. alba</i>
16. PN-733	<i>S. nigra</i>
17. MB-368	<i>S. alba</i>
18. SI-63-007	<i>S. alba</i>
19. SI-63-016	<i>S. jessoensis</i>
20. SI-64-17	<i>S. alba</i>
21. 172	<i>S. babylonica</i> x <i>S. alba</i> x <i>S. matsudana</i>

Year planted: February, 2006

Source of clonal material: National Bureau of Plant Genetic Resources,
New Delhi.

Observation recorded

- i. Height (m)
- ii. Diameter (cm)
- iii. Bark per cent
- iv. Wood per cent
- v. Moisture content (%)
- vi. Specific gravity

- vii. Fibre length (mm)
- viii. Holocellulose (%)
- ix. Lignin (%)
- x. Cold water soluble extractives (%)
- xi. Hot water soluble extractives (%)
- xii. Alcohol-Benzene soluble extractives (%)

3.3 RECORDING OF DATA

i) Height

Height of each tree was measured with the help of Ravi multimeter. Two readings were taken from different locations or sides from where the top and base of the tree were visible. The average of these readings was recorded as the height of the tree in meters.

ii) Diameter

Diameter of tree was measured with the help of tree caliper. It was measured at two points which were at right angle to each other and mean value of those two observations was recorded as dbh (diameter at breast height) in cm.

iii) Wood and bark percentage

Diameter over bark (dob) was measured with tree caliper. Bark of the stem was measured with the help of Swedish bark gauge. Diameter under bark (dub) was calculated by deducting the twice of bark thickness from the diameter over bark. The wood thickness was estimated by deducting the bark thickness from dob. The wood and bark percentages in the main stem were calculated on the basis of dob.

iv) Moisture content (%)

The fresh weight of the samples was recorded just after the samples were removed from the clones. Then after initial weighing, the samples were transferred to drying oven. For first few hours the oven was

run at 60°C then the temperature was raised to 102 ± 1 °C and samples were left in oven overnight. The weight of samples was recorded until the constant weight reached.

The moisture per cent of the samples was calculated by using the following formula given by Desch and Dinwoodie (1996).

$$\text{Moisture content (\%)} = \frac{m_{\text{init}} - m_{\text{od}}}{m_{\text{od}}} \times 100$$

Where,

m_{init} = Initial weight of sample (g)

m_{od} = Oven dry weight of sample (g)

v) **Specific gravity**

Specific gravity was determined by the maximum moisture 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:

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

Where,

Mm = Fresh/Green weight of the sample having maximum moisture

Mo = oven dried constant weight of the sample

GS = Average density of wood substance a constant, having value 1.53

3.4 **PROXIMATE CHEMICAL ANALYSIS**

The proximate chemical analysis was carried out by employing TAPPI (Technical Association of Pulp and Paper Industry) standard methods.

Determination of water soluble extractives

The water soluble extractives were determined by employing following methods.

i) Cold water solubility (T1m-59-Anonymous, 1959a)

Two grams of oven dry wood meal was weighed and transferred into conical flask containing 300ml distilled water. The mixture was digested at room temperature with frequent stirring for 48 hours. The material was then filtered through filter paper and washed thoroughly with cold distilled water and dried to a constant weight in an oven at $102 \pm 1^{\circ}\text{C}$. The cold water solubility was determined by calculating the loss in weight of sample taken and expressed as percentage on the basis of oven dry weight of wood.

ii) Hot water solubility (T1m-59-Anonymous, 1959a)

Two grams of oven dry wood meal was taken in a flask having 100 ml of distilled water fitted with reflux condenser. It was digested on boiling water bath for three hours. The contents were then filtered through filter paper and residue was dried in an oven at $102 \pm 1^{\circ}\text{C}$ till constant weight. The solubility was determined by calculating the loss in weight of the sample taken and expressed as percentage.

iii) Fibre length

It was determined by macerating the shavings of wood in Jeffrey's fluid, i.e. 10 per cent chromic acid and 10 per cent nitric acid for 48 hours (Pandey *et. al.* 1968) after which the samples were thoroughly washed, stained with safranin and teased on 10 per cent glycerin. The measurements were made with the help of ocular micrometer, standardized with the help of stage micrometer.

iv) Alcohol-benzene extractives (T6m-59-Anonymous, 1959b)

Ten grams oven dry wood meal was placed in a porous thimble (ovendried and weighed). The thimble was placed in a soxhlet apparatus

and extracted with 400 ml of alcohol-benzene (1:2 v/v) for six hours. The porous thimble was then taken out and allowed to dry in open air and finally in an oven at $102 \pm 1^{\circ}\text{C}$ till constant weight. The alcohol-benzene soluble extractives were determined by calculating the loss in weight of the sample taken and expressed in percentage.

v) Klason-lignin content (T12m-59-Anonymous,1959c)

Two grams oven dry sample pre-extracted with alcohol-benzene (1:2 v/v) was treated with 15 ml of 72 percent sulphuric acid for 2 hours at $18-20^{\circ}\text{C}$ with constant stirring. The material was brought down to 3 percent by adding 545 ml of distilled water. The solution was refluxed for 4 hours and then allowed to settle. The contents were filtered, washed with hot distilled water and dried in an oven at $102 \pm 1^{\circ}\text{C}$ till constant weight and expressed in percentage on an oven dry weight basis.

vi) Holocellulose (T9m-54-Anonymous, 1954)

Five grams oven dry sample pre-extracted with alcohol-benzene (1:2 v/v) was taken in a conical flask and 160 ml of distilled water was added to it. The contents were treated with 1.5 gram of sodium chlorite and ten drops of acetic acid at $70-80^{\circ}\text{C}$ on a water bath for one hour. The process was repeated four times till the meal became white. The contents were then filtered through filter paper, washed with water and finally with acetone. The sample was dried in an oven at $102 \pm 1^{\circ}\text{C}$ to a constant weight. The extracted holocellulose content was calculated on the basis of the oven dry weight.

3.5 STATISTICAL ANALYSIS

The statistical analysis for each character was carried out as mean values. The data was subjected to randomized block analysis as described by Panse and Sukhatme (1978) and Chandel (1984).

i) Simple correlation

Simple correlation coefficient (Karl Pearson's) between two characters was worked out using the following formula (Panse and Sukhatme, 1978).

$$r(xy) = \frac{\text{Cov}(xy)}{\sqrt{V(x) V(y)}}$$

where,

$r(xy)$ = Simple correlation between x and y

$v(x)$ = Variance of x character

$v(y)$ = Variance of y character

For testing of simple correlation the 't' value was calculated by the following formula given known as student's 't'-test.

$$t = \frac{r}{\sqrt{1-r^2}} \sqrt{n-2} \sim T_{n-2} (5\%)$$

where,

r = Simple correlation

n = Number of coefficients in the samples

This value was compared with the tabulated 't' value at (n-2) as the degree of freedom.

ii) Statistical analysis

The data thus obtained was subjected to statistical analysis as described by Panse and Sukhatme (1978) and Chandel (1984). The design used was Randomized Block Design. The statistical analysis for each parameter was carried out on mean values and the analysis of variance (ANOVA) table was set up as under:

Analysis of variance

Source of variation	Degree of freedom	Mean sum of square	Variance ratio
Replication	(r-1)	Mr	Mt/Me
Treatment	(t-1)	Mt	
Error	(r-1) (t-1)	Me	

Where,

- r = Number of replications
- t = Number of treatments
- Mr = Mean sum of squares due to replication
- Mt = Mean sum of squares due to treatment
- Me = Mean sum of square due to error

The critical difference (CD) was calculated as follows:

$$CD = SE(d) \times t_{0.05}$$

Where,

SE(d) = Standard error of difference calculated as

$$SE(d) = \sqrt{2Me/r}$$

$t_{0.05}$ = t value at 5 percent level of significance.

Computation of variability parameters

Phenotypic and genotypic variances were calculated as follows:

$$V_p = V_g + V_e$$

$$V_g = (Mt - Me)/r$$

Where,

V_p = Phenotypic variance

V_g = Genotypic variance

Coefficient of variability

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

$$\text{PCV (\%)} = \sqrt{(V_p/\bar{x})} \times 100$$

$$\text{GCV (\%)} = \sqrt{(V_g/\bar{x})} \times 100$$

Where,

PCV = Phenotypic coefficient of variation

GCV = Genotypic coefficient of variation

$\bar{x}$ = Population mean of the characters

Estimate of heritability (broad sense)

Heritability in percentage was calculated by the formula suggested by Burton and De Vane (1953) and Johnson *et al.* (1955).

$$H = (V_g/V_p) \times 100$$

Where,

H = Heritability (broad sense)

V_p = Phenotypic variance

V_g = Genotypic variance

Genetic advance

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

$$\text{Genetic advance} = (V_g/V_p) \times \sqrt{V_p} \times K$$

Where,

V_g = Genotypic variance

V_p = Phenotypic variance

K = Selected differential at 5% selection intensity. The value of K
= 2.06 (Allard, 1960).

Genetic gain

Genetic gain was worked out by following the method suggested by Johnson *et al.* (1955) as under:

$$\text{Genetic gain (\%)} = \text{Genetic advance} / \bar{X} \times 100$$

Calculation of correlation coefficients

Phenotypic, genotypic and environmental correlation coefficients were estimated for physico-chemical properties as given by Searle (1961).

Phenotypic correlation coefficient between character x and y

$$r_{(xy)p} = V_{xy}(p) / \sqrt{V_x(p) \times V_y(p)}$$

Genotypic correlation coefficient between character x and y

$$r_{(xy)g} = V_{xy}(g) / \sqrt{V_x(g) \times V_y(g)}$$

Environmental correlation coefficient between character x and y

$$r_{(xy)e} = V_{xy}(e) / \sqrt{V_x(e) \times V_y(e)}$$

where,

$V_p(xy)$ = Phenotypic variance between x and y

$V_g(xy)$ = Genotypic variance between x and y

$V_e(xy)$ = Environmental variance between x and y

The significance of correlation coefficients were tested against 'r' values as given by Fisher and Yates (1963) at (n-2) degree of freedom.

Chapter-4

EXPERIMENTAL RESULTS

The results emanating from the present investigation entitled **“Studies on physico-chemical characteristics of wood of promising willow clones”** carried out at field and laboratory of Forest Products Department in the main campus of Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during the year 2008-2010 have been presented in this chapter. The data obtained from study were subjected to appropriate statistical analysis and the results are presented under the following main headings:

- 4.1 Growth performance
- 4.2 Physical wood characteristics
- 4.3 Chemical properties
- 4.4 Variability and correlation studies

4.1 GROWTH PERFORMANCE

4.1.1 Height and diameter

The data pertaining to the height and diameter of promising willow clones is presented in Table-1. The perusal of data revealed significant variation in height. The mean height ranged from 4.68 to 12.43m. The maximum height of 12.43m was found in clone number 212/03; whereas minimum height of 4.68m was observed in clone number SI-63-016. Clones PN-733(6.08m), SI-63-007 (6.10m), SI-64-17 (6.72m) and Kashmir willow (6.91m) were recorded to be at par. Similarly V-99 (6.83m), PN-227 (6.83m), V-11841 (7.00m), MB-368 (7.07m), 795 (7.22m), NZ-1184 (7.60m) and 084/03 (7.97m) and clones NZ-1140 (10.77m), NZ-1179 (10.90m) and 131/25 (11.00m) clones were also statistically similar in height. The mean diameter ranged from 4.17 to 9.87cm and the maximum value of 9.87cm was recorded in clone number

212/03 whereas, the minimum diameter of 4.17cm was recorded in clone number SI-63-016. Clones NZ-1184 (4.80cm), 172 (4.53cm) and MB-368 (4.20cm), clones SI-63-007 (4.73cm), V-11841 (4.77cm), PN-227 (4.80cm), PN-733 (5.23cm), and V-99 (5.37cm), and also the clones SI-64-17 (7.00cm), V-311 (7.07cm), 131/25 (7.10cm), 795 (7.90cm) and Kashmir willow (7.67cm) were found to be statistically at par. The NZ-1002 (8.53cm), 799 (8.97cm), PN-721 (9.00cm) and 084/03 (9.10cm) clones, were also observed to be statistically similar.

4.1.2 Bark percentage

The data on bark percentage of different promising willow clones are presented in Table-1. The scrutiny of data revealed the significant variation in bark percentage. The maximum bark of 36.13 per cent (6.01) was recorded in clone SI-63-016 which was statistically at par with clone NZ-1184 having 30.49 per cent (5.51) value. The minimum of 12.93 per cent (3.59) was found in clone number 212/03 which was statistically similar with clones PN-721 [14.93 per cent (3.85)], 799 [15.62 per cent (3.94)], NZ-1002 [15.74 per cent (3.96)], NZ-1179 [15.74 per cent (3.96)], 795 [16.05 per cent (4.00)]. The Kashmir willow [16.62 per cent (4.07)], 084/03 [16.91 per cent (4.11)], V-311 [16.94 per cent (4.11)], 131/25 [17.17 per cent (4.14)] and SI-64-17 [19.66 per cent (4.43)] clones were found to be statistically same. Other clones, viz. NZ-1140 [20.93 per cent (4.56)], V-11841 [22.35 per cent (4.72)], PN-227 [22.67 per cent (4.74)], MB-368 [23.74 per cent (4.86)], and also clones SI-63-007 [25.74 per cent (5.07)], PN-733 [26.81 per cent (5.17)] and 172 [28.80 per cent (5.36)] were also observed to be at par.

4.1.3 Wood percentage

The wood percentage showed significant variation among promising willow clones Table-1. The maximum percentage [87.07 per cent (9.33)] was found in clone number 212/03 which was statistically at par with clones PN-721 [85.07 per cent (9.22)], 799 [84.38 per cent

(9.18)], NZ-1002 [84.26 per cent (9.17)], NZ-1179 [84.26 per cent (9.17)], 795 [83.95 per cent (9.16)], Kashmir willow [83.38 per cent (9.13)], V-311 [83.06 per cent (9.11)], 084/03 [83.09 per cent (9.11)] and 131/25 [82.83 per cent (9.09)]. The minimum [63.87 per cent (7.99)] was recorded in clone number SI-63-016. Clones 172 [71.20 per cent (8.43)], PN-733 [73.19 per cent (8.55)], SI-63-007 [74.26 per cent (8.61)], V-99 [74.41 per cent (8.62)] and NZ-1184 [69.51 per cent (8.33)] were at par. The clones MB-368 [76.26 per cent (8.73)], PN-227 [77.33 per cent (8.79)], V-11841 [77.65 per cent (8.81)], NZ-1140 [79.07 per cent (8.89)] and SI-64-17 [80.34 per cent (8.96)], were recorded statistically similar.

Table 1: Variation in physical characteristics of wood of promising willow clones

Clone Name	Height (m)	Diameter (cm)	Bark thickness (%)	Wood (%)
Kashmir willow	6.91	7.67	16.62 (4.07)	83.38 (9.13)
NZ-1002	9.43	8.53	15.74 (3.96)	84.26 (9.17)
NZ-1140	10.77	5.53	20.93 (4.56)	79.07 (8.89)
NZ-1179	10.90	6.77	15.74 (3.96)	84.26 (9.17)
NZ-1184	7.60	4.80	30.49 (5.51)	69.51 (8.33)
795	7.22	7.90	16.05 (4.00)	83.95 (9.16)
799	10.60	8.97	15.62 (3.94)	84.38 (9.18)
084/03	7.97	9.10	16.91 (4.11)	83.09 (9.11)
131/25	11.00	7.10	17.17 (4.11)	82.83 (9.09)
212/03	12.43	9.87	12.93 (3.59)	87.07 (9.33)
V-99	6.83	5.37	25.59 (5.04)	74.41 (8.62)
V-311	11.60	7.07	16.94 (4.10)	83.06 (9.11)
V-11841	7.00	4.77	22.35 (4.72)	77.65 (8.81)
PN-227	6.83	4.80	22.67 (4.74)	77.33 (8.79)
PN-721	8.13	9.00	14.93 (3.85)	85.07 (9.22)
PN-733	6.08	5.23	26.81 (5.16)	73.19 (8.55)
MB-368	7.07	4.20	23.74 (4.86)	76.26 (8.73)
SI-63-007	6.10	4.73	25.74 (4.98)	74.26 (8.59)
SI-63-016	4.68	4.17	36.13 (6.01)	63.87 (7.97)
SI-64-17	6.72	7.00	19.66 (4.42)	80.34(8.96)
172	9.83	4.53	28.80 (5.35)	71.20 (8.43)
Mean	8.37	6.53	21.03 (4.58)	78.97 (8.88)
SE_d	0.38	0.64	0.27	0.16
CD_{0.05}	0.66	1.11	0.47	0.28

Figures in parenthesis are square root transformed values

4.2 PHYSICAL WOOD CHARACTERISTICS

4.2.1 Moisture content

The data related to moisture content presented in Table-2 showed significant variation among promising willow clones. The maximum moisture content of 110.49 per cent (2.04) noticed in clone number 131/25, which was statistically at par with clones NZ-1184 [108.31 per cent (2.04), PN-721 [101.62 per cent (2.01)] and V-311 [106.62 per cent (10.32). The minimum moisture content of 58.83 per cent (1.77) was recorded in clone number SI-63-016. The clones 084/03 [66.08 per cent (1.82)], NZ-1002 [66.14 per cent (1.82)], V-99 [66.58 per cent (1.82)], SI-64-17 [66.79 per cent (1.82)], 212/03 [67.90 per cent (1.83)], 799 [68.61 per cent (1.84)], PN-733 [69.83 per cent (1.84)] and SI-63-007 [70.43 per cent (1.85)], also clones 795 [72.56 per cent (1.86)], Kashmir willow [72.62 per cent (1.86)] and PN-227 [78.21 per cent (1.89)], also 172 [80.90 per cent (1.91)], MB-368 [81.12 per cent (1.91)] and V-11841 [84.47 per cent (1.93)] were statistically at par. The clones NZ-1179 [100.05 per cent (2.00)] and NZ-1140 [100.79 per cent (2.00)] were also found to be statistically similar for moisture content.

4.2.2 Specific gravity

The data related to specific gravity presented in Table-2 revealed significant variation among the promising willow clones. The maximum specific gravity of 0.81 was recorded in MB-368, which was statistically at par with clone numbers PN-227 (0.79) and SI-63-007 (0.79), the minimum specific gravity (0.74) was found in Kashmir willow clone (0.74), which was statistically at par with clones NZ-1140 (0.75), 084/03 (0.75), 131/25 (0.75), PN-721 (0.75) and PN-733 (0.75). Clones NZ-1179 (0.76), NZ-1184 (0.76), 795 (0.76), 799 (0.76), V-311 (0.76), SI-64-17 (0.76), NZ-1002 (0.77), 212/03 (0.77), V-99 (0.77), V-11841 (0.77), SI-63-016 (0.77) and 172 (0.77), were also observed to be on statistically same.

4.2.3 Fibre length

The data on fibre length exhibited significant variation among promising willow clones as shown in Table-2. The longest fibres were noticed in clone number 172 (1.93mm), which was at par with clone numbers SI-64-17 (1.83mm), SI-63-016 (1.72mm). Similarly, clones MB-368 (1.53mm), PN-733 (1.54mm), V-11841 (1.58mm), PN-721 (1.63mm) and PN-227 (1.68mm) and also 799 (1.43mm), SI-63-007 (1.46mm) and V-311 (1.47mm) clones were observed to be statistically same in fibre length. The shortest fibres (0.96mm) were recorded in clone number NZ-1179, which were statistically similar to Kashmir willow (1.13mm), NZ-1002 (1.04mm), NZ-1140 (1.03mm), V-99 (1.21mm), NZ-1184 (1.22mm), 212/03 (1.28mm), 131/25 (1.29mm), 795 (1.33mm) and 084/03 (1.38mm)

Table 2: Variation in moisture content, specific gravity and fibre length of wood of promising willow clones

Clone Name	Moisture content (%)	Specific gravity	Fibre length (mm)
Kashmir willow	72.62(1.86)	0.74	1.13
NZ-1002	66.14(1.82)	0.77	1.04
NZ-1140	100.79(2.00)	0.75	1.03
NZ-1179	100.05(2.00)	0.76	0.96
NZ-1184	108.31(2.04)	0.76	1.22
795	72.56(1.86)	0.76	1.33
799	68.61(1.84)	0.76	1.43
084/03	66.08(1.82)	0.75	1.38
131/25	110.49(2.04)	0.75	1.29
212/03	67.90(1.83)	0.77	1.28
V-99	66.58(1.82)	0.77	1.21
V-311	106.62(2.03)	0.76	1.47
V-11841	84.47(1.93)	0.77	1.58
PN-227	78.21(1.89)	0.79	1.68
PN-721	101.62(2.01)	0.75	1.63
PN-733	69.83(1.84)	0.75	1.54
MB-368	81.12(1.91)	0.81	1.53
SI-63-007	70.43(1.85)	0.79	1.46
SI-63-016	58.83(1.77)	0.77	1.72
SI-64-17	66.79(1.82)	0.76	1.83
172	80.90(1.91)	0.77	1.93
Mean	80.90(1.91)	0.76	1.41
SE_d	0.02	0.01	0.09
CD_{0.05}	0.03	0.02	0.16

Figures in parenthesis are logarithmic transformed values

4.3 CHEMICAL PROPERTIES

4.3.1 Cold water extractives

The data on cold water solubility in different promising willow clones were observed to be statistically significant as shown in Table-3. The highest value of 7.67 per cent (2.74) was recorded in clone number SI-64-17, which was statistically at par with clones 795 [7.17 per cent (2.67)], PN-227 [6.67 per cent (2.57)], NZ-1002 [6.50 per cent (2.54)], 212/03 [6.33 per cent (2.52)] and PN-721 [6.33 (2.52)]. The lowest value of 3.33 per cent (1.82) was obtained for clone PN-733, which was statistically at par with clone numbers 084/03 [4.00 per cent (2.00)] and SI-63-007 [4.00 per cent (1.97)]. The clones V-99 [4.67 per cent (2.15)], 799 [4.93 per cent (2.22)], Kashmir willow [5.00 per cent (2.23)], 131/25 [5.00 per cent (2.22)], V-311 [5.00 per cent (2.22)], V-11841 [5.33 per cent (2.30)], SI-63-016 [5.33 per cent (2.30)], MB-368 [6.00 per cent (2.38)], NZ-1140 [6.00 per cent (2.42)], NZ-1184 [6.00 per cent (2.43)], 172 [6.00 per cent (2.43)] and NZ-1179 [6.00 per cent (2.45)], were observed to be at par statistically.

4.3.2 Hot water soluble extractives

For hot water soluble extractives as presented in Table-3, the maximum value of 11.33 per cent (3.36) was obtained for clone number NZ-1002, which was statistically at par with clones Kashmir willow [10.67 per cent (3.26)], 131/25 [10.33 per cent (3.20)], NZ-1140 [9.67 per cent (3.10)] and 795 [9.50 per cent (3.07)]. The minimum value of 4.67 per cent (2.15) was obtained for clone 172, which was statistically at par with clones PN-721 [5.33 per cent (2.30)], NZ-1184 per cent (2.43)] and MB-368 [6.00 per cent (2.45)]. Clones 799 [6.40 per cent (2.50)], V-99 [6.50 per cent (2.54)], SI-64-17 [6.50 per cent (2.54)], V-11841 [6.67 per cent (2.55)], SI-63-007 [7.00 per cent (2.63)], PN-227 [7.33 per cent (2.68)], SI-63-016 [7.33 per cent (2.70)] and 212/03 [7.50 per cent (2.71)], also clones NZ-1179 [8.00 (2.82)], V-311 [8.33 per cent (2.88)], PN-733

[8.87], and 084/03 [8.67 per cent (2.94)], were found to be statistically at par for hot water extractives.

4.3.3 Alcohol-benzene soluble extractives

The data on alcohol-benzene extractives in different promising willow clones is presented in Table-3. The maximum alcohol-benzene soluble extractives of 7.10 per cent (2.66) were recorded in clone number PN-721, which was statistically at par with clone number PN-733 [6.57 per cent (2.56)]. The lowest value of 2.73 per cent (1.65) was obtained for Kashmir willow, which was statistically at par with clones NZ-1002 [2.77 per cent (1.66)], 084/03 [2.77 per cent (1.66)], SI-63-016 [2.83 per cent (1.68)], 172 [2.90 per cent (1.70)], MB-368 [2.97 per cent (1.72)], PN-227 [3.10 per cent (1.73)], SI-63-007 [3.03 per cent (1.74)] and 131/25 [3.27 (1.80)]. Clones NZ-1140 [3.50 per cent (1.87)], V-311 [3.80 per cent (1.94)], NZ-1179 [3.83 per cent (1.95)], 795 [3.90 per cent (1.95)] and 799 [4.03 per cent (1.98)], also clones V-11841 [4.60 per cent (2.14)], V-99 [4.63 per cent (2.14)] and SI-64-17 [4.87 per cent (2.18)], also 212/03 [5.43 per cent (2.33)] and NZ-1184 [5.73 per cent (2.39)] clones were noticed to be statistically similar for alcohol-benzene extractives.

4.3.4 Klason-lignin content

The data presented in Table-4 revealed significant variation in promising willow clones. The highest value of 26.33 per cent (5.13) was recorded in clone number V-99 which was at par with clones 212/03 [26.17 per cent (5.11)], 084/03 [26.07 per cent (5.10)], 131/25 [26.00 per cent (5.08)], NZ-1184 [25.27 per cent (5.01)] and MB-368 [24.10 per cent (4.90)]. The minimum value of 19.10 per cent (4.37) was observed in clone PN-227, which was statistically at par with clone numbers SI-63-007 [19.50 per cent (4.41)], SI-63-016 [19.83 per cent (4.45)], PN-733 [19.83 per cent (4.45)], NZ-1002 [20.50 per cent (4.52)], V-11841 [20.63 per cent (4.54)] and SI-64-17 [20.67 per cent (4.55)]. Similarly, clones NZ-1179 [21.40 per cent (4.62)], 799 [21.50 per cent (4.64)], PN-721 [21.80 per

cent (4.67)], NZ-1140 [22.00 per cent (4.69)], V-311 [22.50 per cent (4.74)], Kashmir willow [23.10 per cent (4.80)], 172 [23.17 per cent (4.81)] and 795 [23.50 per cent (4.84)], were found to be statistically similar.

Table 3: Variation in soluble extractives (cold water and hot water) and alcohol-benzene soluble extractives of wood of promising willow clones

Clone Name	Cold Water (%)	Hot Water (%)	Alcohol-benzene (%)
Kashmir willow	5.00 (2.23)	10.67 (3.26)	2.73 (1.65)
NZ-1002	6.50 (2.54)	11.33 (3.36)	2.77 (1.66)
NZ-1140	6.00 (2.42)	9.67 (3.10)	3.50 (1.87)
NZ-1179	6.00 (2.45)	8.00 (2.82)	3.83 (1.95)
NZ-1184	6.00 (2.43)	6.00 (2.42)	5.73 (2.39)
795	7.17 (2.67)	9.50 (3.07)	3.90 (1.95)
799	4.93 (2.22)	6.40 (2.50)	4.03 (1.98)
084/03	4.00 (2.00)	8.67 (2.94)	2.77 (1.66)
131/25	5.00 (2.22)	10.33 (3.20)	3.27 (1.79)
212/03	6.33 (2.51)	7.50 (2.71)	5.43 (2.33)
V-99	4.67 (2.15)	6.50 (2.54)	4.63 (2.14)
V-311	5.00 (2.22)	8.33 (2.88)	3.80 (1.94)
V-11841	5.33 (2.30)	6.67 (2.55)	4.60 (2.14)
PN-227	6.67 (2.57)	7.33 (2.68)	3.10 (1.73)
PN-721	6.33 (2.51)	5.33 (2.30)	7.10 (2.66)
PN-733	3.33 (1.82)	8.33 (2.87)	6.57 (2.56)
MB-368	6.00 (2.38)	6.00 (2.44)	2.97 (1.72)
SI-63-007	4.00 (1.97)	7.00 (2.63)	3.03 (1.73)
SI-63-016	5.33 (2.30)	7.33 (2.70)	2.83 (1.68)
SI-64-17	7.67 (2.74)	6.50 (2.54)	4.87 (2.18)
172	6.00 (2.44)	4.67 (2.15)	2.90 (1.70)
Mean	7.14 (2.66)	7.72 (2.72)	4.02 (1.98)
SE_d	0.16	0.18	0.11
CD_{0.05}	0.28	0.31	0.19

Figures in parenthesis are square root transformed values

4.3.5 Holocellulose content

The perusal of data depicted in Table-4 revealed significant variation in the holocellulose content of promising willow clones. The holocellulose content maximum value of 79.33 per cent (8.90) was recorded in clone number 131/25, which was statistically at par with clone numbers NZ-1140 [79.30 per cent (8.90)], PN-227 [79.03 per cent (8.86)], PN-721 [77.73 per cent (8.81)], SI-63-007 [77.22 per cent (8.78)], NZ-

1179 [76.07 per cent (8.72)], SI-63-016 [75.33 per cent (8.67)] and 172 [74.90 per cent (8.65)]. The minimum value of 64.27 per cent (8.01) was obtained for clone 799 which was statistically at par with clones 795 [68.37 per cent (8.26)], 084/03 [68.13 per cent (8.25)], V-99 [67.57 per cent (8.21)] and PN-733 [66.87 per cent (8.17)]. Clones V-311 [71.50 per cent (8.45)], MB-368 [71.47 per cent (8.45)], V-11841 [70.70 per cent (8.40)], Kashmir willow [70.50 per cent (8.39)], NZ-1002 [70.13 per cent (8.37)], NZ-1184 [69.57 per cent (8.33)], SI-64-17 [69.20 per cent (8.31)] and 212/03 [69.20 per cent (8.31)], were also observed to be statistically at par.

Table 4: Variation in lignin and holocellulose contents of wood of promising willow clones

Clone Name	Lignin Content (%)	Holocellulose Content (%)
Kashmir willow	23.10 (4.80)	70.50 (8.39)
NZ-1002	20.50 (4.50)	70.13 (8.37)
NZ-1140	22.00 (4.69)	79.30 (8.90)
NZ-1179	21.40 (4.62)	76.07 (8.72)
NZ-1184	25.27 (5.01)	69.57 (8.33)
795	23.50 (4.84)	68.37 (8.26)
799	21.50 (4.63)	64.27 (8.01)
084/03	26.07 (5.10)	68.13(8.25)
131/25	26.00 (5.08)	79.33 (8.90)
212/03	26.17 (5.11)	69.20 (8.31)
V-99	26.33 (5.13)	67.57 (8.21)
V-311	22.50 (4.74)	71.50 (8.45)
V-11841	20.63 (4.54)	70.70 (8.40)
PN-227	19.10 (4.37)	79.03 (8.86)
PN-721	21.80 (4.66)	77.73 (8.81)
PN-733	19.83 (4.45)	66.87 (8.17)
MB-368	24.10 (4.90)	71.47 (8.45)
SI-63-007	19.50 (4.41)	77.22 (8.78)
SI-63-016	19.83 (4.45)	75.33 (8.67)
SI-64-17	20.67 (4.54)	69.20 (8.31)
172	23.17 (4.81)	74.90 (8.65)
Mean	22.52 (4.74)	72.21 (8.47)
SE_d	0.14	0.16
CD_{0.05}	0.24	0.28

Figures in parenthesis are square root transformed values

4.4 SIMPLE CORRELATION COEFFICIENT

The values for simple correlation coefficients between physico-chemical characteristics of promising willow clones are presented in Table-5. The significant positive correlation to the tune of 0.86 was observed between diameter and wood percentage followed by height vs. wood percentage (0.61), height vs. diameter (0.51), holocellulose vs. moisture content (0.50) and height vs. moisture content (0.47). Highly significant negative correlation value of -1.00 was found between wood and bark percentage followed by diameter vs. bark percentage (-0.86), hot water extractives vs. fibre length (-0.64), height vs. bark percentage (-0.61) and specific gravity vs. diameter (-0.49).

4.5 VARIABILITY AND CORRELATION STUDIES

4.5.1 Estimate of heritability, genetic advance, genetic gain and variability

The values for mean, range, standard deviation, and phenotypic and genotypic coefficients of variability for physical and chemical parameters of wood are presented in Table-6. Among all these characters, moisture content showed the widest range (58.83-110.49 per cent), with mean value of 80.90 per cent, followed by wood percentage (63.87-87.07 per cent), with mean value of 78.97 percentage, holocellulose content (64.27-79.33 per cent, mean 72.21 per cent), bark percentage (12.93-36.13 per cent, mean 21.30 per cent), lignin content (19.10-26.33 per cent, mean 22.52 per cent), hot water extractives (5.33-11.33 per cent, mean 7.72 per cent), diameter (4.17-9.87cm, mean 6.53cm), cold water extractives (3.33-7.67 per cent, mean 5.58 per cent), alcohol-benzene extractives (2.73-7.10 per cent, mean 4.02 per cent), height (4.68-12.43m, mean 8.37m), fibre length (0.96-1.93mm, mean 1.41mm) and the narrowest range was found in specific gravity (0.74-0.81, mean 0.76). The minimum and maximum standard deviation was found in specific gravity (0.02) and moisture content (17.12). Alcohol-



Plate 1: Variation in fibre length of wood of promising willow clones



Plate 2: Holocellulose residue



Plate 3: Lignin residue

Table 5: Simple correlation coefficient between physico-chemical characteristics of wood of promising willow clones

	Specific gravity	Alcohol-benzene soluble extractives (%)	Lignin percentage	Cold water extractives (%)	Hot water extractives (%)	Holocellulose percentage	Height (m)	Diameter (cm)	Fibre length (mm)	Moisture content (%)	Bark percentage	Wood percentage
Specific gravity	1											
Alcohol-benzene soluble extractives (%)	-0.29	1										
Lignin percentage	-0.18	0.04	1									
Cold water extractives (%)	0.16	0.04	-0.06	1								
Hot water extractives (%)	-0.41	-0.38	0.03	-0.09	1							
Holocellulose percentage	0.13	-0.24	-0.25	0.16	0.03	1						
Height (m)	-0.24	-0.01	0.37	0.14	0.19	0.09	1					
Diameter (cm)	-0.49*	0.21	0.36	0.14	0.38	-0.32	0.51*	1				
Fibre length (mm)	0.30	0.05	-0.30	0.09	-0.14	0.06	-0.39	-0.32	1			
Moisture content (%)	-0.23	0.19	0.32	0.11	-0.01	0.50*	0.47*	-0.08	-0.23	1		
Bark percentage	0.33	-0.10	-0.21	-0.23	-0.38	0.12	-0.61**	-0.86**	0.41	-0.14	1	
Wood percentage	-0.33	0.10	0.21	0.23	0.38	-0.12	0.61**	0.86**	-0.41	0.14	-1.00**	1

*Significant at 5 percent level of significance

** Significant at 1 percent level of significance

benzene extractives had the highest coefficient of variation (35.94 per cent) while specific gravity showed the minimum coefficient of variation (2.47).

Table 6: General mean, range, standard deviation and coefficient of variance of wood of promising willow clones

Parameter	Mean	Range	S.D.	C.V.
Diameter (cm)	6.53	4.17-9.87	2.03	31.16
Height (m)	8.37	4.68-12.43	2.20	26.27
Wood percentage	78.97	63.87-87.07	7.09	8.97
Bark percentage	21.03	12.93-36.13	7.09	33.70
Moisture content (%)	80.90	58.83-110.49	17.12	21.16
Specific gravity	0.76	0.74-0.81	0.02	2.47
Fibre length (mm)	1.41	0.96-1.93	0.34	24.18
Cold water extractives (%)	5.58	3.33-7.67	1.56	27.89
Hot water extractives (%)	7.72	5.33-11.33	2.22	28.79
Alcohol-benzene extractives (%)	4.02	2.73-7.10	1.44	35.94
Lignin percentage	22.52	19.10-26.33	2.96	13.14
Holocellulose percentage	72.21	64.27-79.33	5.89	8.16

The estimates of heritability, genetic advance, genetic gain, phenotypic and genotypic coefficients of variability for physical and chemical characteristics of wood of promising willow clones are presented in Table-7 and 8. Among the physical parameters (Table-7), maximum heritability value was shown by height which was 0.92 (92.00 per cent) and minimum of 0.59 (59.00 per cent) was recorded for wood and bark percentage. Highest value of genetic advance (31.20) was recorded in moisture content and the lowest (0.03) for specific gravity. The highest (50.18 per cent) and lowest (3.95 per cent) genetic gain values were recorded for height and specific gravity, respectively. The phenotypic (34.21 per cent) and genotypic (26.77 per cent) coefficients of variability showed highest values for bark percentage and diameter, respectively, whereas the lowest values was observed in specific gravity, respectively. For chemical parameters of wood of promising willow clones (Table-8), maximum heritability of 0.73 (73 per cent) was recorded for alcohol-benzene extractives and minimum of 0.24 (24 per cent) for cold water soluble extractives.

Table 7: Estimates of heritability, genetic advance, genetic gain and variability for physical characteristics of wood of promising willow clones

Character	Heritability	Genetic Advance	Genetic Gain (%)	Variability	
				PCV (%)	GCV (%)
Diameter (cm)	0.72	3.04	46.55	31.66	26.77
Height (m)	0.92	4.20	50.18	26.61	25.45
Wood percentage	0.59	8.68	10.99	9.11	6.97
Bark percentage	0.59	8.68	41.27	34.21	26.18
Moisture content (%)	0.87	31.20	38.57	21.47	20.05
Specific gravity	0.69	0.03	3.95	2.51	2.09
Fibre length (mm)	0.74	0.45	31.91	20.56	17.73

Genetic advance (Table-8) was observed maximum in holocellulose (4.64) and the minimum values was found in cold water extractives (0.77). The maximum genetic gain (53.73 per cent) was found in alcohol-benzene extractives and minimum (3.95 per cent) was obtained for specific gravity. The highest values for phenotypic and genotypic coefficients of variability were 35.63 and 30.49 per cent, respectively, for alcohol-benzene extractives. The lowest values of 2.51 and 2.09 per cent were obtained for phenotypic and genotypic coefficients of variability respectively, for specific gravity.

Table 8: Estimates of heritability, genetic advance, genetic gain and variability for chemical characteristics of wood of promising willow clones

Character	Heritability	Genetic Advance	Genetic Gain (%)	Variability	
				PCV (%)	GCV (%)
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 extractives (%)	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

4.5.2 Genotypic, phenotypic and environmental correlation coefficients

4.5.2.1 Physical parameters

The data pertaining to genotypic, phenotypic and environmental correlation coefficients for physical parameters of wood of promising willow clones is presented in Table-9.

i) Genotypic correlation coefficients: Highly significant positive correlation value of 0.90 was obtained between diameter and wood percentage followed by height vs. wood percentage (0.66), moisture content vs. holocellulose (0.63), height vs. diameter (0.51), height vs. moisture content (0.50), hot water extractives vs. wood percentage (0.50) and fibre length vs. bark percentage (0.49).

Highly negative correlation to the tune of -1.00 was recorded between wood and bark percentage followed by diameter vs. bark percentage (-0.90), hot water extractives vs. fibre length (-0.84), height vs. bark percentage (-0.66), specific gravity vs. hot water extractives percentage (-0.57), alcohol-benzene extractives vs. hot water extractives percentage (-0.56), diameter vs. specific gravity (-0.52), hot water extractives vs. bark percentage (-0.50), fibre length vs. wood percentage (-0.49) and holocellulose percentage vs. diameter (-0.47). Rest of the values for genotypic correlation coefficients were found to be non significant.

ii) Phenotypic correlation coefficient: Highly significant positive phenotypic correlation coefficient to the tune of 0.80 was observed between diameter and wood percentage followed by height vs. wood percentage (0.54) and height vs. diameter (0.50). Highest significant negative correlation coefficient (-1.00) was obtained between wood and bark percentage followed by diameter vs. bark percentage (-0.80) and height vs. bark percentage (-0.54). The rest of the characters had recorded non-significant correlation coefficient values.

iii) **Environmental correlation coefficient:** Highly significant positive environmental correlation coefficient (0.63) was obtained between diameter and wood percentage followed by height vs. diameter (0.57). Highly significant negative correlation coefficient to the tune of -1.00 was found between wood and bark percentage followed by diameter vs. bark percentage (-0.63). The rest of the characters have recorded non-significant correlation coefficient values.

Table 9: Genotypic, phenotypic and environmental correlation coefficients between physical characteristics of wood of promising willow clones

character		Fibre length (mm)	Height (m)	Diameter (m)	Moisture content (%)	Bark %age	Wood %age
Specific gravity	G	0.42	-0.29	-0.52*	-0.29	0.40	-0.40
	P	0.25	-0.29	-0.46	-0.21	0.34	-0.34
	E	-0.19	-0.36	-0.32	0.08	0.22	-0.22
Fibre length (mm)	G		-0.42	-0.37	-0.26	0.49*	-0.49*
	P		-0.32	-0.25	-0.19	0.31	-0.31
	E		0.17	0.07	0.10	-0.05	0.05
Height (m)	G			0.51*	0.50*	-0.66**	0.66**
	P			0.50*	0.42	-0.54*	0.54*
	E			0.57*	-0.21	-0.30	0.30
Diameter (m)	G				-0.07	-0.90**	0.90**
	P				-0.10	-0.80**	0.80**
	E				-0.22	-0.63**	0.63**
Moisture content (%)	G					-0.16	0.16
	P					-0.13	0.13
	E					-0.06	0.06
Bark %age	G						-1.00**
	P						-1.00**
	E						-1.00**

* Significant at 5 percent level of significance

** Significant at 1 percent level of significance

4.5.2.2 Chemical parameters

The data pertaining to genotypic, phenotypic and environmental correlation coefficients for chemical parameters of wood of promising willow clones is presented in Table-10.

i) **Genotypic correlation coefficients:** Highly significant positive correlation value of 0.97 was found between alcohol-benzene extractives and lignin content followed by cold water extractives vs. alcohol-benzene extractives (0.68). The significant negative correlation value of -0.65 was observed between lignin content and Holocellulose.

ii) **Phenotypic correlation coefficients:** Highly significant negative correlation value of -0.71 was noticed between hot water extractives and alcohol-benzene extractives. The other parameters showed non significant correlation among parameters.

iii) **Environmental correlation coefficients:** All values were found to be non significant these among parameters regarding environmental correlation coefficients.

Table 10: Genotypic, phenotypic and environmental correlation coefficients between chemical characteristics of wood of promising willow clones

Character		Hot water extractives (%)	Alcohol-benzene extractives (%)	Lignin (%)	Holocellulose (%)
Cold water extractives (%)	G	-0.34	0.68**	0.30	0.14
	P	-0.08	0.14	-0.38	-0.03
	E	-0.12	0.30	-0.43	-0.21
Hot water extractives (%)	G		-0.15	-0.21	-0.06
	P		-0.71**	-0.27	0.10
	E		0.56*	0.21	0.40
Alcohol-benzene extractives (%)	G			0.97**	-0.17
	P			0.39	-0.07
	E			-0.20	0.36
Lignin (%)	G				-0.65**
	P				-0.14
	E				0.16

* Significant at 5 percent level of significance

** Significant at 1 percent level of significance

4.5.2.3 Physico-chemical parameters

The data pertaining to genotypic, phenotypic and environmental correlation coefficients for physico-chemical parameters of wood of promising willow clones is presented in Table-11.

i) **Genotypic correlation coefficients:** Highly significant positive correlation value of 0.90 was obtained between diameter and wood percentage followed by height vs. wood percentage (0.66), moisture content vs. holocellulose (0.63), height vs. diameter (0.51), height vs. moisture content (0.50), hot water extractives vs. wood percentage (0.50) and fibre length vs. bark percentage (0.49).

Highly negative correlation to the tune of -1.00 was recorded between wood and bark percentage followed by diameter vs. bark percentage (-0.90), hot water extractives vs. fibre length (-0.84), height vs. bark percentage (-0.66), specific gravity vs. hot water extractives percentage (-0.57), alcohol-benzene extractives vs. hot water extractives percentage (-0.56), diameter vs. specific gravity (-0.52), hot water extractives vs. bark percentage (-0.50), fibre length vs. wood percentage (-0.49) and holocellulose percentage vs. diameter (-0.47). Rest of the characters had non-significant relationships.

ii) **Phenotypic correlation coefficients:** Highly positive correlation coefficient value of 0.80 was found between diameter and wood percentage followed by height vs. wood percentage (0.54) and height vs. diameter (0.50). Highly negative correlation coefficient value of -1.00 was found between bark percentage and wood percentage followed by diameter vs. bark percentage (-0.80) and height vs. bark percentage (-0.54). The rest of the characters did not show significant relationships.

iii) **Environmental correlation coefficients:** Highly significant positive environmental correlation coefficient (0.63) was obtained between diameter and wood percentage followed by height vs. diameter (0.57). Highly significant negative correlation coefficient to the tune of -1.00 was found between wood and bark percentage followed by diameter vs. bark percentage (-0.63). The rest of the characters have recorded non-significant correlation coefficient values. The rest of characters had non-significant relationships.

Table 11: Genotypic, phenotypic and environmental correlation coefficients between physico-chemical characteristics of promising willow clones

character		Alcohol-benzene extractives (%)	Lignin content (%)	Cold water extractives (%)	Hot water extractives (%)	Holocellulose content (%)	Height (m)	Diameter (cm)	Fibre length (mm)	Moisture content (%)	Bark percentage	Wood percentage
Specific gravity	G	-0.29	-0.21	0.34	-0.57*	0.11	-0.29	-0.52*	0.42	-0.29	0.40	-0.40
	P	-0.23	-0.06	0.06	-0.38	0.13	-0.29	-0.46	0.25	-0.21	0.34	-0.34
	E	-0.08	0.13	-0.16	-0.14	0.17	-0.36	-0.32	-0.19	0.08	0.22	-0.22
Alcohol-benzene extractives (%)	G		0.07	-0.03	-0.56*	-0.34	-0.01	0.16	0.10	0.23	-0.06	0.06
	P		0.01	0.10	-0.17	-0.14	-0.01	0.18	0.10	0.19	-0.06	0.06
	E		-0.07	0.24	0.42	0.09	0.02	0.24	0.08	0.03	-0.04	0.04
Lignin content (%)	G			-0.02	-0.08	-0.36	0.42	0.34	-0.40	0.23	-0.21	0.21
	P			-0.09	0.13	-0.15	0.29	0.26	-0.24	0.16	-0.23	0.23
	E			-0.13	0.29	-0.01	0.11	0.18	-0.03	0.05	-0.24	0.24
Cold water extractives (%)	G				-0.22	0.02	0.20	0.21	0.18	0.19	-0.40	0.40
	P				-0.01	0.25	0.11	0.09	0.03	0.04	-0.11	0.11
	E				0.10	0.36	0.07	0.01	-0.11	-0.16	0.08	-0.08
Hot water extractives (%)	G					-0.04	0.22	0.34	-0.84**	-0.04	-0.50*	0.50*
	P					0.10	0.15	0.37	-0.41	0.02	-0.34	0.34
	E					0.19	0.04	0.44	0.24	0.18	-0.18	0.18
Holocellulose content (%)	G						0.10	-0.47*	0.07	0.63**	0.14	-0.14
	P						0.09	-0.16	0.05	0.37	0.11	-0.11
	E						0.14	0.19	0.03	0.02	0.09	-0.09
Height (m)	G							0.51*	-0.42	0.50*	-0.66**	0.66**
	P							0.50*	-0.32	0.42	-0.54*	0.54*
	E							0.57*	0.17	-0.21	-0.30	0.30
Diameter (cm)	G								-0.37	-0.07	-0.90**	0.90**
	P								-0.25	-0.10	-0.80**	0.80**
	E								0.07	-0.22	-0.63**	0.63**
Fibre length (mm)	G									-0.26	0.49*	-0.49*
	P									-0.19	0.31	-0.31
	E									0.10	-0.05	0.05
Moisture content (%)	G										-0.16	0.16
	P										-0.13	0.13
	E										-0.06	0.06
Bark percentage	G											-1.00**
	P											-1.00**
	E											-1.00**

* Significant at 5 percent level of significance

** significant at 1 percent level of significance

Chapter-5

DISCUSSION

The present investigations were carried out on the “**Studies on physico-chemical characteristics of wood of promising Willow clones**” with the aim to study the extent and pattern of variation in wood characteristics among different promising willow clones. The physico-chemical properties of wood are important parameters for the preliminary characterization of lignocellulosic raw material and its potentiality for pulp and paper, fuelwood and for certain other related uses. The variation in wood characteristics may be attributed either to the genotypic or environmental/site factors.

The genus *Salix*, commonly known as willow has many species having potential to raise as short rotation coppice tree crop and the plantations of fast growing clones can supplement the increasing demand of lignocellulosic raw material. The best performing clones from their worldwide distribution areas were introduced at our University campus by Department of Tree Improvement and Genetic Resources. In the present investigations, four year old plantations of these clones are evaluated for the physico-chemical characteristics of their wood.

Willows have wide range of distribution accompanied with considerable amount of variability which is to be trapped according to our specific objectives like to grow for a specified end use along the road sides, as a shade tree in the gardens, as a component of agroforestry system and for rehabilitation of degraded woodlands. The wood of willows is soft, light, pliant and tough. Willow sawn timber is suitable for joinery, decorative paneling, wood work, battens, block boards, 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 (cricket bats), play things, carved

wood and tool handles (Leclercq, 1997). This species becomes a material of paramount importance to be worked upon especially for its future benefits owing to its diverse uses. The results obtained from the present study has been discussed in this chapter to establish cause and affect relationship among various parameters studied to draw information in the light of available literature in the following headings:

5.1 GROWTH PERFORMANCE

5.1.1 Height and diameter

In the present study both height and diameter have shown significant variation among promising willow clones (Figure-1). This variation could be attributed to the genetic constitution, environment and the interaction with the microsite. The sensitivity of height growth to the microsite in *Dryobalanops lanceolata* has been explained by Jaffrin and Kelvin (2009) and in *Salix discolor* and *S. viminalis* by Labrecque and Teodorescu (2003) and the heredity control per height growth has been emphasized by Kumar *et al.* (2005a).

Kwon *et al.* (2007) reported that analysis of variances for height and diameter have shown significant variations due to provenance, site and provenance site interaction in *Pinus rigida* x *P. taeda*. Zeng *et al.* (2006) while working in *Cunninghamia lanceolata* and Tunctaner (2002) in 53 willow (*Salix* sp.) clones have also reported significant variation in height and diameter growth of different provenances. These results are also in conformity with the findings of Nguyen *et al.* (2009) in *Acacia mangium*, *A. auriculiformis* and artificial acacia hybrid clones. Himmapan *et al.* (2009) has also shown similar results in *Azadirachta indica* provenances.

5.1.2 Bark and wood percentage

The data on bark percentage of different promising willow clones have shown significant variation among the tested clones. This bark

percentage is dependent upon the genetic material of the trees, hence variability of bark percentages in the selected promising willow clones is about to be there. The maximum bark thickness value is found to be about 36.13 per cent higher in clone SI-63-016 as compared to the other clones. These results are in agreement with Kumar *et. al.* (2005a) in *Dalbergia sissoo*. They recorded maximum value in Dhartaloh-L (28.03 per cent) *Dalbergia* clone compared to other clones studied. Popovic and Todorovic (2006) have reported that variation of bark thickness with tree age.

In the present investigations on the wood percentage of twenty one clones of willow has also shown significant variation. This variation may be attributed to variable growth potential of different clones. Popovic and Todorovic (2006) have also reported variation of sapwood and heartwood in the *Quercus petraea*. The maximum wood percentage (87.07 per cent) has been observed in clone 212/03 as compared to the other clones. This finding receives support from the similar findings by Kumar *et. al.* (2005a) in *Dalbergia sissoo*. It emphasized that the increased wood percentage may due to provenance, site and province and site interactions in the species. Apart from this, wood percentage is dependent upon the genetic material of the trees; hence variability of wood percentage in the selected promising willow clones is expected.

5.2 PHYSICAL WOOD CHARACTERISTICS

5.2.1 Moisture content (%)

Significant variation has been observed for moisture content of the wood samples taken from promising willow clones. The maximum moisture content (110.49 per cent) was recorded in 131/25 willow clone and minimum in SI-63-016 (58.83 per cent). Increased moisture content percentage in all the promising willow clones might be due to the variation in wood percentage and also due to the variation in wood porosity among different clones which affect the moisture content. However, similar

results are reported by El Baha *et. al.* (2002) in *Leucaena leucocephala*, where they have obtained maximum 119.32 per cent of moisture content and also by Nicholls *et. al.* (2003) in *Tsuga heterophylla*, where maximum moisture content is reported to be 149.7 per cent.

5.2.2 Specific gravity

There is significant difference in specific gravity of the tested willow clones. The maximum specific gravity is recorded in MB-368 (0.81) and minimum in Kashmir willow (0.74). Extractives are located mainly in the cell lumen. So they fill vacant space in the wood and thus decrease the porosity and thereby increase the specific gravity. Even the variable lignin deposition on the cell wall influences the specific gravity of the wood. The present study is congruous with the study of Monteoliva *et. al.* (2005), who has also reported significant differences in the specific gravity among different willow clones. The significant variation in the specific gravity of wood has also been noticed by Cox *et. al.* (2001) in *Shorea acuminata*, *S. ovalis*, *S. leprosula* and *Dryobalanops aromatica*, who have reported that specific gravity is heritable and the difference between clones are due to the genetic make up of the clones. The specific gravity has shown significant variation among selected promising willow clones studied. 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.* (2005a) in *Dalbergia sissoo*.

5.2.3 Fibre length

There is significant variation in fibre length of different selected promising willow clones. The maximum fibre length of 1.93mm is recorded in 172 and minimum of 0.96mm in NZ-1179 willow clones. Sykes *et. al.* (2006) have reported that fibre length is genetically controlled and is not under influence of environmental fluctuation. But environment in

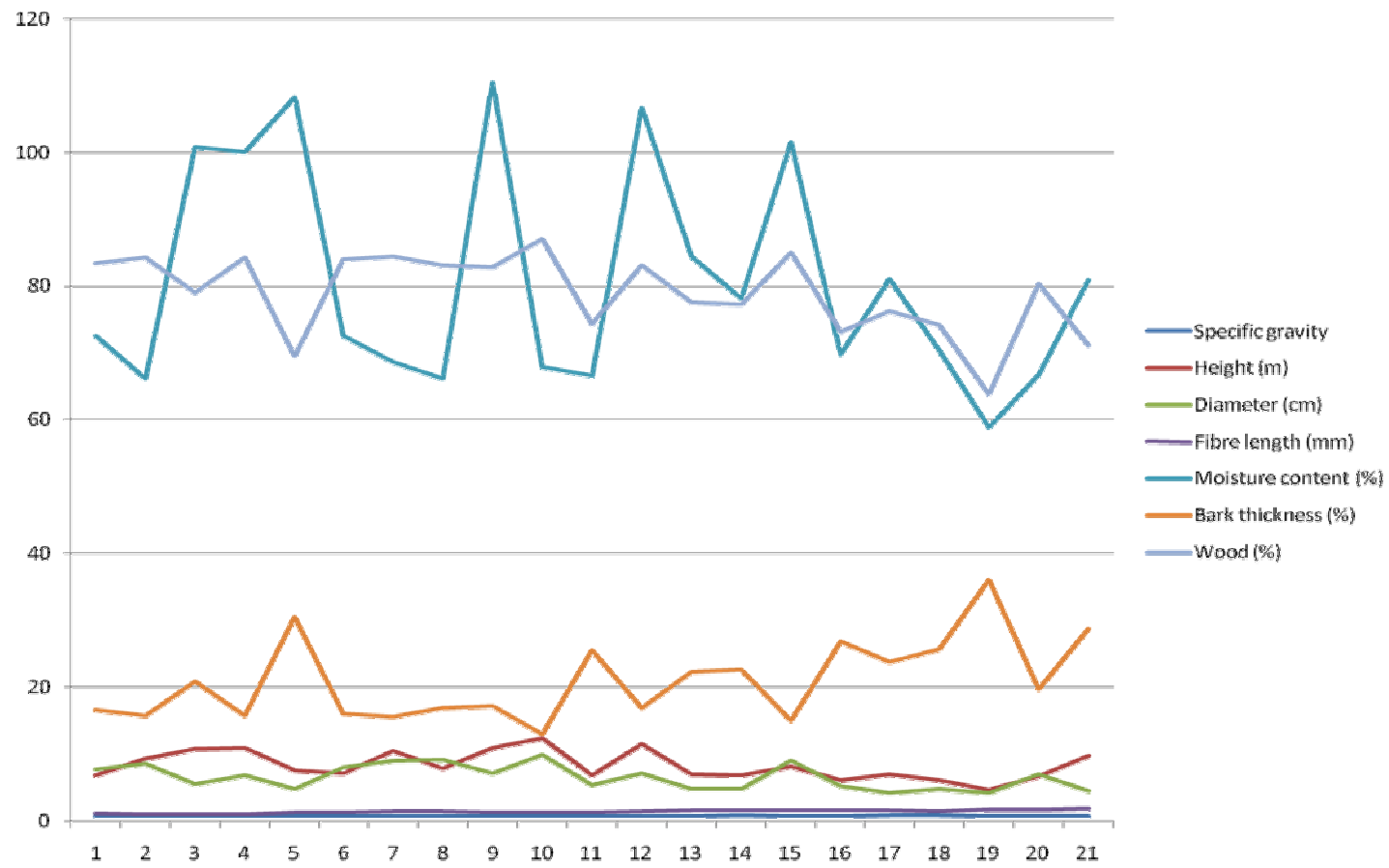


Figure 1: Variation in physical characteristics of wood promising willow clones

combination with genetic variability also plays an important role in the alteration of fibre length as has shown by Tesfaye (2007). Jiang *et. al.* (2004) also observed significant variation in fibre length of poplars varieties and El Baha (2002) in *Leucaena leucocephala*.

5.2.4 Extractives

The species containing large amount of extractives have better durability, dimensional stability and plasticization. The species which contain phenolic extractives reduce the weathering and drying qualities (Sandermann and Schwarz, 1956). The heartwood in *Dalbergia sissoo* contains more extractives than the sapwood, which is adduced to explain the better plasticization of heartwood (Narayanamurti and Das, 1955). The content, type and position of extractives affect the strength properties of wood (Narayanamurti and Verma, 1964). For these reasons, it is imperative to study the extractives present in wood. The cold water solubility contents are generally tannins, gums, sugars and salts while, the hot water soluble contents of wood are tannins, gums, sugars, salts and phenols. The components soluble in alcohol-benzene are oleoresins, fats and waxes.

The significant differences are noticed (Figure-2) among different willow clones studied for cold and hot water soluble extractives of wood. This variation is due to the varied level of accumulation of extractives in different promising willow clones studied. The variation in wood extractives has been reported by Kumar *et. al.* (2005a) in *Dalbergia sissoo*, Orea *et. al.* (2005) in *Eucalyptus saligna*, Silva *et. al.* (2005) in *Eucalyptus grandis*, Esteves *et. al.* (2005) in *Pinus pinaster* Ait., Bautista Hernandez and Honorato Salazar (2006) in *Quercus coccolobifolia*, *Q. durifolia*, *Q. rugosa* and *Q.oleoides* and Gierlinger *et. al.* (2004) in *Larix* species.

Alcohol-benzene solubility of wood is an important character representing extractives present in wood which affect the pulping quality.

Statistically significant differences are observed for alcohol-benzene solubility with maximum extractives of 7.10 per cent in clone PN-721 and minimum of 2.73 per cent in Kashmir willow clone. The present investigations are similar to the studies of Liang (2004) in *Acacia mangium*, Mahdavi *et. al.* (2004) in *Eucalyptus camaldulensis*, Bautista Hernandez and Honorato Salazar (2006) in *Quercus coccolobifolia*, *Q. durifolia*, *Q. rugosa* and *Q.oleoides* and Fakhrian *et. al.* (2005) in *Alnus glutinosa*. These species are found growing in different varied habitat hence have variation in growth, so accumulation of extractives may be variable.

The significant differences have been observed among different promising willow clones studied for cold water, hot water and alcohol-benzene soluble extractives of wood. 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*.

5.2.5 KLASON LIGNIN AND HOLOCELLULOSE CONTENT

It is evident from the Figure-2 that there is significant variation of lignin and holocellulose content among promising willow clones. The values for lignin and holocellulose content ranged between 19.10-26.33 and 64.27-79.33 percent, respectively. Bealeam and Harkin (1975) have reported that lignin content varies among species, individual and within plant. The possible reason for variation in cell wall constituents can be assigned to the varied production of dry matter. The lignocellulosic materials having higher lignin have lower holocellulose content and vice-versa (Sharma, 1997).

In present study, there is significant difference in both holocellulose and lignin contents of wood. 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*

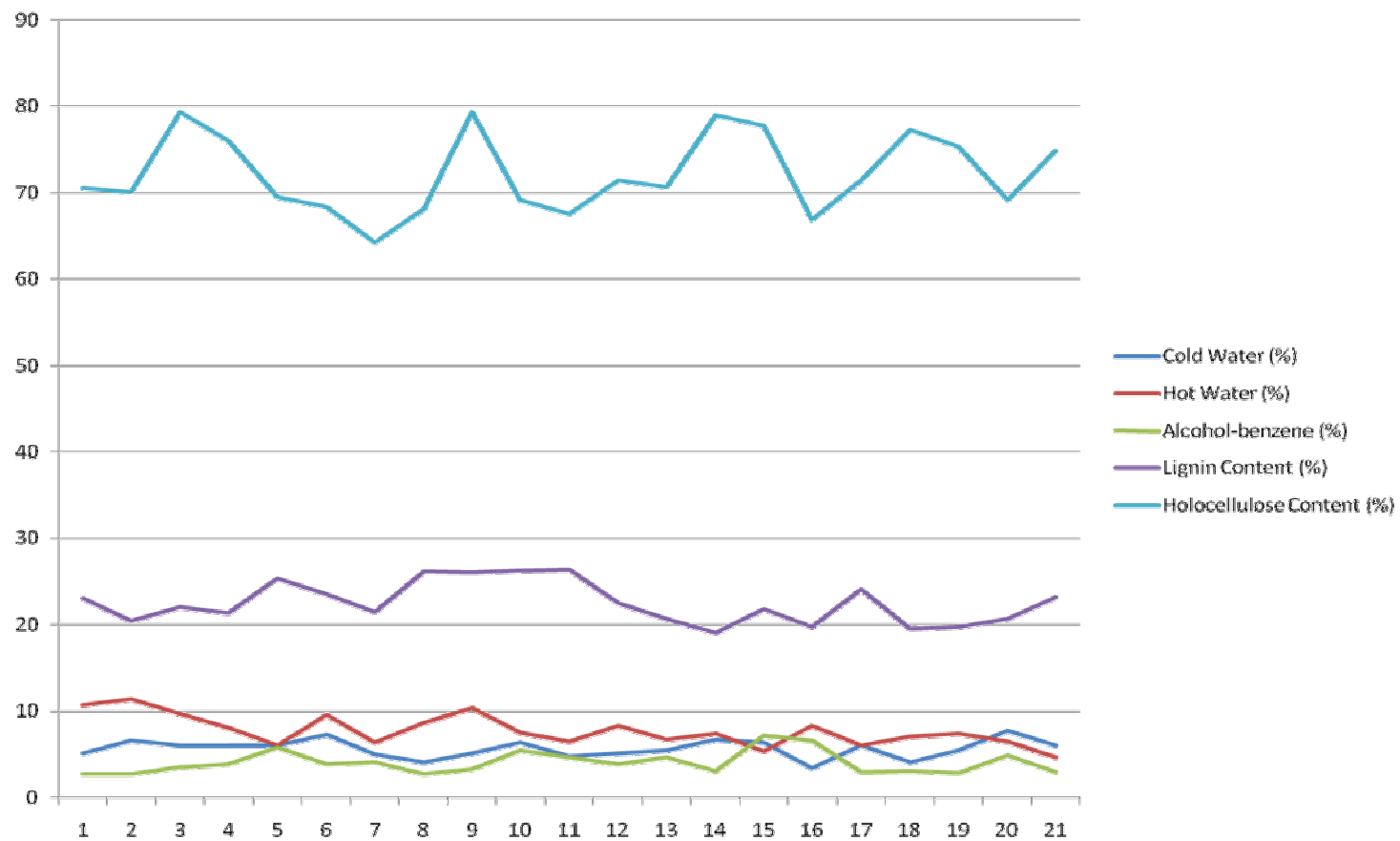


Figure 2: Variation in chemical characteristics of wood of promising willow clones

and Bealeam and Harkin (1975) in *Eucalyptus* hybrid also reported the similar findings.

5.3 GENERAL MEAN, RANGE, STANDARD DEVIATION (S.D.) AND COEFFICIENT OF VARIANCE (C.V.)

Significant variations are observed among the promising willow clones with regard to the physico-chemical characteristics. Therefore, the data for different promising willow clones have been pooled for calculation of variability estimates and genetic parameters for different characters. Variability has been estimated in terms of range, mean, standard deviation and coefficient of variance.

Critical appraisal of Table-6 shows that moisture content has the widest range (58.83-110.49 per cent, mean 80.90 per cent) followed by holocellulose content (64.27-79.33 per cent, mean 72.21 per cent). Minimum range was shown by specific gravity (0.74-0.81, mean 0.76). Though the maximum standard deviation has been found in moisture content (17.12), but the minimum standard deviation was found in specific gravity (0.02). The highest and the lowest values for the coefficient of variance are observed in alcohol-benzene extractives (35.94 per cent) and specific gravity (2.47 per cent), respectively. As explained in earlier paragraphs moisture content shows variation due to variable wood porosity and similarly Holocellulose content is also dependent on the growth of the clones. Hence these results are in accordance to the earlier findings of various workers (Kwon *et. al.* 2007, El Baha *et. al.* 2002 and Szczukowski *et. al.* 2008).

5.4 SIMPLE CORRELATION COEFFICIENT BETWEEN PHYSICO-CHEMICAL CHARACTERISTICS OF PROMISING WILLOW CLONES

Simple correlation coefficient depicts a relationship between two characters. The positive correlation value depicts that increase in one parameter will show the increase in the other, while negative value shows decrease in one with increase in the other or vice versa. Highly significant

positive correlation coefficient is observed in growth parameter i.e. diameter vs. wood percentage, height vs. wood percentage and diameter vs. height. Similar relationships have been found by Kumar and Sharma (2005) in *Dalbergia sissoo* (height, diameter, sapwood and heartwood percentage), Semple *et. al.* (1999) in *Acacia mangium* (diameter vs. heartwood percentage), Wang Kesheng *et. al.* (1996) in poplar clones (height vs. diameter).

For physical wood characteristics significant positive correlation is observed between specific gravity and fibre length. Luxmi *et. al.* (2001) also observed similar type of correlation in *Populus deltoides*.

The negative relationship was found between growth parameters like wood percentage vs. bark percentage, bark percentage vs. diameter, bark percentage vs. height. It is obvious, that increase in wood percentage will result in decrease in bark percentage and vice-versa. The similar type of relationship has also existed in hot water extractives vs. fibre length and specific gravity vs. diameter.

5.5 ESTIMATION OF VARIABILITY AND GENETIC PARAMETERS

Variation refers to the observable differences in individuals for a particular trait. These differences may be partly due to genotypic factors and partly due to the environmental effects. The combined reflection of both these factors is the phenotypic effect. The observed value of a trait measured on an individual is the phenotypic value of that individual. The relative magnitude of these components determines the genetic properties of any particular species.

For the proper utilization of observed variation in a species, it is a requisite to know the extent of variation, and also that whether it is due to the genetic or the environmental factors. Hence, information on variation in the desired parameters and their correlation is vital for any breeding programme (Johnson *et. al.*, 1955). Therefore, a species exhibiting wide variability (in terms of wide range of parameters value and high standard deviation, variance, coefficient of variation and genotypic coefficient of

variation) offer ample scope for undertaking screening for the desired traits.

In the present studies, the results obtained (Tables-6, 7, 8) with regards to variability of parameters for different characters indicate that the values have a wide range depicting the presence of good amount of variation. The genotypic variances indicate the presence of large amounts of genetic component. This is accompanied with high heritability and high genetic gain.

The observed variation in a character is partly composed of heritable variation and partly of non heritable. The proportion of total variation, which is heritable, is termed as the heritability in broad sense (Lush, 1937). Heritability provides a measure of genetic variation upon which all the possibilities of changing the genetic composition of the species depend. In other words knowledge of its magnitude gives an idea about the scope for affecting genetic improvement, through selection etc., while genetic gain gives the relative measurement of change produced by selection in mean genetic level of species. This is the mean genotypic value for a particular trait of the selected individuals in relation to the entire population. High heritability is recorded in height about 0.92, followed by moisture content (0.87), fibre length (0.74), alcohol-benzene extractives (0.73), diameter (0.72) and specific gravity (0.69), which indicates that these are least influenced by the environment. These findings are in conformity with those reported by Kumar (2007), Tesfaye *et. al.* (2007), Hou *et. al.* (2006), Yang (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 acutissima* (Toda *et. al.* 1994).

5.6 GENOTYPIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS

The expression of overall merit, is sum total of the contribution of several attributes. Therefore, selection based on various components

contributing towards the manifestation of character is likely to be more effective and rewarding. For this purpose the understanding of inter-relationship among different components is necessary. The biometrical tool for helping this is correlation which gives the degree and magnitude of relationship of one character with other character. But by computing simple correlations it will be misleading as it is composed of both genotypic as well as environmental correlations, therefore, to avoid this, we go for computation of correlation coefficients at genotypic, phenotypic and environmental levels as well.

Genetic correlation gives an idea about the extent to which the two characters are under the control of the same set of genes or have the same physiological basis for their expression. If correlation coefficient is high than pleiotropy is more conspicuous but if the traits are inherited independently then they are under the control of different sets of genes (Jain, 1982). Correlation studies has shown that for most of the growth parameter pairs, genotypic and phenotypic associations are in the same direction and genotypic estimates are higher than the phenotypic ones, indicating an inherent association between these characters. The characters which are highly correlated could be directly used for selection. Highly significant positive genotypic and phenotypic correlation is obtained between diameter vs. wood percentage and diameter vs. bark percentage. Similar results are reported by Kumar (2007) in *Gmelina arborea* and Fries and Eriesson (1998) in Scot pine. In general, the genotypic correlation coefficients are more than phenotypic ones which indicates that this could be either due to modifying effect of the environment or the strong inherent association of these characters at genetic level. Similarly, in the present investigations, the correlation coefficients at genotypic level are higher than those at phenotypic and environmental level for various physico-chemical properties of the willow clones.

Chapter-6

SUMMARY AND CONCLUSION

The present investigations entitled, “**Studies on physico-chemical characteristics of wood of promising Willow clones**” carried out to study variation within promising willow clones with respect to their physico-chemical properties. The results obtained from the experiments are summarized as below:

Among different promising willow clones, significant differences were observed for all characters. The maximum height, diameter and wood percentage were recorded in clone 212/03 while minimum for the same parameters were found in clone SI-63-016. The maximum bark percentage was observed in clone SI-63-016 while minimum was noticed in clone 212/03.

The highest moisture content was observed in clone 131/25 and minimum was found in SI-63-016 clone. The maximum specific gravity value was noticed in MB-368 clone while minimum was observed for Kashmir willow clone. The fibre length maximum value was recorded for 172 clone and minimum value was found for Nz-1179 clone. The highest values for cold water, hot water and alcohol-benzene extractives were noticed for SI-64-17, NZ-1002 and PN-721, respectively. The lowest values for cold water, hot water and alcohol-benzene extractives were shown for PN-733, 172 and Kashmir willow clones, respectively. The maximum lignin and holocellulose contents were reported for clones V-99 and 131/25, respectively. The minimum lignin and holocellulose contents were found for PN-227 and 799 clones, respectively.

The physico-chemical properties of promising willow clones viz. height, diameter, bark percentage, wood percentage, moisture content, specific gravity, fibre length, cold water solubility, hot water solubility,

alcohol-benzene solubility, lignin content and Holocellulose content ranged between 4.68-12.43m, 4.17-9.87cm, 12.93 per cent (3.59)-36.13 per cent (5.97), 63.87 per cent (7.97)-87.07 per cent (9.33), 58.83 per cent (1.77)-110.49 per cent (2.04), 0.74-0.81, 0.96-1.93mm, 3.33 per cent (1.82) -7.67 per cent (2.74), 4.67 per cent (2.15)-11.33 per cent (3.36), 2.73 per cent (1.65)-7.10 per cent (2.66), 19.10 per cent (4.37)-26.33 per cent (5.13) and 64.27 per cent (8.01)-79.33 per cent (8.90), respectively.

Highly significant positive correlation for physico-chemical characteristics of wood of promising willow clones were noticed between diameter vs. wood percentage, height vs. wood percentage and diameter vs. height. On the other hand, highly negative correlation was observed between wood percentages vs. bark percentage, bark percentage vs. diameter, bark percentage vs. height while the slightly positive and negative correlations were also seen between extractives.

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 per cent, 2.09-30.49 per cent, 24.00-92.00 per cent, 0.03-31.20 and 3.95-53.73 per cent, respectively.

The values for physical parameters for phenotypic and genotypic coefficients of variability, heritability, genetic advance and genetic gain ranged between 2.51-34.21 per cent and 2.09-26.77 per cent, 0.59 (59.00 per cent)-0.92 (92.00 per cent), 0.03-31.20 and 3.95-50.18 per cent, respectively.

The values for chemical parameters for phenotypic and genotypic coefficients of variability, heritability, genetic advance and genetic gain ranged between 8.24-35.63 per cent and 5.07-30.49 per cent, 0.24 (24.00 per cent)-0.73 (73.00 per cent), 0.77-4.74 and 6.43-53.73 per cent, respectively.

Highly significant positive genotypic and phenotypic correlation coefficients were obtained between diameter and wood percentage while highly negative genotypic and phenotypic correlation coefficients were noticed between wood percentage and bark percentage for physical parameters. Highly significant positive and negative environmental correlation coefficients were recorded between diameter vs. wood percentage and bark and wood percentage, respectively. For chemical parameters, highly significant positive genotypic correlation coefficient was found between alcohol-benzene extractives vs. lignin content while phenotypic and environmental correlation coefficients have non-significant positive relationships between parameters studied. Highly significant positive environmental correlation coefficient was observed between hot water and alcohol-benzene extractives. Highly significant negative genotypic and phenotypic correlation coefficients were found for lignin vs. holocellulose and hot water vs. alcohol-benzene extractives, respectively. Environmental correlation coefficient had non-significant relationships.

CONCLUSIONS

- Among 21 promising willow clones, 212/03 clone performed better in height and diameter, it also had maximum wood percentage while clone SI-63-016 had maximum bark percentage.
- The maximum moisture content was observed in clone 131/25.
- The maximum specific gravity was observed in clone MB-368.
- The maximum fibre length was obtained in clone 172.
- The maximum cold water solubility, hot water solubility, alcohol-benzene solubility, lignin content and holocellulose content was observed in clones SI-64-17, NZ-1002, PN-721, V-99 and 131/25, respectively.
- Highly significant positive correlation for the physico-chemical properties of wood of promising willow clones was found between diameter and wood percentage. The significant negative correlation of the physico-chemical properties of wood of promising willow

clones was observed between wood percentage and bark percentage.

- Genotypic correlation coefficient was found to be higher than the phenotypic and environmental correlation coefficients of physico-chemical properties of wood of promising willow clones.
- The maximum heritability, genetic advance, genetic gain, phenotypic and genotypic coefficient of variability was recorded in height, moisture content, alcohol-benzene extractives, alcohol-benzene extractives and alcohol-benzene extractives, respectively.
- The widest range and maximum mean and standard deviation were observed in moisture content. The maximum coefficient of variance was seen in alcohol-benzene extractives.

Chapter-7

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Title of Thesis : “Studies on physico-chemical characteristics of wood of promising willow clones”
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Year of Award of Degree : 2010
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ABSTRACT

The present investigation entitled “Studies on physico-chemical characteristics of wood of promising willow clones” was carried out at the established trial plots by Department of Tree Improvement and laboratory of the Department of Forest Products, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) during the year 2009-10. 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 15 km south east of Solan with 30° 51' N latitude and 76° 11' E longitude (survey of India Toposheet no. 55 F/1). The experimental area situated at the University Campus. The study revealed significant variation between physico-chemical characteristics of wood of promising willow clones. Among different physical characteristics clone 212/03 registered significantly maximum height, diameter and wood percentage of 12.43m, 9.87cm and 87.07 percent, respectively. The maximum bark percentage of 36.13 percent was exhibited in clone SI-63-016. Also moisture content, specific gravity and fibre length showed significant variation. The maximum moisture content of 110.49 was found in clone 131/25, specific gravity of 0.81 in clone MB-368 and fibre length of 1.93mm in clone 172. Among chemical characteristics of wood of promising willow clones, significant variation was observed for those parameters studied. The maximum cold water extractives, hot water extractives, alcohol-benzene extractives, lignin and holocellulose contents was noticed in clones SI-64-17 (7.67 percent), NZ-1002 (11.33 percent), PN-721 (7.10 percent), V-99 (26.33 percent) and 131/25 (79.33 percent), respectively. The wood percentage had highly significant positive correlation with other studied physical parameters viz. diameter and height. Also significant positive correlation was seen between diameter and height, moisture content and holocellulose content, and moisture content and height. The highly significant negative correlation was observed in bark percentage and wood percentages followed by bark percentage vs. diameter, fibre length vs. hot water extractives, bark percentage vs. height and diameter vs. specific gravity. Slightly positive and negative correlations were shown between extractives. Highly significant positive genotypic and phenotypic correlation coefficients were obtained between diameter and wood percentage while highly negative genotypic and phenotypic correlation coefficients were noticed between wood percentage and bark percentage. 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 percent, 2.09-30.49 percent, 24.00-92.00 percent, 0.03-31.20 and 3.95-53.73 percent, respectively.

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APPENDIX-I

Mean monthly meteorological data of Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) for the year 2009-10 (w.e.f. March, 2009 to February, 2010)

Months	Temperature (°C)			Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum	Mean		
March, 2009	24.90	8.40	16.65	41.00	43.40
April, 2009	28.80	16.60	22.70	56.00	26.50
May, 2009	30.80	15.90	23.37	56.00	29.60
June, 2009	33.30	18.50	25.90	48.00	37.30
July, 2009	29.00	19.50	24.25	70.00	90.30
August, 2009	28.40	18.80	23.60	84.00	54.10
September, 2009	27.10	15.60	21.35	85.00	408.00
October, 2009	26.20	9.70	17.95	66.00	2.20
November, 2009	22.20	5.00	13.60	68.00	14.70
December, 2009	19.20	1.90	10.65	70.00	0.00
January, 2010	19.80	1.50	10.65	64.00	0.40
February, 2010	19.90	3.70	11.80	67.00	3.50

Source: Meteorological Observatory, Department of Environment Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) 173 230

APPENDIX II
Analysis of variance for physical characteristics of wood of
promising willow clones

Parameter	Mean sum of squares			
	Source	Clone	Replication	Error
	d.f.	21	3	63
Height (m)		14.031	0.978	0.423
Diameter (cm)		10.380	9.476	1.219
Wood percentage		0.375	1.185	7.333
Bark percentage		1.220	6.973	0.219
Moisture content (%)		2.207	9.023	1.070
Specific gravity		8.741	4.144	1.136
Fibre length (mm)		0.210	1.085	2.161

APPENDIX III
Analysis of variance for chemical characteristics of wood of
promising willow clones

Parameter	Mean sum of squares			
	Source	Clone	Replication	Error
	d.f.	21	3	63
Cold water extractives (%)		0.163	0.180	7.409
Hot water extractives (%)		0.315	3.434	9.188
Alcohol-benzene extractives (%)		0.286	0.197	3.345
Lignin content (%)		0.186	1.070	5.449
Holocellulose content (%)		0.212	4.214	7.502

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