

STUDIES ON PROVENANCE VARIATION IN *Toona ciliata* M. ROEM

Thesis

by

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FRONTISPIECE



Toona ciliata M. Roem

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CERTIFICATE - I

This is to certify that the thesis titled “**Studies on provenance variation in *Toona ciliata* M. Roem**” submitted in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy (Forestry)** in the discipline to **Forest Genetic Resources** of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P)-173 230 is a bonafide research work carried out by **Mr. Narendra Singh** under my supervision and no part of this thesis has been submitted for any other degree or diploma.

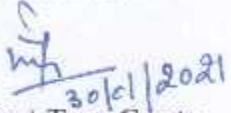
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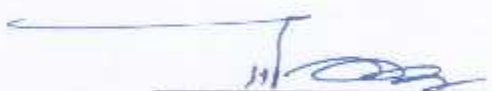
This is to certify that the thesis entitled, "Studies on provenance variation in *Toona ciliata* M.Roem", submitted by Mr. Narendra Singh (F-2015-08-D) to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) 173 230, India, in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY)** in the discipline of **FOREST GENETIC RESOURCES** has been approved by the Student's Advisory Committee after an oral examination of the student in collaboration with the External Examiner.


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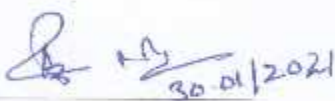

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(Narendra Singh)

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LIST OF ABBREVIATIONS

%	:	Per cent
AB	:	Alcohol: Benzene soluble extractives
CD _{0.05}	:	Critical difference at 5 % level of significance
g	:	Gram
H.P.	:	Himachal Pradesh
UK	:	Uttarakhand
UP	:	Uttar Pradesh
°C	:	Degree centigrade
RBD	:	Randomized Block Design
SE	:	Standard error
DBH	:	Diameter at breast height
i.e.	:	That is
viz	:	Videlicet (namely)
ANOVA	:	Analysis of Variance
mm	:	Millimetre
cm ³	:	Cubic Centimetre
sp. or spp.	:	Species
<i>et al.</i>	:	And others
etc.	:	Etcetera
m	:	Meter
cm	:	Centimeter
WCC	:	Wood Chemical Characteristics
Hme	:	Heartwood Moisture Content
S mc	:	Sapwood Moisture Content
H Mmc	:	Heartwood Maximum Moisture Content
S Mmc	:	Sapwood Maximum Moisture Content
P	:	Provenances
MC	:	Moisture Content
MMC	:	Maximum Moisture Content

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Chapter-1

INTRODUCTION

Toona ciliata M. Roem is one of the best Indian timber species of the Meliaceae family, also known as Tun, Toon and Red Cedar. The wood is light brown, straight grained, rather uneven and moderately hard with specific gravity of 0.57 (Troup, 1981). The other timber yielding species of the genus occurring in India are *Toona febrifuga*, *Toona microcarpa* and *Toona serrata*. The Mahogany family is known for producing quality timber, hence recognized as back bone of forest industries in many countries (Bahadur, 1988). *Toona ciliata* is a large deciduous moderate light demanding tree species, with a spreading crown, commonly attaining a height of 20-30m and a girth of 1.8-3.0m. In India, it is found throughout the sub-Himalayan tract, Western Himalaya and valleys of the outer Himalaya including Manipur, Assam and Khasi Hills up to an elevation of 1600 m. This species is also distributed in the plains of Madhya Pradesh, Tamil Nadu and Karnataka (Singh, 1982) and on moist localities such as ravines, stream banks or swamps (Troup, 1981). This species enjoys best growth in deep loamy soils supplemented with good moisture regimes, therefore fast growth is maintained on cultivated fields and also preferred for roadside avenue plantations in Himachal Pradesh, Uttar Pradesh, Uttarakhand etc. Meliaceae is a large family of tropical woody species, comprising of 50 genera with approximately 575 species (Pennington and Styles, 1975; Mabberley *et al.*, 1995; Chase *et al.*, 1999) and further categorized into four sub-families viz., Meliodeae (7 tribes; 35 genera) Swietenioideae (3 tribes; 13 genera) and the monogeneric Quivisianthoideae and Capuronianthoideae, which contain a relatively wide range of floral, fruit and seed morphologies (Pennington and Styles, 1975).

The versatile timber of *T. ciliata* is used for house constructions, furniture, musical instruments, carvings and numerous other uses like dyes and tans from flowers and bark respectively (Lemmens, 2008). Traditional medicine makes use of various parts of the plant, chiefly the bark and leaves (Lemmens, 2008). The leaves are rarely used as an animal fodder in India (Edmonds, 1993). Cotton and woollen fabric can be dyed a dull yellow by mere immersion in a boiling extract of *Toona ciliata* flowers. The flowers contain a red colouring matter which is used in conjunction with safflower and turmeric to produce a sulphur yellow colour. Bark contains tannin, and it has also been used traditionally for twines and the manufacture of string bags. The bark is powerful astringent and used in various forms of

ulceration, antiperiodic in fever, rheumatism, tonic, beneficial in chronic dysentery, powdered bark externally applied to ulcer, leprosy, cures fever, headache and blood complaints. In Yunani medicine it is also used as cardio tonic, aphrodisiac, scabies and expectorant (Kritikar and Basu, 1995).

In the Hawaiian Islands, the performance of introduced tree species have been examined in the sampled areas, but forest tree productivity was poorly understood (Wick, 1971; Whitesell and Walters, 1976; Buck and Imoto, 1982). A more comprehensive research approach on provenances can aim to understand the factors those limit tree growth, on the basis of suitability of the to cope with limited resources, and to understand the mechanisms which allow them to adjust with changes in environmental conditions.

Provenance in forestry refers to the population of trees growing at a particular place of origin. Provenance research defines the genetic and environmental components of phenotypic variation associated with geographic source. Information on provenance is important in assuring sources of seed to give well-adapted, productive trees and in directing breeding of interracial and inter specific hybrids toward adaptation to particular localities (Callahan, 1964). According to Duffield (1954) provenance research has importance for the planned breeding and one must direct breeding to produce a hybrid combination of provenances having the highest adaptation and productivity. Seed source studies are a part of the bio-systematic investigation of variation.

Information on morphological variations in seed characteristics amongst the provenances of a species will be useful for tree improvement programs. A study on seed morphological, germination and early seedling traits of the different provenances of *Toona ciliata* at nursery stages will help to evaluate the suitability of provenances of *Toona ciliata* from the study areas viz., Himachal Pradesh, Uttarakhand and Uttar Pradesh. In view of the increasing demand for the valuable timber produce by this species, along with other multipurpose uses like medicinal, fodder values and soil conservation in hilly terrains; there is a need to establish a provenances trial, in order to establish an identity of superior provenances across a vast geographical stretch.

The research on “**Studies on provenance variation in *Toona ciliata* M. Roem**” has been taken up under the following objectives:

- i) Morphological characterisation of *Toona ciliata* provenances in three states.
- ii) Variation in seed characteristics and seedling attributes.
- iii) Provenance variations in wood characteristics.

Chapter-2

REVIEW OF LITERATURE

Variation is the occurrence of differences among individuals due to their genetic composition and the environment in which they were raised. Therefore, the study of variation is the priority step for any breeding and improvement work. The effectiveness of such programmes depends upon the understanding of tree variation in nature and utilizing it is for future use. The studies pertaining to variation help to analyse the natural pattern of variation and group the individuals as representative of provenance and to depict the extent of within provenance variation. These studies help in the comparison of individuals and to identify the superior genotypes, which have a great importance in tree improvement programme.

Zobel and Talbert (1984) emphasized the role of selection on natural variability for governing a successful tree improvement programme. The largest, cheapest and quickest gain in most forest tree improvement programs can be made by assuring the appropriate choice of species and sources within species. Variation study is the first and foremost step in assessing the evolutionary biology and tree improvement potentials of a species. It is observed that most of forest tree species possess greater variability. Forest trees are investigated as the tremendous and among the most complex organisms in the world with huge diversity. The relevant literature regarding plus tree selection, seed sources variations and various parameters of juvenile growth in *Toona ciliata* and other tree species have been reviewed. The literature available in this context in this species is sparse. Accordingly, the work done on these aspects is reviewed under the following heads:

2.1 Morphological and phenotypic traits

2.2 Seed traits

2.3 Nursery growth performances

2.4 Wood chemical studies

2.5 Genetic studies

2.6 Correlation studies

Plus tree selection: selection is a key part of all applied tree improvement programs based on general principal that is to find and selected superior trees for use as parents in breeding programs. Numbers of selection criteria varied from selection of single trait to multiple traits

have been developed for diverse species and stand types. The most efficient and productive approach is that which results in the superlative genetic improvement per unit of time and effort expended. Hazel and Lush (1942) described three methods of independent culling levels. Tandem method involved the selection for one trait at a time until the desired level of improvement was achieved, then approached for second trait. Total score method involved all the traits under consideration simultaneously by using some index of net merit. Independent culling method involved a certain level of merit for each trait and all the individuals falling below fixed index would be rejected regardless of superiority of their other traits over selected ones. They found that method of total score was seemed to be more efficient whereas tandem selected was least efficient of the three.

2.1 MORPHOLOGICAL AND PHENOTYPIC TRAITS

Paray *et al.* (2017) selected hundred CPTs of *Salix alba* based on the comparison tree method from twenty places across the two selected districts of Kashmir valley. The tree characteristics used were height, bole height, DBH, and crown diameter. Furthermore, the mean values recorded for these dimension were as 12.50 m for height, 28.70 cm for DBH, 5.40 m for bole height, and 3.40 m for crown diameter respectively.

Khobragade *et al.* (2013) reported the criteria for efficient selection of CPTs of *Terminalia chebula* and *T. bellerica* in two sites each in Maharashtra and Madhya Pradesh. Crown volume, girth and clear bole height were given considerable importance for the selection of trees of *T. chebula* whereas in case of *T. bellerica* crown diameter, girth, height, and fruit weight were given more weightage. These parameters found to be more in genetic improvement and conservation programme of these species.

Danquah *et al.* (2011) investigated the pattern of leaf morphometric variation and similarities among populations of two species of African mahoganies (*Khayain vorensis* and *Khayaan thothea*) and suggested that two clusters of populations of *Khayain thothea* and one cluster of *Khayain vorensis* were morphologically related. Moreover, it was indicated that the two species of khaya spp. might have existed as separate species, although their distributions overlap in some ecological zones. However, it was being recommended that comprehensive studies involving molecular analysis should be performed on the two species of African mahogany.

Sankhyan *et al.* (2008) studied morphological variations in *Grewia laevigata* revealed that some of the traits, viz., branch length, number of leaves per branch, branch nodal length, leaf length, leaf area and seed weight, exhibited variation between the sites but not among the trees. However, leaf width, number of seeds per fruit, seed length and seed width showed non-significant variations. Genotypic correlation coefficients were found greater than phenotypic for almost all the morphological traits.

Nagesh *et al.* (2007) reported seed production areas and seed source identified for qualitative variations in *Tectona grandis* fruit traits such as nature of fruit, calyx attachment, hairiness and splitting nature. These variations could be helpful during identification of seeds of different sources and it may have an important role in germination.

Kaushik *et al.* (2007c) analysed the performance of ninety plus trees of *Azadiracta indica* collected from different agro climatic zones of Haryana and revealed that geographical diversity is not only the factor in determining divergence, consequently selection of genotypes should be based on genetic diversity. There was a variation of seed traits, germination and growth traits.

Arya and Toky (2006) evaluated the progenies of 50 plus trees of *Acacia nilotica* collected from five states at Hisar and found wide variability in seed weight, seed germination, seedling height and collar diameter.

Candidate plus trees of *Dalbergia sissoo* were selected by Yadav *et al.* (2005) based on the intensive survey in the states of Haryana, Uttar Pradesh and Himachal Pradesh. They reported wide variation in plant height, clear bole height, straightness, and 100 seed weight and germination per cent among plus trees selected at the different locations of Himachal Pradesh and reported considerable variability among individual trees for a particular trait.

Wani (2005) studied that reproductive biology and morphological variation in 32 plus trees of *Bauhinia variegata* under house and field conditions. The studies revealed that plus tree progeny of Pinjor, Kanddaghata and Giripul exhibited outstanding performances for morphological characters viz., Height, diameter, number of branches, leaf area etc., in comparison to all other superior tree progenies under glasshouse. Whereas, Renuka plus tree showed the best performances, progeny followed by Subathu, Kunihar and Narag under field conditions for the above characters studies.

Kumar and Sharma (2005) conducted a study on forty five CPTs *D. sissoo* which were selected at the different locations of Himachal Pradesh and reported consideration variability among individual trees for a particular trait.

Roy *et al.* (2004) found a wide range of variability for cone traits cone length, cone width, fresh weight and number of seeds per cone, seed traits (1000 seed weight, seed length, seed width) and nursery traits germination percent, survival percent, days taken for bud break, collar diameter, one year extension growth) among provenances of *Pinus roxburghii*.

Sidhu (1997) selected sixteen CPTs of *Dalbergia sissoo* and recorded the observations on tree height, clear bole height, diameter, fork diameter, number of crooks. From them, twelve plus trees of shisham were selected by mean value for total height, clear bole height and apical dominances which were significantly better than baseline trees.

Sidhu (1996) studied that methods of plus tree selection for raising the first generation population for a tree breeding programme and revealed that the plus tree was selected either by comparison methods (comparison tree method, base line method and regression method) or individual tree methods (sum total of scores, independent culling method and selection indices).

Garcia (1972) presented a morphological description of *Melia azedarach* and information on its phenology, with particular reference to flowering, and described suitable methods of artificial pollination in seed orchards of dwarf grafts.

Leidig (1947) found that base line selection method was the reliable approach for selection in mixed and uneven aged stands wherein, average value for the different traits under consideration for the site or stand was made and used for comparison.

2.2 SEED TRAITS

Bhat *et al.* (2017) proposed that conventional practice of seed extraction from cones of *Pinus wallichiana* consist of drying the cones in the sun. This process takes about four weeks. A reliable technique for quick seed extraction was developed by employing different seed extraction methods. Among the seed extraction methods, hundred per cent of seeds were extracted on 8th day (T_4) when the cones were dipped in water for 10 minutes and oven drying at 30°C followed by T_3 i.e. dipping cones in water for 10 minutes and oven drying at

20°C, which took nine days for complete extraction of seeds. Oven drying of cones at 30°C also took nine days for complete extraction of seeds as compared to 29 days in traditional drying of cones in sun. There was no negative effect on germination percent of extracted seeds by different methods, highest germination percentage of 71.8 % was recorded when seeds were extracted by traditional method of sun drying followed by T₃: dipping of cones in water for 10 minutes and oven drying at 20 (70.25 %) and T₁: drying of cones at 20 (69.75 %) respectively. Highest percentage of (12.51 %) seeds extracted on daily basis was recorded when cones were dipped in water for 10 minutes followed by drying at 30 .

Medeiros *et al.* (2015) evaluate the germination of Australian cedar seeds *Toona ciliata* M. Roem in three different substrates and two photoperiods and evaluate the effect of salt stress with sodium chloride (NaCl) on the viability and vigor of seeds, conducting two experiments. Results were expressed as percentage of normal seedlings. The photoperiod of 24 hours light, does not influence the final seed germination and the use of paper on substrate provided the highest percentage of germinated seeds.

Tomar (2015) investigation was carried out in two different seed sources viz., Uttarakhand and Uttar Pradesh on *Stereospermum chelonoides*. The aim of the study was to determine variability and germination divergence in seed traits of *Stereospermum chelonoides* collected from two states. A variation was observed in germination percent, mean daily germination, peak value, germination energy and germination value and seed growth parameters (capsule/seed length, capsule/seed width and seed weight) of two states. The seeds from Uttarakhand found better as per selected parameters in comparison to the seeds from Uttar Pradesh.

Genotypic variance (V_g) and genotypic coefficient of variation (GCV) were found to be higher than corresponding environmental (V_e) and environmental coefficient of variability (ECV) for most of the parameters except cone length, germination energy, germination energy index and collar diameter which indicate the dominance of environment on the expression of these traits. Moderate to high percentage of heritability coupled with high genetic gains for cone diameter and weight, seed/cone, seed length, thickness and weight, germination per cent and value, cotyledon number, radicle and hypocotyls length, nursery germination percent & value and extension growth imply that these traits were under strong genetic control and there was ample scope for exploitation of heritable additive genetic component for further breeding and improvement in this species. UPGMA clustering analysis

of various traits of cone, seed and seedling grouped all seed sources into 5 clusters with large inter-cluster distances. Clustering of geographically distant seed sources into one group revealed that distantly located sources was genetically close.

Wu *et al.* (2014) investigated the seedling cultivation techniques among 151 *Toona ciliata* families. Analysis of variance showed that there were significant differences on studied traits among treatments, Families; Coefficients of genotypic variation were 32.96% for height, 24.27% for diameter, and 48.23% for number of leaves. Heritability was 0.96 for height, 0.81 for diameter, and 0.91 for number of leaves. The strongly positive phenotypic correlations suggested that selection on one trait can be effective to predict other studied traits of *Toona ciliata* families.

Rubaiyat *et al.* (2013) conducted a study in the nursery of the Institute of Forestry and Environmental Sciences, University of Chittagong, Bangladesh to evaluate the performance of *Toona ciliata* seedlings grown under three different categories of soil viz., polluted, moderately polluted soil of ship breaking yard and nursery soil. The leaf elongation, stem elongation and root growth of seedlings were negatively affected under polluted and moderately polluted soil. It was suggested that nitrogen fixing and pollution resistant species can be used for landscaping polluted areas. Adequate study should be carried out to find out indigenous species that are suitable to plant in the ship breaking yard.

Khobragade *et al.* (2013) reported the criteria for efficient selection of CPTs of *Terminalia chebula* and *T. bellerica* in two sites each in Maharashtra and Madhya Pradesh. Crown volume, girth and clear bole height were given considerable importance for the selection of trees of *T.cheblula* whereas in case of *T. bellerica* crown diameter, girth, height, and fruit weight were given more weight age. These parameters found to be more useful in genetic improvement and conservation programme of the species.

Ferreira *et al.* (2012) estimated genotypic parameters of *Toona ciliata* at individual level through the use of BULB procedure, with repeated measures, by means of conventional evaluation procedures and the introduction of innovative digitation of the measurements by digital camera with the images provided the image system. They observed low accuracy canopy diameter, caused by the high environmental influences which disqualify this characteristics for selection procedure in *Toona ciliata*. However, DBH appears to be the best option for selection because of having high uniformity in the sequential evaluations.

Rana *et al.* (2009) studied on Progenies of 25 seed sources (plus trees) of *Toona ciliata* collected from different seed zones of Himachal Pradesh and were evaluated under nursery and field conditions. Analysis of variance for seedling height, collar diameter and number of leaves indicated significant mean squares for all the characters studied under nursery conditions. Seedling height and collar diameter after 120 days of sowing exhibited high heritability (broad sense) coupled with high genetic advance. Under field evaluation, seed sources viz., S₁, S₂, S₅ and S₆ exhibited faster growth rate based on the values of growth parameters.

Dordel (2009) concluded that *Toona ciliata* M. Roem Plantations require a nurse-tree overstore to minimize damage from drought and frost in north-eastern Argentina. The final objective was to link *Toona ciliata* establishment success and early growth to soil water availability, by calibrating the two-dimensional forest hydrology model, *G. robusta*, by contrast, increased water and phosphorus availability to *T. ciliata*. Density effects varied with nurse species and performance traits. Good predictive capability for early *T. ciliata* performance, and was especially discriminatory among nurse species effects. This study shows that nurse species that nurse species choice can be more important for increasing early *Toona ciliata* performance.

Singh and Kushwaha (2006) showed a 7 to 9 months long fruiting phenophase. The leafless period for *Acacia catechu* is 1-3 month. Phenology of a species may show some sort of variation with different seed sources depending upon climatic, physiological and edaphic conditions.

Luna *et al.* (2006) observed seed source and within tree variation in Katha and cutch content for fifteen sources of Khair were studied in Shiwalik area of Punjab. In order to study within tree variation, wood sample were taken from three different positions i.e. at breast height, 50% of tree height and 75% of tree height. Out of 15 sources Salari-III, Seonk, Palampur and Mansooh were found best with respect to Katha and cutch content, whereas lower position had maximum Katha content.

Variation with respect to different pod and seed characteristics among 20 seed sources of *Albizia lebbeck* from Punjab, Haryana and Uttaranchal was studied. It was found that there was high variation in seed germination percentage among all the seed sources (Luna *et al.*, 2006).

Khera and Singh (2005) found germination of *Acacia catechu*, *A. nilotica* and *Dalbergia sissoo* was less dependent on direct light. With regards to choice of substrates small sized seeds showed higher germination in paper method, whereas germination of medium sized seeds was higher in sand and soil.

Bhat and Chauhan (2002) studied on seeds of *Albizia lebbek* which were collected from 24 localities of Himachal Pradesh, Jammu and Punjab. Seed were measured for seed length, seed width and 100 seed weight and sown in the nursery field to study variation in germination and growth parameters. For almost all the traits studied, Rajpura and Nauni sources of Himachal Pradesh performed best than other localities.

Sharma and Wadhera (2000) studied on seeds of *A. catechu* when pretreated with cold water, hot water and different concentrations of H_2SO_4 showed that the seed pre pagated with 60% H_2SO_4 for 10 minutes germinate well within short period of time. Twenty six seed sources of *Acacia nilotica* scattered over nine states of India were studied to know the pattern and extent of variation in seed morphology and germination. Statistically significant differences were observed among the seed sources for all the characters studied. The variation in germination percentage was large as compared to other character studied (Shekhar *et al.*, 2002).

Dogra *et al.* (1988) studied on regeneration and genetic diversity of forest trees emphasized that these were regulated by the reproduce characteristics of species through seed and vegetative propagation and helps in producing high genetic gain by multiplying superior trees raised through seeds which was achieved by natural regeneration and also through different asexual methods.

Bal and Toky (1995) studied on seed collection of *Acacia nilotica* from 21 provenances in India and for each provenance mature pods from 10-16 trees were collected during March-April from Southern India and during May-June from Northern India. There was significant variation in seedling height, branch, leaf and spine growth characters among the provenances at 6 and 23 months stage after transplantation. In general provenances from North-Western and central India was found to be superior to those from south India. There existed considerable variation amongst the different provenances with respect to seeds and seedling traits which have been reported in a number of species belonging to genus *Acacia*, such as *Acacia mangium* (Hagedorn and Nixon, 1984; Johan and Chew, 1987; Chung *et al.*,

1990; Bhumibhamon 1992; Pingyophsarerk, 1992; Yantasath *et al.*, 1992), *A. Quniculiformis* (Huang, 1989), *Acacia albida* (Sneizko and Stewart, 1986), *Acacia Qulococorpa* (Pingyophsarerk, 1992; Vuokko *et al.*, 1992) and *Acacia crassicropa* (Pingyophsarerk, 1992). Salazara (1989) recorded that more than 93 % of variation in *A. mangium* was contributed due to the provenances.

Nautiyal and Thapliyal (1993) studied seeds of *Toona ciliata* and reported changes in percentage germination and seed moisture content over 360 days of storage at room or low (5-8 degrees) temperatures. Germination was 100% immediately after collection and over the first month of storage. However, after 60 days storage at room temperature germination had fallen to 36%, and by 90 days it was zero. Under storage at low temperature, germination only fell to 90% after 360 days storage. Seed moisture loss was rapid on storage at room temperature, dropping from about 34% to 4% over 90 days, but was very little in low temperature storage, dropping to 30% over 240 days and 13% by 360 days.

Chauhan and Verma (1993) evaluated progeny performances of 8 different provenances of *Acacia catechu* collected from different agro climatic zones of Himachal Pradesh. The study revealed high heritability coupled with high genetic advances for seedling height, collar diameter number of leaves and branches /plant thereby indicating the importance the importance of additive gene action.

In a study on seed colour and germination, Mishra (1991) reported that mawkish brown seeds of *Dalbergia sissoo* had better germination than brown and black seeds. Sharma (1996) reported that brown colour seed of *Albizia chinensis* may be the maturity stage for seed collection.

Beniwal *et al.* (1990) collected seeds and broadcast in raised beds of soil, sand and FYM (2:1:1) in July, and covered with a thin layer of soil and river sand (2:1). Beds were either kept open, shaded overhead with grasses or mulched with dry leaves and pine needles. Germination was recorded for 5 week and was faster and higher in the shaded treatment (5.2 days and 79.07% respectively); germination in the mulched treatment was 62.70 % and in the open bed 32.75%. Success in establishment and productivity of forest plantations were largely determined by the species used and the source of seed material. Therefore, the choice of seed source may be decisive for the success or failure of future plantings.

Duguma *et al.* (1988) observed that freshly harvested mature brown seeds of *Leucaena leucocephala* gave higher germination percentage (97%) than green seeds (73%). Singh (1982) recommended brown colour pod of *Acacia catechu* and light brown coloured pods of *Albizia chinensis* as ripening indicator. Fruit and seed colour can affect germination and vigour in many tree species. Srimathi *et al.*, (1991) found that green seed of *Acacia mellifera* possessed distinctly high viability measured as maximum germinability compared to this germinability of 77 per cent of the greenish brown and brown seeds recorded only 55 per cent and 47 per cent germination.

Rehman *et al.* (1988) exhibited marked differences among the seed source of *Acacia nilotica* and *Prosopis juliflora* for height growth and survival under nursery conditions, however Huang (1989) found non-significant variation in seed and seedling traits viz., height, basal area, seed length and width except for seed weight among five provenances of *Acacia auriculiformis*

Khalil (1986) studied that seed weight has been reported to be one of useful criteria for early selection of superior provenances, while seed size and colour are important markers for identifying plant populations (Harper *et al.*, 1970).

Yousheng and Sziklai (1985) carried out seed germination studies on eleven provenances of Chinese mahogany *Toona sinensis* and were tested on a thermo plate gradient germinator at temperatures of 15°C, 18°C, 22°C, 25°C, and 28°C. It was concluded that the three upper temperatures provided the fastest and highest germination among the eleven provenances and on an average 25°C was considered as optimum temperature for germination of the species.

Mathur *et al.* (1981) studied germination behavior for 12 provenances of *Acacia nilotica* spp. Indica. Among them 4 provenances were reported to be the best for germination rate index and germination per cent.

Hagedom and Nixon (1984) reported significance differences for seedling height and diameter between different provenances of *Acacia mangium*. Seed sources with higher seed weight were expected to give higher seed germination per cent. Similar finding have been reported in *Acacia nilotica* (Ginwal *et al.*, 1994; Gera *et al.*, 2000) and in *Dalbergia sissoo* by Vakshasya *et al.* (1992).

Tripathi *et al.* (1984) observed that over mature and young trees should be avoided since the seeds from such trees may be of low viability and vigour. Per cent survival in *Anogeissus pendular* increased gradually with increased in girth of parent tree and thereafter decreased in older plants because the vigour of seed change in relation to maximum value of girth of parent trees. Similar finding was also recorded in *Albizia chinensis* by Kumar *et al.* (2000).

Baker (1972) observed that variation in seed germination percentage may be due to seed coat hardness/sensitivity of different sources as reported in differential germination percentage for hardness of seed and the factors responsible were environmental conditions, place of origin, degree of maturation of seeds etc. seed size and seed weight can vary according to seed source Heavy and large seed contain more food reserve than smaller seeds, which is helpful in germination by providing more energy. Seed size may also affect germination behavior and early seedling growth in the nursery (Hawkins, 1998). The effect of seed size on germination behavior is variable and somewhat controversial (Chaisurisri, 1992; Reich *et al.*, 1994).

Allen (1961) studied that most important explanation for germination variation was the seed sources or provenances and family characteristics (Chaisurisri *et al.*, 1992). For example, population from higher altitude tends to have earlier and more rapid germination (Roche, 1969).

2.3 NURSERY GROWTH PERFORMANCES

Pei and Yang (2017) studied on *Toona ciliata* seedlings from 18 provenances to provide scientific basis for breeding and screening high-quality *T. Ciliata* provenance. Heights and ground diameters of one-year-old *T. ciliata* seedlings from 18 provenances were regularly observed. The correlations between seedling height, ground diameter and geographical, factors were investigated. The GCV of seedling height and ground diameter of *T. ciliata* were 43.31% and 36.25% respectively. The geographic variations in two traits were mainly influence by longitude. The growths of the two traits were both in a "slow-fast-slow" pattern showing a similar "S" curve. The growth of *T. ciliata* seedlings could be divided into three stages, including the early, fast and late growth stages. *T. ciliata* from different provenances had different starting and ending time for the three stages.

Shu *et al.* (2012) collected *Magnolia officinalis* seeds from 15 different provenances, ranging from 336 to 1387 m in China. There were significant differences among provenances in all studied attributes. Seed weight exhibited maximum variation among provenances in seed morpho-metric traits. Seedling height decreased by geographical latitude gradually from south to north, while stem diameter declines from east to west indicated geographic variation of the plant at the seedling stage.

Kaushik *et al.* (2007c) analysed the performance of ninety plus trees of *Azadiracta indica* collected from different agro climatic zone of Haryana and revealed that geographical diversity was not only the factor in determining divergence, consequently selection of genotypes should be based on genetic diversity. Variation of seed traits were germination and growth traits.

Arya and Toky (2006) evaluated the progenies of 50 plus trees of *Acacia nilotica* collected from five states at Hisar and found wide variability in seed weight, seed germination, seedling height and collar diameter.

81 CPTs of *Dalbergia sissoo* were selected by Yadav *et al.* (2005) based on the intensive survey in the states of Haryana, Uttar Pradesh and Himachal Pradesh. They reported wide variation in plant height, clear bole height, straightness and 100 seeds weight and germination per cent among selected CPTs at different locations of Himachal Pradesh and reported considerable variability among individual trees for a particular trait.

Sidhu (1997) selected sixteen CPTs of *Dalbergia sissoo* and recorded the observations on tree height, clear bole height, diameter, fork diameter and number of crooks. From them, twelve plus trees of shisham were selected by mean value for total height, clear bole height and apical dominances which were significantly better than baseline trees.

Wilcox and Ledgard (1983) reported that a provenances variation study on growth and morphological of seedlings of *Nothofagus menziesii*, *N. truncata*, *N. solandri* var. *Solandri* and *N. Solandari* var. reported considerable variation between provenances, with strong differentiation into regional ecotypes and possibly altitudinal clines.

2.4 WOOD CHEMICAL STUDIES

Okon (2014) investigated the specific gravity and shrinkage characteristics of wood of *Gmelina arborea* and the results showed the mean values for tangential shrinkage, radial

shrinkage and volumetric shrinkage were 6.4 per cent, 4.47 per cent and 11.32 per cent respectively.

Kumar *et al.* (2012) evaluated the pharmacognostical study of leaf of *Toona ciliata* M Roem and found that total ash values was not more than 11.5% and acid insoluble ash values was not more than 15.4 %. In case of extractive values, petroleum ether-soluble was 14.08 %, alcohol soluble was 8.72 % and hydro-alcoholic-soluble values were 23.12 % and for water -soluble was 16%.

Hindi and Bakhaswain (2010) reported valorisation for fibre production of eight Saudi lignocellulosis: *Phoenix dactilefera* surface fibre, leaflet and rachis and wood from each of *Conocarpus erectus*, *Leucaena leucocephala*, *Simmondsia chinensis*, *Azadiracta indica* and *Maringa peregrine* were investigated for specific gravity, chemical composition, total extractive, lignin, holocellulose and of the eight lignocellulose materials were determined, *Leucaena leucocephala* was found to be the best resources due to high content of holocellulose (70.82 %) and to its specific gravity (0.597) approaching those of other hardwoods and its low contents of total extractive (9.74 %) lignin (18.86 %) compared to the other resources examined.

Yang *et al.* (2009) worked on 3 year old culms of 8 provenances of *Bambusa chungii* from Guangdong, Gungi and Hainan provenances and they reported significant differences in 1 per cent NaOH extractive and lignin were 0.54 and 0.38 respectively. A significant negative correlation was found between per cent NaOH extractive, alcohol-benzene extractive contents bamboo culm yield.

Raiskila (2008) had examined three different Norway spruce cutting clones grown in three different environments within the boreal zone and reported maximum sapwood lignin content from fast growing clones than fertile sites, whereas slow growing clones had the minimum lignin content.

Gular *et al.* (2007) had examined the chemical properties of black pine juvenile wood and found that juvenile wood had higher lignin and lower holocellulose contents as compared to the mature wood. The extractive content of juvenile wood was also found to be lower than mature wood. On the other hand, hot and 1 per cent NaOH solubility values were found be lower for juvenile wood.

Nimkar and Sharma (2006) reported that specific gravity of wood of Chir pine varies from 0.543 to 0.656 among high resin yielders. Sharma and Venkaiha (1992) observed that the specific gravity of *Bombax ceiba* L. fall in the range of 0.34-0.394.

Silva *et al.* (2006) studies the chemical composition variation in *Eucalyptus grandis* wood of four different ages (10, 15, 20 and 25 years) from commercial stands. The samples were removed from three discs taken from the base and top of the first two 3 m logs, from 16 trees. The mean values of holocellulose, lignin and extractives contents were 69, 27 and 4 per cent respectively. The extractive and lignin contents increased with age, with greater concentration near the base. The holocellulose content also decreased near the base with age, with greater concentrations in discs removed from upper parts of the trunk.

Kumar *et al.* (2005) had studied variation in physico- chemical characteristics of wood of candidate plus trees CPTs of Shisham (*Dalbergia sissoo*). The results revealed that among different CPTs of *Dalbergia sissoo*, significant differences were noticed for all the character 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 2.25-6.75%, 3.50-9.15%, 1.01-7.56% and 23.90-30.50%, respectfully. While 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 5.25-10.15%, 9.15-11.55 %, 30.50-39.70% and 62.00-70.00 %, respectively. Fakharian *et al.* (2005) investigated the chemical characteristics of 4 years old *Alnus glutinosa* and recorded in 48.5 per cent cellulose, 25.35 per cent lignin, 0.31 per cent ash as well as 2.36 per cent extractives.

The photochemistry of the toon plant reported the presences of cedrelone in the heartwood, 5 methylocoumarines in the stem bark and lemnones and siderin in the leaves of the plant (Chaudhary, 2004; Lio *et al.*, 2007). Cedrelone isolated from the benzene extract of heartwood of *Toona ciliata* and yield various compounds from it by photooxidation Gopalakrishnan *et al.* (2000).

Morais *et al.* (2005) analysed the chemical composition of *Pinus oocarpa* wood cultivated in the Brazilian cerrado and reported α-cellulose (59.05 per cent), hemicellulose (21.22 per cent), lignin (25.18 per cent), dichloromethane extractives (2.78 per cent), ethanol:

toluene extractives (4.38 per cent), hot water extractive (4.31 per cent) and ash (91.26 per cent).

Rigatto (2004) studied variations in wood properties attributable to the different distribution patterns of its micro structures, its arrangement, size and dimension of components cells. Variations in wood quality with tree growth can strongly be related to physical and chemical properties of the soil as well as environmental factors such as temperature, light, water and internally controlled genetic factors (Panshin and Zeeuw, 1980).

Sharma and Sharma (2005) found that the lignin content decreased, while holocellulose content increased from ground level to top of the tree of *Eucalyptus tereticornis*. Kumar and Sharma (2005) worked on the chemical characteristics of wood of candidate plus of *Dalbergia sissoo* and reported mean holocellulose content ranged from 66.00 per cent to 76.45 per cent.

Goodell (2003) reported that most of the white rot fungi utilize cellulose, hemicellulose and lignin at rates similar to the relative amounts originally present in the wood. He also observed that a few white rot fungi, termed selective white rot fungi, remove lignin and hemicellulose preferentially during early stages of decay whereas, most brown rot fungi only utilize cell wall hemicellulose and cellulose, leaving the lignin essentially undigested, but modified.

You et al. (1997) studied the 10 provenances of 10 years old *Pinus taeda* and found variations in wood chemical compositions among and within provenances. The results revealed that there were no significant differences in cellulose and lignin content among provenances except those of pentosan and benzene – alcohole extractives, cellulose content, lignin, pentosan and alcohole-benzene found to be 41.47 to 43.15 %, 28.85 to 30.10 %, 14.85 to 16.45 % and 1.45 to 2.78 %, respectively. Further analysis also indicated variation in extents of main chemical constituents within a given provenance of *Pinus taeda* was greater than those among provenances.

Pari et al. (1997) studied nine Indonesia species and reported that holocellulose content ranged from 69.61 to 75.21 per cent, lignin from 24.79 to 39.39 per cent and specific gravity from 0.36 to 0.85 g/cm². The solubility in cold water, hot water and alcohol-benzene 1:2 ranged from 4.33 to 7.41 per cent, 4.67 to 9.47 per cent and 1.99 to 9.21, respectively.

Major chemical components in wood are lignin (18-35%) and carbohydrates (65-75 %) which is complex, polymeric materials. Minor amount of extraneous materials, mostly in the form of organic extractives and inorganic extractives and inorganic materials (ash), are also present in wood (4-10%). Overall, wood has an elemental composition of about 50 % carbon, 6% hydrogen, 44% oxygen and trace amounts of several metal ions. Cellulose and hemicellulose, together described as holocellulose, is a term used to denote the polysaccharides in wood. Pure cellulose, often referred to as cellulose consists of chain molecules similar to pure cellulose but containing polysaccharides other than glucose, such as galactose, rhamnose, arabinose, mannose and oxygen (Bland, 1985). The chemical composition of wood depends not only on tree species but also on many other factors, such as: tree part, age, site condition, geographical provenance and season of cutting (Samkova and Nagyova, 1987).

Kirk *et al.* (1980) concluded that microbial degradation of lignin received considerable attention in recent years. Fungi that selectively remove lignin without loss of appreciable amounts of cellulose are extremely attractive for use in biological pulping processes, to improve the digestibility of highly lignified plant residues, and for bioconversion of lignocelluloses into industrial products.

Browning (1963) studied that *Eucalyptus regnans* wood, water absorption is lower in lignin than in the hemicelluloses and cellulose. He also found that the fractional contribution of each cell wall polymer to the total water absorption was 47 per cent for cellulose, 37 per cent for hemicelluloses and 16 per cent for lignin which means that lignin (to a small degree), the hemicelluloses, the non- crystalline portion of cellulose and the surfaces of the cellulose crystallites are responsible for moisture uptake by wood.

Goldstein (1955) reported that swelling agents such as furfuryl alcohol caused more swelling in wood than water. The treated wood would swell further upon exposure to high humidity or saturation with water which showed that some previously ordered regions of the wood cellulose were made accessible to water by the furfural alcohol. This behaviour demonstrated that complete stabilization of wood (100% ASE) was not possible.

2.5 GENETIC STUDIES

Banyal and Sharma (2015) revealed significant variation for seedling height, collar diameter and survival among progenies of plus trees of *Cedrus deodara*. Further, higher

extent of genotypic variation for survival (102.1%), medium for germination (63.39 %) and height (61.44%) and low for collar diameter (23.90%) was found.

Thakur *et al.* (2014) carried out a variation study on *Ulmus villosa* in Himachal Pradesh and found higher genotypic coefficient of variation for dry root weight (47.67%) and for dry shoot dry weight (55.66%). Shoot dry weight and shoot fresh weight had higher heritability with moderate genetic gain, suggesting their importance for the success of improvement through selection. They found highly significant and positive genotypic and phenotypic correlations between fresh shoot weight and fresh root weight indicating their significances in the indirect selection.

Aslam *et al.* (2014) revealed that a large portion of phenotypic variability in respect of collar diameter, seedling height, and needle diameter and seedling survival among the progenies of blue pine (*Pinus wallichiana*) was genetic and highly heritable in Kashmir Himalaya. Higher estimates of heritability and genetic gain were for the characteristics seedling height and collar diameter depicting the role of additive gene action in the inheritances of these traits.

Sharma (2014) reported significant variations among fifty two plus trees of *Cedrus doedara* selected from Himachal Pradesh for cone and seed traits including cone diameter, its weight, seed length, number of seed, seed width and seed weight. Seed traits viz., seed length and seed width, seed length and seed weight and seed width and seed weight were observed to have positive and highly significant genetic correlation, suggesting the importance of these traits for the selection of productive genotypes.

Rawat and Bakshi (2011) reported that significant results for cone traits length (length, diameter, weight), seed traits (length, width, thickness, 100 seed weight, seed volume) germination traits (germination percent, germination value, germination energy, germination energy index, germination period), cotyledon number, shoot length and root length among the twenty seed sources of *Pinus wallichiana* at FRI Dehradun. They invested that variability studies in different seed sources of *Pinus wallichiana* (Blue Pine) with respect to cone, seed and seedling traits were undertaken at Forest Research Institute, Dehra Dun, India under the framework of USDA pine project. The study revealed significant variability in terms of mean values, critical difference, and coefficient of variation, broad sense heritabil-

ity, genetic advance and genetic gain. Most of the traits showed significant correlation with geographical factors viz., longitude, latitude and altitude.

Uppal and Singh (2010) conducted study on the effect of seed sources variation on seed and seedling characteristic of *T. ciliata* in Himachal Pradesh and found the significant variations for seed traits, nursery germination percent, and growth and biomass characters. Further they reported that the root lengths were influenced by genetic makeup, with higher estimates of heritability (h^2), genetic gain and genetic advances whereas germination percentage controlled by environmental influence. Estimate of heritability was found to be higher for root length and lesser for seed weight and germination percentage. Based on the present study, they concluded that seedling height and number of leaves being higher estimates of heritability and genetic advances found to be suitable for selection of superior progenies.

Divakara *et al.* (2010) revealed the significant differences for pod and seed traits among the CPTs of *Pongamia pinnata* while conducting a study in Ranchi. Genotype CPT-19 was found superior on others in terms of maximal values of pod length (65.64 mm), 100- pod weight (542.35 g), 2D surface area (351.18 mm²), seed length (27.93 mm), 100 seeds weight (202.89 g) and total oil content (44.33 %). They concluded that presence of substantial genetic variation could be utilized for the further tree improvement works in future.

Dhillon *et al.* (2009) studied the genetic variation among open pollinated progenies of *Melia azedarach* under nursery and field conditions in Punjab. Significant differences were recorded for collar diameter and plant height at nursery stage. Medium estimates of heritability were recorded higher for height (35.34%) under nursery conditions. Similarity PCV and GCV were recorded for height (22.50 %) under nursery conditions and for diameter (17.88 %) under field conditions.

Luna and Singh (2009) observed higher estimates of heritability and genetic gains for height, diameter and clean bole among the progenies of 11 CPTs of Eucalyptus hybrid during a trial conducted at Hoshairpur (Punjab) up to three year of observations. Significant genotypic correlation was observed for height and diameter indicating that improvement in one character will be accompanied by another.

Rana *et al.* (2009) reported considerable variations for all growth parameters of *Toona ciliata* under the nursery condition viz., seedling height, collar diameter and number of

leaves. Further, they found that seedling height and number of leaves showed moderate estimate for genotypic and phenotypic coefficient of variation. Phenotypic variations were also recorded for the seed color ranging from light creamish yellow to blackish brown. They found that collar diameter showed high genetic advances (23.67%), indicating non –additive gene action in the inheritance of this trait. On the basis of estimates of heritability and genetic advance, seedling height and number of leaves were found to be amenable for selection of superior progenies.

Kaushik *et al.* (2007a) reported significant variations for seed length (mm), seed breadth (mm), seed thickness (mm), and 100 seed weight (g) among the 24 accessions of *Jatropha curcas* collected from the different agro climatic zones of Haryana.

Kaushik *et al.* (2007b) conduct a study on the genetic variability in pod and seed traits among forty CPTs of *Pongamia pinnata* selected from the different locations of Haryana state and observed significant genetic variability and association for pod seed traits. They also observed higher phenotypic coefficient of variation favoring the predominant role of environment.

Bahadur and Singh (2007) assessed the significant variation in fruit diameter, fruit weight, seed diameter and seed weight among all seed sources of *Sapindus mukorossi*, obtained by collecting the seeds from thirteen localities of Himachal Pradesh.

A variation study was carried out by Chaudhary *et al.* (2007) among the open pollinated seeds of *T. ciliata* collected from 50 trees from 10 different sites in Himachal Pradesh revealed significant differences for seed traits, germination behavior, growth and biomass characters. In case of seed traits, higher estimates of broad sense heritability (89.90%) with moderate genetic gain (31.40%) and higher genetic advances (0.42) was found for seed length (with wings) and lower for 100 seed weight. However in overall performance of seed morphology and germination characteristics, they recorded higher estimates of genotypic coefficient of variation (30.46%), phenotypic coefficient of variation (30.84%), heritability (97.50%) genetic advances (37.71) and genetic gain (61.90%) for germination energy.

Gera and Gera (2000) found highly significant differences for pod traits (pod length, pod width, number of seeds per pod), seed traits (length, width and weight), germination

percent, growth traits (seedling height, collar diameter, and number of nodules) and biomass traits (shoot and root biomass) among twenty genotypes of *Acacia catechu* scattered over Jammu region. Furthermore, genotypic variance and genotypic coefficient of variation were recorded higher for germination and growth characters. They observed higher values of heritability and genetic gain for all the parameters except germination.

Luna *et al.* (2006) studies variations for different pod and seed traits among 20 seed sources of *Albizia lebbeck* from Punjab, Haryana and Uttarakhand and observed significant correlation for seed weight, seed width, and seed length. They also found that germination percent was positively correlated with number of seed per pod.

Singh *et al.* (2006) observed significant variations for seed traits viz., seed length, seed weight, seed germination, survival percent and other growth and biomass traits among 13 provenances of *Celtis australis* in Central Himalayas. Further significant ($P=0.01$) positive correlation was found between morphological characters of seeds including seed weight and elevation range of seed sources as well as between growth performances of seedling and altitude of seed sources.

Sehgal *et al.* (2006) reported significant variation between and within seed sources for various seed traits viz., seed length, seed breadth and 100 seed weight among open pollinated seeds of *Toona ciliata* collected from 50 trees from ten seed sources in Himachal Pradesh. Similarly, they observed significant variations for germination energy and seedling survival.

Erschine *et al.* (2005) suggested that *T. ciliata* is the proper performing species among the members of the Meliaceae, because of insect damage. Toon is highly susceptible to shoot borer (*Hypsipyla robusta*), which appears in the first summer after planting and has reappeared every summer since then.

Roy *et al.* (2004) found a wide range of variability for cone traits (cone length, cone width, fresh weight and number of seeds per cone), seed traits (1000 seeds weight, seed length, seed width) and nursery traits (germination percent, survival percent, days taken for bud break, collar diameter, one year extension growth) among provenances of *Pinus roxburghii*.

Uniyal *et al.* (2003) observed significant variations in seed and seedling characteristics of *Grewia oppositifolia*. Furthermore, higher estimates of genotypic variance,

genotypic coefficient of variation and heritability were recorded more genetic variances and genotypic coefficient of variation favoring genetic control over these parameters. Characters that showed greater genetic influence could be utilized for the improvement of this species.

Ginwal *et al.* (1994) studied provenances variation in *Acacia nilotica* using 32 provenances from five countries (India, Sudan, Pakistan, Yemen and Senegal). Significant differences were observed for collar diameter and seedling dry weight under nursery conditions.

Kaushik (1993) worked on genetic variation studies in *Toona ciliata* and reported significant differences among twelve seed sources for seed germination, seed viability, dewinged seed length, seed width, seedling height and collar diameter. However, the hundred seed weight and seed length (winged) were found to be non - significant. He also observed the variation for seed color and classified them in color categories as dark brown, light brown and bright brown.

Jaswal (1992) reported significant variations among the seed sources of *Grewia optiva* seedlings for the various growth viz., collar diameter, height, leaf area, length and dry weight of root and shoot and their respective ratios.

Veerandra and Sharma (1990) carried out variation studies in *santalum album* and revealed significant differences among different seed sources for the various parameters viz., collar diameter, root length and number of leaves per plant where as seedling height showed non-significant differences.

Sneizko and Stewart (1986) found significant variation for seed weight and seedling traits including seedling height, leaf color, number of nodules per seedlings, total dry weight among the provenances of *Acacia albida* in Zimbabwe.

Salazar and Quesada (1987) evaluated eight seed sources of *Guazauma ulmifolia* in Costa Rica for first 2 to 6 years and found the genetic variation in height growth, stem growth and leaf form among the provenances and concluded that considerable genetic variation among natural range of distribution could be encountered by examining the seed sources from a whole range of climatic conditions where the species is naturally found.

2.6 CORRELATION STUDIES

The parameters under study need to be discussed in context to their correlation with each other to highlight the importance and manifestation of traits; hence the literature was consulted on correlation studies as below:

Dhiman (2018) reported that *Toona ciliata* was an important timber yielding and agroforestry tree species, occurs extensively on farmlands throughout India. With the objective to determine extent and nature of variations in seed and seedling growth traits, thirty six phenotypically superior genotypes were identified from twelve different locations across Punjab and Himachal Pradesh following the baseline method. The tree characteristics used were tree height, clear bole height and girth with the mean of 13.20 m, 3.79 m and 94.54 cm respectively. Considerable variations were observed in 100 seeds weight (704.63-846.62 mg), germination percent (27.00-67.25%), survival percent (62.50-87.97 %), seedling height (8.69-28.65 cm) and number of leaves (27.42-66.25), among seed sources. Simple correlation coefficient among seed traits, germination behavior and growth and biomass traits of progenies was also estimated. The correlation matrix revealed that highly significant and positive correlation exists between seed weight and germination percent, germination percent and survival percent, seedling height and collar diameter, therefore improvement in one trait is bound to make positive response in the correlated trait. The higher estimates of genotypic coefficient of variability, phenotypic coefficient of variability and heritability (broad sense) were found for seed traits suggesting additive gene control in the inheritance of these traits.

Wani and Singh (2016) reported that provenance was considered to be the origin place of *Pongamia pinnata* in Chhattisgarh. The daily germination per cent was found highest on 8th and 10th day during germination. The average germination value, germination energy index were 87.5 ± 5.12 , 33.99 ± 1.24 and 18.84 respectively. To find out their rate of dependency correlation matrix was completed and it was found that a significant positive correlation (0.84 to 0.99) exist between different germination parameters of *Pongamia pinnata* at 0.05 level of probability.

Maya and Narasimhamurthy (2015) found no correlation between lignin content and fiber length. However, a clear correlation had been observed between lignin content and fiber diameter. On other hand, the holocellulose and alpha-cellulose content have not shown a clear relationship with the fiber morphological progenies. Carrillo *et al.* (2015) studies six 15-

year old *Eucalyptus globulus* trees, ranging in wood density from 474 to 575 kg m³ at breast height for fiber length versus density, density versus wall thickness, and coarseness versus fiber length at different sections along the radius analyzed.

Shirsat *et al.* (2011) studies correlation between physical, chemical and anatomical characteristics in *Acacia nilotica* and found strong positive correlation between diameters and bark percentage. Highly significant and negative correlation was recorded with hot water and alcohol-benzene solubility. They also observed that the genetic variability of *Acacia nilotica* sapwood were quantitatively measured for grain angle, bark percentage, specific gravity, fiber length, cold water soluble extractives, hot water soluble extractive alcohol-benzene soluble extractives, hot water soluble extractives, lignin and holocellulose percentage. The highest value for phenotypic and genotypic coefficients of variability was observed for specific gravity of sapwood.

Wani and Ahmed (2013) reported positive and significant correlation for germination traits, growth and biomass characters among the candidates plus trees of *Madhuca indica* at Allahabad Agricultural Institute and concluded that these traits could be utilized for early screening / selection of genotypes.

Sharma and Lekha (2012) studies that the variability in physico- chemical properties of sapwood and heartwood of *Acacia catechu* and reported that Katha content and cutch content was significantly and positively correlated with moisture content in heartwood and negatively correlated with lignin content. The values of the heritability factor were high for the holocellulose (0.981), lignin (0.944) and specific gravity (0.870). The genetic advances, genetic gain, phenotypic and genotypic coefficient of variation ranged from 0.05-24.31, 2.84-42.81, 1.33-20.77, respectively for various parameters in sapwood. The maximum heritability value of 0.051 (5.10%) was noticed in lignin content in heartwood.

Steffenrem *et al.* (2009) had studies 15-year old spruce (*Picea mariana*) trees of 40 open pollinated families grown in New Brunswick to examine the genetic variation and inheritance of wood density and its relationship with growth traits (tree diameter, tree height and bole volume). They investigated that traits were under strong genetic control (h^2 ranged from 0.60 to 0.86 and overall wood density showed negative genetic correlation with growth traits ranging from -0.34 to 0.41).

Liu *et al.* (2008) reported significant differences among the plus tree progenies of *Toona ciliata* var. Pubescence's at China. Significant and positive correlation was observed between seedling height and seedling ground diameter and dry weight of stems. Based on the heritability and correlation analysis of all characters, it was concluded that seedling height and seedling ground diameter could be regarded as the most important criteria for selection.

Rao *et al.* (2008) observed significant differences for all the seed characters among 32 CPTs of *Jatropha* from different locations in Andhra Pradesh. Significant variation was recorded for plant height and it was significantly positively correlated with yield. Significant negative phenotypic correlation was recorded for plant height and female to male flower ratio.

Devagiri *et al.* (2007) observed significant positive correlations for growth characters viz., seedling height, collar diameter and root length among 20 seed sources of *D. sissoo*.

Cunningham and Floyd (2004) used near-infrared spectroscopy (NIRS) to quantify the variation in tissue composition in order to determine compositional variation and its relation with differences in *H. robusta* damage in the field trials of *T. ciliata* in Australia. They found that the taller trees were more frequently damaged indicating that plant heights were significantly correlation with *H. robusta* damage.

Kumar *et al.* (2004) observed significant correlation for seed weight and germination percentage among the 13 seed sources of *A. catechu* from Haryana, Punjab, Uttaranchal and J&K. They found that seed sources were statistically significant for all the traits except for the seed thickness. Based on the study they concluded that seed weight could be an important trait for the early for the early selection of seed sources.

Jiang *et al.* (1994) measured wood basic density, fiber length, tree height and diameter at breast height for 8 years old clones of *Populus deltoids*. The results revealed that the basic wood properties and tree growth were moderate and had strong genetic correlation between wood basic density and tree growth rate as well as positive genetic correlation between the fiber length and growth.

Khosla *et al.* (1979) reported strong correlations between height and diameter, diameter and age of *Populus ciliata*. Between provenances variation and low genetic variation was found to occur among natural stands.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “**Studies on provenance variation in *Toona ciliata* M. Roem**” was carried out in the department of Forest Genetic Resources of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan. The details of material used and methodologies followed for conducting the current research work are as follows:

- 3.1 Morphological characterization of *Toona ciliata* from different provenances.
- 3.2 Variation in seed traits and seedling attributes
- 3.3 Provenance variation in wood characteristics

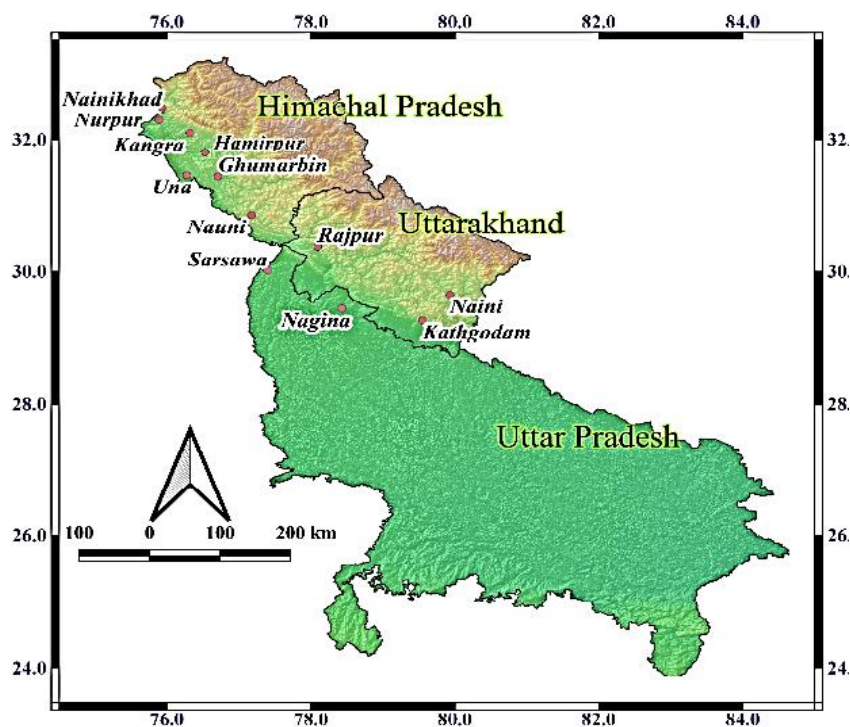


Figure 1: Location map of *Toona ciliata* provenances

The samples were collected from twelve districts of three states of India i.e., Himachal Pradesh, Uttarakhand and Uttar Pradesh. The aspects and elevations of the sites were measured using, QGIS. These were considered to be the major parameters to differentiate between the sites. Different provenances of *Toona ciliata* were selected in different districts where species were naturally growing. The selected provenances of twelve districts were:

Table 1: Geographical details of the provenances of *Toona ciliata*

Provenances		Districts	State	Altitude (m)	Latitude (°N)	Longitude (°E)
Code	Location					
P ₁	Nauni	Solan	Himachal Pradesh	1285	30.8600	77.1730
P ₂	Hamirpur	Hamirpur		780	27.1340	81.9619
P ₃	Thakurduara	Kangra		733	32.0977	76.2716
P ₄	Ghumarwin	Bilaspur		685	31.4491	76.7048
P ₅	Nurpur	Kangra		752	32.1060	76.3800
P ₆	Nainikhad	Chamba		938	32.4919	75.9245
P ₇	Una	Una		349	31.2814	76.1654
P ₈	Rajpur	Dehradun	Uttarakhand	447	30.3847	78.0894
P ₉	Kathgodam	Haldwani		424	29.2183	79.5130
P ₁₀	Naini	Almora		520	29.4980	79.9535
P ₁₁	Nagina	Bijnour	Uttar Pradesh	282	29.4426	78.4327
P ₁₂	Sarsawa	Saharanpur		272	30.0198	77.3985

3.1 MORPHOLOGICAL CHARACTERIZATION OF *TOONA CILIATA* FROM DIFFERENT PROVENANCES

3.1.1 Phenotypic characters

1. Tree height (m):

Height of the trees was measured by using Christen hypsometer and 2 m wooden staff. The staff is fixed to base of the tree at 90° angle and the height was measured using hypsometer at distance of 5-10 m from the tree base. The reading for height was recorded on the hypsometer scale at coinciding top point of staff and hypsometer.

2. Tree diameters (cm):

The diameter was calculated by actually measuring the girth. The girth was measured at breast height (1.37 m) from base of tree with measuring tape.

3. Crown spread (m):

The crown spread was measured in two directions viz., north-south and east-west by using plumb bob, perpendicular staff and measuring tape. The perpendicular staff was fixing on the ground in two directions according to last branch of crown by the use of plumb bob. The measuring tape was used to measure the distance (crown spread) between last branches in both the directions. This process was firstly use to measure the crown spread in N-S direction and the same process was repeated to measure the crown spread in E-W direction

4. Clear bole height (m):

Spiegel Relaskop was used on 30 m scale for recording clear bole height of each tree as per the method for tree height measurement (Chaturvedi and Khanna, 1982).

5. Crown areas (m²):

Crown area was calculated on the principal of a triangle, taking crown length and crown width as the vertical and horizontal lengths and was expressed in square meters.

3.1.2 Leaf Characters

1. Leaflet area (cm²):

The leaves recorded for their length and breadth were detached from the plant and were measured for their area using leaf area meter (LICOR area meter Modal 3100).

2. Leaf bases:

The leaf base was the slightly expanded area where the leaf attaches to the stem. It was worked out with physical observation.

3. Leaf apices:

Apices are the shapes of the tip of the leaf furthest from the petiole.

4. Leaflet margin:

Individual tree leaves were observed for selected leaves, wavy and for serrated margins.

3.1.3 Flowers characterization:

1. Duration of flowering:

Time and duration of flowering was recorded from the selected genotypes.

2. Number of flowers per inflorescence:

The character was studied by taking flower counts for each of the three inflorescences collected per tree.

3.2 VARIATION IN SEED TRAITS AND SEEDLING CHARACTERISTICS OF *Toona ciliata*

3.2.1 Seed collection:

Seeds were collected from twelve seed sources, representing the entire range of distribution of *Toona ciliata* in Himachal Pradesh, Uttarakhand and Uttar Pradesh. Seeds were collected from the selected trees during second and third week of April beginning from the seed sources of lower altitudes and moving toward higher altitudes. Seeds, processed separately for each seed source, were used for studying following characters:

1. 100 seeds weight (gm):

A random sample of 100 seeds per tree was weighed with the help of electronic balance (modal:Libor AEU- 210 of shimadzu) as per ISTA 1996 regulations

2. Seed colour:

Seed colour of all the trees within seeds sources was observed by displaying all at a platform for comparative colour observation. For this three colour categories were made:

- a) Light brown
- b) Brown
- c) Dark brown

3. Seed germination (%):

Seed germination studies were carried out in laboratory. From each seed source, 100 seeds per replication were placed in petri plates well covered with germination paper at the base. The germination percentage was calculated as given below:

$$\text{Germination \%} = \frac{\text{Seeds germinated}}{\text{Seeds sown}} \times 100$$

4. Seed viability (%):

Seed viability was tested using germination test as the index for seed viability (ISTA, 1966). Cleared seeds were stored in air tight glass containers, at room temperature and were allowed to germinate after 3 month period. Similarly, another set of stored seeds were placed for germination after 6 months (at room temperature).

3.2.2 Seedling characters:

1. Germination energy index (%):

This was computed as per (Grouse and Zimer, 1958) with some modification.

$$GEI (\%) = \frac{A_1 + (A_1 + A_2) + (A_1 + A_2 + A_3) + \dots + (A_1 + A_2 + A_3 + \dots + A_n)}{N + n} \times 100$$

where:

$A_1 + (A_1 + A_2) + (A_1 + A_2 + A_3) + \dots + (A_1 + A_2 + A_3 + \dots + A_n)$ = cumulative number of seeds germinated up to nth day.

N = Total number of seeds used for the treatment

n = Number of observation days

2. Seedling height (cm):

Height was measured with a scale and meter rod from the polybag ground level to the shoot tip of the seedling. After four month height of seedling was being measured from the ground level up to the apex of leading shoot.

3. Collar diameter (mm):

It was measured with a vernier digital caliper at the ground level and the mean of two values at right angle to each other per seedling was taken

4. Number of leaves per plant:

Total number of leaves per plant was counted. However, very young and small leaves were ignored.

5. Leaf area (cm²):

The leaves recorded for their length and breadth were detached from the plant were measured for their area using leaf area meter (LICOR area meter model 3100).

6. Number of branches and branchlets per seedling:

Number of primary branches and branchlets for seedling was recorded. Secondary or tertiary branch for seedling were not counted because the entire seedling did not exhibit such branches. Only the primary branches longer than 5 cm were recorded.

7. Leaf length (cm):

Length of leaf was measured with a ruler from the leaf base to its tip. Five representative (fully grown) leaves per seedling were recorded. Leaf length was measured using scale and expressed in centimeters (cm).

8. Seedling survival percent (%):

Survival percentage was calculated as the number of seedling that survived after it reached 3-4 leaves stage out of number of germinated seedlings and expressed in percentage. Surviving plants in each bed were counted for recording varies seedling traits (height, collar diameter, etc.) In the nursery and the survival per was worked out as follows:

$$\text{Survival percent} = \frac{\text{Plant count in a bed}}{\text{Number of seeds germination in that bed}} \times 100$$

Fives representatives (randomly selected) plants of each seed provenances per replication were selected for recording the following traits:

3.3 PROVENANCES VARIATION IN WOODCHARACTERISTICS

In order tothe study of timber quality, the following wood parameters were studied by taking core sample from three selected trees representing each provenance. Wood samples were extracted with increment borer from the selected trees at right to the DBH height. The length of wood samples ranged from 10-12m which contained the sapwood and portion of heartwood. Wood samples were collected from month of January to April. These extracted wood samples were used from sapwood and heart wood. Freshly extracted samples were marked to differentiate between sap and heart wood portion. These samples were also used to calculate the fresh weight, moisture content, maximum moisture content and specific gravity of both sapwood and heartwood. For chemical analysis, Toon wood samples were collected by using chisel and hammer. A 5×5 cm² cut was made on tree stem, which was taken out carefully. Then inner wood was extracted up to a depth of about 5-15 cm and wood pieces were collected for chemical analysis. After samples collection bark portion was carefully fixed over the wound for acceleration of healing process. The further experimental detail is as follows:

Observation recorded:

Tree girth was recorded for calculation of DBH. Different toon increment borer extracted wood samples from all selected provenances were separated into sapwood and heartwood parts with length range of 3-5 cm. Fresh cylindrical samples were marked with carbon pencil and their fresh weight was taken. The following physical and chemical characteristics were recorded as shown in plate.

1. Moisture content (%):

Fresh weight of the wood samples was recorded just after their extraction from trees of different provenances. After initial weight on balance, the samples were oven dried at $105 \pm 2^\circ\text{C}$ till constant weight. This weight of samples was recorded as oven dried weight (g). The moisture per cent of the samples on oven dry weight basis were calculated by the formula given by Desch and Dinwoddie (1996).

$$\text{Moisture content (\%)} = \frac{M_i - M_o}{M_o}$$

where,

M_i = Initial weight of sample (g)

M_o = Oven dried weight of sample (g)

2. Maximum moisture content (%):

Maximum moisture content (MMC) of wood samples was determined as per procedure by Indian Standard IS: 1708 BIS, (1986). The extracted wood samples were dipped fully in distilled water in glass beakers separately for 7 days for complete saturation. The saturated wood samples were taken out and weighed. These samples were then dried first in air and then oven dried at $105 \pm 2^\circ\text{C}$ till constant weight. The maximum moisture content % was calculated by following formula.

$$\text{Maximum moisture content (\%)} = \frac{M_m - M_o}{M_o} \times 100$$

where,

M_m = Saturated weight of sample (g)

M_o = Oven dried weight of sample (g)

3. Specific gravity:

Same wood samples which were dipped in water for maximum moisture content was used for determine specific gravity of toon wood from different sites of different provenances. The weight of these samples was recorded day by day to get the constant weight at maximum fiber saturation point. After maximum saturation point with water treatment, samples were first dried in air and then dried at $105\pm 2^{\circ}\text{C}$ to constant weight. The data on weights were used to find the specific gravity of sapwood and heartwood samples. Every care was taken to avoid fungus attack and foul smell by regular changing of the water. Specific gravity was determined by the maximum moisture content method using formula given by Smith (1954).

$$\text{Specific gravity} = \frac{1}{\frac{M_m - M_o}{M_o} + \frac{1}{GS}}$$

where,

M_m = fresh / green weight of the sample having maximum moisture

M_o = Oven dried constant weight of the sample

GS = Average density of wood substances a constant having value of 1.53

3.4 CHEMICAL ANALYSIS OF *TOONA CILIATA* WOOD

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

3.4.1 Determination of water soluble extractives

The water soluble extractives were determined by employing following methods:

1. Cold water solubility:

Two grams of oven dry wood meal was weighed and transferred into a conical flask containing 300 ml of distilled water. The mixture was digested at room temperature with frequent stirring for 48 hours. Then material was filtered through IG-1 crucible and washed thoroughly with cold distilled water and dried to a constant weight in an oven at $105\pm 2^{\circ}\text{C}$. The cold water solubility was determined by calculating the loss in weight of sample taken and was expressed as percentage on basis of oven dry weight of wood.

2. Hot water solubility:

Two grams of oven dry wood meal was taken in a flask having 100 ml of double distilled water filtered with reflux condenser. It was digested on boiling water bath for 3 hours. Then contents were filtered through IG-1 crucible and residue was dried in an oven at $105 \pm 2^\circ\text{C}$ till constant weight. The solubility was determined by calculating the loss in weight of the sample taken and expressed as percentage.

3.4.2 Determination of Chemical soluble extractives:

1. Alcohol-benzene extractives:

Two grams oven dry powdered wood sample was placed in a porous thimble (oven dried and weighed). The thimble was placed in a Soxhlet Apparatus and extracted with 200 ml of alcohol-benzene (1:2 v/v) for six hours. Then, porous thimble was taken out and allowed to dry in open air and finally in an oven at $105 \pm 2^\circ\text{C}$ till constant weight. The alcohol-benzene solubility was determined by calculating the loss in weight of the sample taken and expressed in percentage.

2. Determination of Holocellulose:

Two grams of oven dried 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. Then contents were treated with 1.5 gram of Sodium chlorite and 10 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. Then contents were filtered through IG-2 crucible, washed with water and finally with acetone. The sample was dried in an oven at $105 \pm 2^\circ\text{C}$ to a constant weight. The per cent holocellulose content was calculated on the basis of the oven dry weight.

3. Determination of Klason-lignin content:

Two grams oven dry sample pre-extracted with alcohol-benzene (1:2 v/v) was treated with 15 ml of 72 per cent sulphuric acid for 2 hours at $18-20^\circ\text{C}$ with constant Stirring. The material was brought down to 3 per cent by adding 345 ml of double 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 $105 \pm 2^\circ\text{C}$ till constant weight and expressed in percentage on oven dry weight basis.

3.5 STATISTICAL ANALYSIS:

A) Analysis of Variances (ANOVA) for RBD

The data obtained on natural variation was subjected to statistical analysis using RBD. The statistical analysis for each parameter was carried out on mean values bases. Separate analysis of variance was performed for each character.

Table 2: Analysis of Variance for RBD

Sources of variation	Degree of freedom	Mean sum of square	Variance ratio
Replication	(r-1)	M_r	M_r/M_e
Treatment	(t-1)	M_t	M_t/M_e
Error	(r-1)(t-1)	M_e	
Total	(r x t)-1		

where,

r = number of replication

t = number of treatment

M_r = mean sum of square due to replication

M_t = mean sum of square due to treatment

M_e = mean sum of square due to error

B) Analysis of Variance (ANOVA) for CRD

The data recorded in the laboratory experiments were subjected to Completely Randomized Design as procedure given by Panse and Sukhatme (1978) & Chandel (1984).

Table 3: Analysis of Variance for CRD

Sources of variation	Degree of freedom	Mean sum of squares	Variance ratio
Treatment	(t-1)	M_t	M_t / M_e
Error	t(r-1)	M_e	
Total	(r x t)-1	M_t	

where,

r = number of replication

t = number of treatment

M_t = mean sum of square due to treatment

M_e = mean sum of square due to error

Critical difference (CD_{0.05})

Critical difference shall be calculated to find out the superiority of one treatment over the others.

$$CD_{0.05} = SE_d \times t_{0.05} \text{ (error degree of freedom)}$$

where,

$$CD_{0.05} = \text{Critical difference at 5\% level of significance}$$

$$SE_d = \text{Standard error of difference of mean } \sqrt{\frac{2M_e}{r}}$$

$$t_{0.05} = \text{t (table) value at 5\% level of significance}$$

3.6 GENETIC ESTIMATES:

1. Coefficient of variation (%):

Coefficients of variability were worked out by formula suggested by Burton and Devane (1953).

$$\text{Genotypic coefficient of variance (GCV)} = \frac{\sqrt{\text{Genotypic variance } (\sigma_g^2)}}{\text{Population mean of character } (\bar{X})} \times 100$$

$$\text{Phenotypic coefficient of variance (PCV)} = \frac{\sqrt{\text{Phenotypic variance } (\sigma_p^2)}}{\text{Population mean of character } (\bar{X})} \times 100$$

$$\text{Environmental coefficient of variance (ECV)} = \frac{\sqrt{\text{Environmental variance } (\sigma_e^2)}}{\text{Population mean of character } (\bar{X})} \times 100$$

2. Broad Sense Heritability (%):

Broad Sense Heritability (H_{BS}^2), had be calculated as suggested by Burton and Devane (1953) and Johnson *et al.* (1955).

$$\text{Broad Sense Heritability } (H_{BS}^2) = \frac{\text{Genotypic variance } (\sigma_g^2)}{\text{Phenotypic variance } (\sigma_p^2)} \times 100$$

4. Genetic Advance:

Genetic advance was calculated using following formula (Lush,1940;Burton and Devane, 1953; Johnson *et al.*,1955).

$$GA = H_{BS}^2 \times \sigma_p^2 \times K$$

where,

$H_{BS}^2(\%)$ = Broad Sense Heritability

σ_p = Phenotypic standard deviation

K = 2.06(selection differential at 5% selection intensity)

5. Estimation of genetic gain (%):

Genetic gain was calculated using following formula (Lush,1940;Burton and Devane, 1953; Johnson *et al.*,1955).

$$GG(\%) = \frac{\text{Genetic advance (GA)}}{\text{Population mean of character } (\bar{X})} \times 100$$

6. Correlation coefficient:

Karl Pearson's correlation coefficient was calculated as:

$$r_{xy} = \frac{CoV_{xy}}{\sqrt{V_x V_y}}$$

where,

r_{xy} = Correlation between x and y

CoV = Covariance of x and y

V_x = Variance of x

V_y = Variance of y

Chapter-4

RESULTS AND DISCUSSION

The present investigation entitled “**Studies on provenance variation in *Toona ciliata* M. Roem**” was carried out to examine the extent of variation between different provenances and variation within each provenance. The results obtained from the present studies on *Toona ciliata* provenances for the morphological and phenotypic characters along with seed traits, progeny performances and wood chemical characteristics have been presented and discussed herewith for twelve provenances. The results are presented under the following heads:

4.1 Variation in morphological and phenotypic traits

4.2 Variation in seed traits

4.3 Nursery growth performances

4.4 Wood chemical studies

4.5 Genetic studies

4.6 Correlations studies

4.1 VARIATION IN MORPHOLOGICAL AND PHENOTYPIC TRAITS

The study reported pronounced variation among selected provenances for various morphological traits. Variation among the different characters viz., tree height, tree diameter, crown spread, clear bole height and crown area were presented in Table 4.

4.1.1 Tree height (m):

Tree height recoded from different provenances ranged from 18.47 to 28.70 m. The maximum height was recorded from P₁ (Nauni) provenance with the mean height as 28.70 m which was at par with P₅ (Nurpur; 26.69 m), P₁₀ (Naini; 25.77 m), P₃ (Thakurduara; 25.75 m) and P₉ (Kathgodam; 25.54 m) provenances. Minimum tree height was recorded from P₆ (Nainikhad) with mean value of 18.47 m and was statistically at par P₇ (Una) with mean tree height as 21.21 m.

4.1.2 Tree diameter (cm):

Tree diameter measured from different provenances was found to range from 29.97 cm to 33.19 cm. Maximum tree diameter was recorded in P₁₀ (Naini) provenance with mean value of 33.19 cm, which was statistical at par with by P₁ (Nauni; 33.05 cm), P₈ (Rajpur;

32.69 cm), P₉ (Kathgodam; 32.41 cm), P₄ (Ghumarwin; 32.4 cm), P₂ (Hamirpur; 32.19 cm) and P₁₂ (Sarsawa; 31.99 cm), while the minimum tree diameter (29.97 cm) was recorded in P₃ (Thakurduara).

Table 4: Morphological variation between different provenances of *Toona ciliata*

Code No.	Provenances	Tree height (m)	Tree diameter (cm)	Crown spread (m)	Clear bole height (m)	Crown area (m ²)
P ₁	Nauni	28.70	33.05	9.74	2.99	27.44
P ₂	Hamirpur	25.06	32.19	10.14	2.66	30.20
P ₃	Thakurduara	25.75	29.97	10.20	2.62	31.11
P ₄	Ghumarwin	22.38	32.40	11.29	2.87	36.78
P ₅	Nurpur	26.69	31.65	10.09	2.77	29.32
P ₆	Nainikhad	18.47	31.83	10.38	2.57	31.12
P ₇	Una	21.21	31.68	10.14	2.76	29.91
P ₈	Rajpur	24.40	32.69	12.27	2.85	43.71
P ₉	Kathgodam	25.54	32.41	12.84	2.54	48.73
P ₁₀	Naini	25.77	33.19	12.24	3.19	43.43
P ₁₁	Nagina	22.63	31.39	12.36	2.75	44.76
P ₁₂	Sarsawa	22.76	31.99	12.14	2.33	40.44
CD _{0.05}		3.49	1.28	1.23	0.16	8.35

4.1.3 Crown spread (m):

Crown spread of Toon was found maximum in P₉ (Kathgodam; 12.84 m) provenance, which was statistically at par with P₁₁ (Nagina; 12.36 m), P₈ (Rajpur; 12.27 m), P₁₀ (Naini; 12.24 m) and P₁₂ (Sarsawa; 12.14 m). On the other hand, lowest crown spread (9.74 m) was observed in P₁ (Nauni) which was statistically at par with P₅ (Nurpur; 10.09 m), P₇ (Una; 10.14 m), P₂ (Hamirpur; 10.14 m), P₃ (Thakurduara; 10.20 m) and P₆ (Nainikhad; 10.38 m) provenances.

4.1.4 Clear bole height (m):

Clear bole height of Toon was found maximum in P₁₀ (Naini; 3.19 m) followed statistically by P₁ (Nauni; 2.99 m). However, lowest clear bole height (2.33 m) was observed in P₁₂ (Sarsawa) which was followed statistically by P₉ (Kathgodam; 2.54 m). Similarly, clear bole height was comparable in P₂, P₃, P₄, P₅, P₆, P₇, P₈ and P₁₁.



a) Selection of Plus trees



b) Measurement of the tree height with help of Ravi-multimeter

Plate 1. Plus trees selection

4.1.5 Crown area (m²):

Maximum crown area (48.73 m²) of Toon was found in P₉ (Kathgodam) provenance which was statistically identical to P₁₁ (Nagina; 44.76 m²), P₈ (Rajpur; 43.71 m²), P₁₀ (Naini; 43.43 m²) and P₁₂ (Sarsawa; 40.44 m²) provenance. In contrast, lowest crown area (27.44 m²) was observed in P₁ (Nauni) which was statistically at par with P₅ (29.32 m²), P₇ (Una; 29.91 m²), P₂ (Hamirpur; 30.20 m²), P₃ (Thakurduara; 31.11 m²) and P₆ (Nainikhad; 31.12 m²) provenance.

Dhiman (2018) documented mean values of tree height, clear bole height and girth of 36 Toon plus trees in Punjab and Himachal Pradesh, which ranged from 11.4 to 14.8 m, 3.0 to 7.5 m and 135.6 to 70.9 cm, respectively. Kumari (2015) reported parallel results for DBH, height, crown diameter and crown area of Toon trees, ranging from 25.5 to 66.9 cm, 9 to 25 m, 7.07 to 11.73 m, and 39.29 to 108.42 m², respectively, in Sirmour district of Himachal Pradesh. Kumar (2004) observed Toon tree DBH, height, clear bole height and crown area under agrisilviculture system in Solan district of Himachal Pradesh, which ranged from 22.9 to 56.95 cm, 11.97 to 22.4 m, 2.17 to 5.53 m and 19.9 to 58.53 m², respectively. Handa (1994) observed such variation in *Alnus nitida* with respect to six morphological characters viz., height, diameter, age, crown length, clear bole height and taper of tree. 81 CPTs of *Dalbergia sissoo* were selected by Yadav *et al.* (2005) based on the intensive survey in the states of Haryana, Uttar Pradesh and Himachal Pradesh. They reported wide variation in clear bole height, straightness among selected trees. Sidhu and Rishi (1997) selected sixteen of plus trees *D. sissoo* and recorded the observation on tree height, clear bole height, and diameter. From them, twelve plus trees of shisham were significantly better than baseline trees. Khobragade *et al.* (2013) reported the criteria for efficient selection of *Terminalia chebula* and *T. bellerica* in two sites each in Maharashtra and Madhya Pradesh. Crown volume, girth and clear bole height were given considerable importance for the selection of trees of *T. chebula* whereas in case of *T. bellerica* crown diameter, girth, height was given.

These parameters found to be more diverse in genetic improvement and conservation programme of these species. Paray *et al.* (2017) selected hundred CPTs of *Salix alba* based on the comparison tree method from twenty places across the two selected districts of Kashmir valley. The tree characteristics used were height, bole height, DBH, and crown diameter. Furthermore, the mean values recorded for these dimension were as 12.50 m for

height, 28.70 cm for DBH, 5.40 m for bole height, and 3.40m for crown diameter respectively. Otegbeye and Samarawira (1992) observed such variation for 10 growth and quality characteristic of *Eucalyptus tereticornis* grown at two sites within the Northern Guinea Savannah zone of Nigeria.

4.1.6 Leaf area (cm²):

Different leaf characters of *Toona ciliata* were presented in Table 5. Leaf area of Toon was found maximum in P₇ (Una; 371.82 cm²) provenance, which was significantly followed by P₁₂ (338.53 cm²), P₂ (325.11 cm²), P₁₁ (318.44 cm²), P₅ (299.20 cm²), P₃ (264.26 cm²), P₆ (251.95 cm²), P₁ (245.40 cm²), P₄ (240.89 cm²) and P₈ (238.35 cm²), respectively. Contrariwise, lowest leaf area (222.58 cm²) was observed in P₉ (Kathgodam) which was statistically at par with P₁₀ (225.58 cm²).

Table 5: Variation in leaf characters of different provenances

Code No.	Provenances	Leaf area (cm ²)	Leaf bases	Leaf apices	Leaflet margin
P ₁	Nauni	245.40	Oblique	Attenuate	Entire
P ₂	Hamirpur	325.11	Oblique	Acuminate	Wavy
P ₃	Thakurduara	264.26	Oblique	Acuminate	Wavy
P ₄	Ghumarwin	240.89	Acute	Acuminate	Toothed
P ₅	Nurpur	299.20	Rounded	Attenuate	Toothed
P ₆	Nainikhad	251.95	Rounded	Attenuate	Toothed
P ₇	Una	371.82	Rounded	Attenuate	Wavy
P ₈	Rajpur	238.35	Rounded	Attenuate	Wavy
P ₉	Kathgodam	222.58	Oblique	Attenuate	Toothed
P ₁₀	Naini	225.58	Acute	Acuminate	Entire
P ₁₁	Nagina	318.44	Acute	Attenuate	Entire
P ₁₂	Sarsawa	338.53	Acute	Acuminate	Entire
CD _{0.05}		13.86	-	-	-

4.1.7 Leaf bases:

Leaf bases for different provenances were compared on individual tree basis and comparative numbers in each of these leaf bases were categorized into oblique, acute and rounded. Four provenances in each leaf bases category viz., oblique (P₁, P₂, P₃ and P₉), acute (P₄, P₁₀, P₁₁ and P₁₂) and rounded (P₅, P₆, P₇ and P₈), were reported and presented in Table 5.

4.1.8 Leaf apices:

Leaf apices for different provenances were compared on individual tree basis and comparative numbers in each of these leaf apices were categorized as attenuate and acuminate, which were found in seven (P₁, P₅, P₆, P₇, P₈, P₉ and P₁₁) and five (P₂, P₃, P₄, P₁₀ and P₁₂) provenances, respectively (Table 5).

4.1.9 Leaflet margin:

Leaflet margin for different provenances were compared on individual tree basis and comparative numbers falling in each of these leaflet margin were categorized as entire (P₁, P₁₀, P₁₁ and P₁₂), toothed (P₄, P₅, P₆ and P₉) and wavy (P₂, P₃, P₇ and P₈), and each category was found in four provenances, respectively, (Table 5).

4.1.10 Duration of flowering:

Duration of flowering for different provenances was compared on individuals tree basis and duration of flowering was categorized into three periods viz., April to May, March to April and May to June (Table 6).

4.1.11 Number of flowers per inflorescences:

Number of flowering per inflorescences (497.14) of Toon was found maximum in P₁₂ (Sarsawa) provenance, which was statistically at par with P₁ (474.65), P₅ (487.08) and P₁₀ (491.61). On the hand, lowest number of inflorescences (376.22) was observed in P₂ (Hamirpur) which was statistically at par with P₇ (411.32). Similarly, number of flowers per inflorescences was comparable in P₂, P₄, P₆, P₈, P₉ and P₁₁.

Wani (2005) studies reproductive biology and morphological variation in 32 plus tree of *Bauhinia variegata* group under house and field conditions. The studies revealed that plus tree progeny of Pinjor, Kandaghat and Giripul exhibited outstanding performances for morphological characters viz., height, diameter, number of branches, leaf area etc., in comparison to all other superior tree progenies under glasshouse, whereas, Renuka plus tree showed the best performing progeny followed by Subathu, Kunihar and Narag under field conditions for the above characters studied. Singh and Gupta (2017) studied reproductive biology of Toon trees at Solan district of Himachal Pradesh in 2011 and they observed flower bud initiation from third week of March to second week of April and floral bud and

inflorescence development from second week of April to last week of May, with 503.5 mean numbers of flowers per inflorescence.

Table 6: Variation in flower characters of different provenances

Code No.	Provenances	Duration of flowering	Number of flowers per inflorescences
P ₁	Nauni	April - May	474.65
P ₂	Hamirpur	April - May	376.22
P ₃	Thakurduara	April - May	439.02
P ₄	Ghumarwin	April - May	460.12
P ₅	Nurpur	April - May	487.08
P ₆	Nainikhad	April - May	435.60
P ₇	Una	March - April	411.32
P ₈	Rajpur	March - April	460.01
P ₉	Kathgodam	March - April	433.88
P ₁₀	Naini	May - June	491.61
P ₁₁	Nagina	February - March	430.33
P ₁₂	Sarsawa	March - April	497.14
CD _{0.05}		-	24.76

4.2 VARIATION IN SEED TRAITS

The data pertaining to variations in seed traits viz., hundred seed weight, seed germination (%), seed viability (%) after three and six months of storage and seed colour were given in Table 7.

4.2.1 100 seeds weight (gm):

The weight of 100 seeds were found to differ significantly among different provenances and ranged from 0.23 gm to 0.32 gm. The maximum seed weight was recorded from P₈ (Rajpur) provenance with mean value of (0.32 gm), which was at par with P₆ (Nainikhad; 0.31 gm). However, minimum seed weight (0.23 gm) was recorded in P₂ (Hamirpur) which was statistically at par with mean value of P₇ (0.24 gm). Similarly, seed weight was comparable in P₁, P₃, P₄, P₅, P₉, P₁₀, P₁₁, and P₁₂ provenances.

4.2.2 Seed germination (%):

Seed germination (81.67%) of Toon was found maximum in P₁ (Nauni) provenance which was at par with P₂, P₄ and, P₅. On the other hand, lowest seed germination (46.67%) was observed in P₉ (Kathgodam) which was statistically at par with P₆ (64.67%). Similarly, seed germination was comparable in P₃, P₆, P₇, P₈, P₉, P₁₀, P₁₁ and P₁₂.

4.2.3 Seed storage and viability (%):

Seed were stored for a period of 3 and 6 months and seed viability was estimated, which have been presented in Table 7.

Table 7: Variation between provenances in seed traits

Code No.	Provenances	100 Seeds weight (gm)	Seed germination (%)	Seed storage and viability (%)		Seed colour		
				3-month	6-month	Depicted in decreasing proportion		
P ₁	Nauni	0.28	81.67	59.67	33.00	Brown	Light brown	Dark brown
P ₂	Hamirpur	0.23	74.33	54.00	47.67	Light brown	Dark brown	Brown
P ₃	Thakurduara	0.27	71.33	56.67	44.00	Brown	Light brown	Dark brown
P ₄	Ghumarwin	0.26	78.33	68.00	37.00	Dark brown	Brown	Light brown
P ₅	Nurpur	0.25	75.67	62.00	51.00	Dark brown	Brown	Brown
P ₆	Nainikhad	0.31	64.67	38.33	34.00	Light brown	Light brown	Brown
P ₇	Una	0.24	66.33	46.00	36.33	Light brown	Dark brown	Dark brown
P ₈	Rajpur	0.32	67.33	42.33	40.00	brown	Brown	Light brown
P ₉	Kathgodam	0.29	46.67	40.67	36.33	Light brown	Dark brown	Dark brown
P ₁₀	Naini	0.30	68.00	50.00	34.67	Brown	Brown	Light brown
P ₁₁	Nagina	0.29	70.67	42.67	40.00	Brown	Brown	Light brown
P ₁₂	Sarsawa	0.27	69.00	51.00	31.67	Light brown	Light brown	Brown
	Mean	0.28	69.47	51.78	38.81	-	-	-
	CD _{0.05}	0.01	10.14	7.89	3.33	-	-	-

(a) Seed viability after 3-months storage:

Seed viability after 3-months of storage was recorded from different provenances which ranged from 38.33 to 68.00 %. The maximum seed viability was recorded from P₄ (Ghumarwin) with mean value of (68.00 %) which was at par with P₅ (Nurpur). Minimum seed viability was recorded from P₆ (Nainikhad) with mean value of (38.33 %) and was statistically at par P₉ (Kathgodam) showing mean of value of (40.67 %).

(b) Seed viability after 6-months storage:

Seed storage and viability recorded from different provenances which varied from 31.67 to 51.00 %. The maximum viability was recorded from P₅ (Nurpur) with mean value of (51.00 %) which was at par with P₂ (Hamirpur). Minimum viability was recorded from P₁₂ (Sarsawa) with mean value of (31.67 %) and was statistically at par P₁ (Nauni) showing mean value of (33.00 %).

4.2.4 Seed colour:

Seed colour for different provenances were compared on individual tree basis and comparative numbers falling in each of these colour categories (brown, light brown and dark Brown) were recorded, and is presented in Table 7.

It is clear from the results that the nature and extent of observation for traits under consideration was large. The variation observed, might have occurred due to climatic and microclimatic conditions as this species grows over the wide range of climatic conditions. Seed weight depends on the reserve food material (endosperm) formed as a result of double fertilization which is controlled by the traits, and is also affected by the nutrient availability during seed setting and other geoclimatic conditions. Harpar *et al.* (1970) reported that seed size may vary due to external (environmental) and internal conditions. Baker (1972) observed that variation in seed germination percentage may be due to seed coat hardness/sensitivity of different sources as reported in differential germination percentage for hardness of seed and the factors responsible were environmental conditions, place of origin, degree of maturation of seeds etc. seed size and seed weight can vary according to seed to seed source Heavy and large seed contain more food reserve than smaller seeds, which is helpful in germination by providing more energy. Seed size may also affect germination behavior and early seedling growth in the nursery (Howkins, 1998). The effect of seed size on germination behavior is variable and somewhat controversial (Chaisurisri, 1992; Reich *et al.*, 1994).

Dhiman (2018) collected seeds from 36 plus trees of Toon in Punjab and Himachal Pradesh and observed 100 seeds weight and seed germination, mean value of these parameters ranged from 0.704 and 0.843 gm and 27.00 to 67.25 %, respectively. Medeiros *et al.* (2015) reported high first count of germination (FCG) of Toon seeds in the 24hours photoperiod (13.77 %) and in the sand substrate (12.16 %). Arya and Toky (2006) evaluated the progenies of 50 plus trees of *Acacia nilotica* collected from five states at Hisar and found wide variability in seed weight, seed germination, seedling height and collar diameter. Chand (1994) reported rapid loss of Toon seed viability (75 %) when stored for three months in polythene bags at room temperature, while seeds stored for one year in polythene bags at 0.0 ± 1.0 °C temperature retained 93 % viability.

4.3 NURSERY GROWTH PERFORMANCES

In the nursery experiment observation for germination energy index (%), seedling survival percentage, seedling height, collar diameter, leaf length, number of leaves and number of branches were taken after four months, eight months and one year of age to study the variation within provenances (individual tree variation) by maintaining individual tree progenies after four months.



a) Germination of seeds



b) One month old of seedling



c) Four months old of seedling



d) Eight months old of seedling



e) Seedling of one year

Plate 2. Nursery growth performances

4.3.1 Germination energy index (%):

There are some provenances that have non-significant tree variation except present P₂, P₄, P₅, P₆, and P₁₂.

*Maximum germination energy index was obtained from P₈ (86.78%) which was statistically at par with P₁, P₄ and P₉ provenances and minimum germination energy index was obtained from P₆ (63.80%).

In P₁ (Nauni) provenance maximum germination energy index (%) varied from 80.44 to 96.56 per cent T₃ (87.68%) and T₄ (80.67%) whereas minimum germination energy index was recorded from T₂ with mean value of (80.44%) which was statistically at par with T₄ (80.67%) and T₁ (58.61%).

In P₂ (Hamirpur) provenance highest germination energy index % was obtained in T₄ with mean value of (88.25%) which was statistically at par with T₂ (77.85%) and T₅ (80.28%) while lowest germination energy index was recorded from T₃ with mean value of (61.81%) which was statistically at par with T₁ (71.24%) and T₂ (77.85%).

In P₃ (Thakurduara) provenance germination energy index varied from (69.56 to 81.23%).

In P₄ (Ghumarwin) provenance maximum germination energy index was recorded in T₅ with mean value of (88.00%) which was statistically at par with T₁ (80.46%) and T₃ (84.99%) whereas minimum germination energy index was recorded from T₂ with mean value of (67.74%) which was statistically at par with T₄ (68.85%).

In P₅ (Nurpur) provenance highest germination energy index was obtained in T₃ with mean value of (91.41%) which was statistically at par with T₁ (80.67%) and T₅ (84.74%) whereas lowest germination energy was recorded from T₂ with mean value of (65.34%) which was statistically at par with T₄ (71.48%).

In P₆ (Nainikhad) provenance maximum germination energy index was recorded in T₃ with mean value of (79.39%) which was statistically at par with T₁ (71.30%) whereas minimum germination energy index was recorded from T₂ with mean value of (46.74%) which was statistically at par with T₄ (59.24%).

In P₇ (Una) provenance germination energy index varied from 69.84 to 76.51 %

In P₈ (Rajpur) provenance maximum germination energy index was recorded in T₄ with mean value of (91.45%) which was statistically at par with T₁ (89.60%), T₂ (84.62%) and T₃ (85.15%) whereas minimum germination energy index was recorded from T₅ with mean value of (83.05%) which was statistically at par with T₂ (84.62%).

Table 8: Variation in germination energy index (%)

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	85.61	80.44	87.68	80.67	96.56	86.19
P₂	Hamirpur	71.24	77.85	61.81	88.25	80.28	75.88
P₃	Thakurduara	72.20	75.69	81.23	69.56	73.10	74.36
P₄	Ghumarwin	80.46	67.74	84.99	68.85	88.00	78.00
P₅	Nurpur	80.67	65.34	91.41	71.48	84.74	78.73
P₆	Nainikhad	71.30	46.74	79.39	59.24	62.33	63.80
P₇	Una	72.34	64.95	76.51	74.67	69.84	71.66
P₈	Rajpur	89.60	84.62	85.15	91.45	83.05	86.78
P₉	Kathgodam	81.41	78.87	67.51	82.14	76.16	77.22
P₁₀	Naini	78.34	80.82	69.62	75.96	78.08	76.56
P₁₁	Nagina	66.63	79.87	68.44	75.96	73.41	72.86
P₁₂	Sarsawa	76.03	55.60	72.69	64.43	78.48	69.45
CD_{0.05}							
Between provenances				: 7.34			
Within provenances				: 11.42			

In case of P₉ (Kathgodam) provenance maximum germination energy index was obtained in T₄ with mean value of (82.14%) which was statistically at par with T₁ (81.41%), T₂ (78.87%), T₃ (67.51%) and T₅ (76.16%) while minimum germination energy index was recorded from T₃ with mean value of (67.51%) which was statistically at par with T₅ (76.16%).

In P₁₀ (Naini) provenance highest germination energy index ranged from (69.62 to 80.82 %), T₂ (80.82%), which was statistically at par with T₁ (78.34%), T₃ (69.62%) and T₄ (75.96%) whereas minimum germination energy index was obtained from T₃ with mean value of (69.62%) which was statistically at par with T₄ (75.96%).

In P₁₁ (Nagina) provenance germination energy index ranged from 66.63 to 79.87 %. And highest was recorded in T₂ with mean value of (79.87%) which was statistically at par

with T₁ (66.63%), T₃ (68.44%), T₄ (75.96%) and T₅ (73.41%) while minimum germination energy index was recorded from T₁ with mean value of (66.63%) which was statistically at par with T₄ (68.44%).

In P₁₂ (Sarsawa) provenance maximum germination energy index was recorded in T₅ with mean value of (78.48%) which was statistically at par with T₁ (76.03%), T₃ (72.69%) and T₄ (64.43%), while lowest germination energy index was recorded from T₂ with mean value of (55.60%) which was statistically at par with T₄ (64.43%).

Germination value, an index combining speed and completeness of germination, was influenced by seed size and weight (Baldwin, 1942; Dunlap & Barnett, 1983). Differences for germination percent, germination value and germination energy could be nature because environmental deviations are negatively related for experimental condition and seeds of both states were in similar condition.

Lucchese *et al.* (2018) showed rapid seed germination of *T. ciliata* at temperatures of 25 °C with 16 hours of light, in which more than 50% of their seeds had already germinated after 10 days of incubation. Likewise, in a study carried out by Wani and Singh (2016) for *Pongamia pinnata* average germination energy index and germination speed were observed to be 33.99±1.24 and 18.84, respectively.

4.3.2 Variation in seedling survival (%)

*Maximum seedling survival percent was obtained from P₁ (78.77%) and minimum seedling survival percent was obtained from P₆ (59.06%).

In P₁, (Nauni) provenance highest seedling survival per cent was recorded in T₂ (86.94 %), whereas minimum seedling survival per cent was obtained from T₁ (67.29%).

In P₂ (Hamirpur) provenance non-significant seedling survival percent was obtained and varied from 54.52 to 65.13 per cent.

In P₃ (Thakurduara) provenance maximum seedling survival per cent was recorded in T₅ (81.23 %) and minimum seedling survival was recorded from T₃ (52.77%) which was statistically at par with T₁ (64.74%).

In P₄ (Ghumarwin) provenance highest seedling survival per cent was obtained in T₄ (69.93%) which was statistically at par with T₁ (62.28%), T₂ (63.20%) and T₃ (61.23%)

while minimum seedling survival was recorded from T₃ (61.23%) which was statistically at par with T₁ (62.28%).

Table 9: Variation in seedling survival after 3-4 leaves stage among different provenances

Code No.	Tree No. Provenances	T ₁	T ₂	T ₃	T ₄	T ₅	Mean
P ₁	Nauni	67.29	86.94	79.10	83.86	76.68	78.77
P ₂	Hamirpur	54.52	63.85	58.33	56.31	65.13	59.63
P ₃	Thakurduara	64.74	73.98	52.77	64.76	81.23	67.50
P ₄	Ghumarwin	62.28	63.20	61.23	69.93	67.99	64.93
P ₅	Nurpur	69.35	68.45	67.99	69.23	68.20	68.64
P ₆	Nainikhad	64.70	65.42	61.86	39.18	64.13	59.06
P ₇	Una	78.90	72.97	67.45	65.96	61.35	69.33
P ₈	Rajpur	57.82	66.76	70.87	79.35	73.25	69.61
P ₉	Kathgodam	60.87	65.42	66.69	82.56	75.46	70.20
P ₁₀	Naini	72.55	70.72	68.36	71.28	71.25	70.83
P ₁₁	Nagina	71.05	66.33	72.49	69.54	59.38	67.76
P ₁₂	Sarsawa	54.20	63.39	60.57	81.70	69.38	65.85
CD _{0.05}							
Between provenances				: 6.41			
Within provenances				: 14.23			

In P₅ (Nurpur) provenance maximum seedling survival percent varied from 54.52 % in T₁ to 65.13 % in T₅ Tree.

In P₆ (Nainikhad) provenance maximum seedling survival percent was recorded in T₂ (65.42) which was statistically at par with T₁ (64.70%), T₂ (61.86%) and T₅ (64.13%) whereas lowest seedling survival was recorded from T₄ (39.13%) which was statistically at par with T₃ (61.86%).

In P₇ (Una) provenance maximum seedling survival percent was obtained in T₁ (78.90%) whereas minimum seedling survival was recorded from T₅ (61.35%) which was statistically at par with T₄ (65.96%).

In P₈ (Rajpur) provenance maximum seedling survival percent was recorded in T₄ (79.35%) while minimum seedling survival was recorded from T₁ (57.82%).

In P₉ (Kathgodam) provenance highest seedling survival percent was recorded in T₄ (82.56%) whereas minimum seedling survival was recorded from T₁ (60.87%) which was statistically at par with T₂ (65.69%).

In P₁₀ (Naini) provenance non-significant seedling survival percent were observed in T₁ (72.55%) whereas minimum seedling survival was recorded from T₃ (68.36%) varied from 68.36 % (T₁ Tree) to 72.55% (T₁ Tree)

In P₁₁ (Nagina) provenance maximum seedling survival percent was obtained in T₃ (72.49%) whereas lowest seedling survival was recorded from T₅ (59.38%) which was statistically at par with T₄ (69.54%).

In P₁₂ (Sarsawa) provenance highest seedling survival percent was recorded in T₄ (81.70%) which was statistically at par with T₁ (71.05%), while lowest seedling survival was recorded from T₁ (54.20%) which was statistically at par with T₃ (60.57%).

In P₃ best performing trees were T₅, T₂ and T₃ where as in P₆ best trees were T₂, T₁ and T₅. In P₇ best performing trees were T₁, T₂ and T₃, where as in P₈ best trees were T₄, T₅ and T₃. In P₉ best performing trees were T₄, T₅ and T₃, where as in P₁₀ best performing trees were T₁, T₄ and T₅. In P₁₁ best performing trees were T₃, T₁ where as in P₁₂ best performing trees was T₄.

All variations observed might have been occurred due to the genetic structure of plant or impact of parent plant environment (Bewely and Black, 1982; Fenner, 1991). Germination characters are assumed to be inherited traits affected by age, growth, macro and micro habitat of mother tree. The existence of species over a wide geographic range encloses a great variety of edaphoclimatic conditions of its habitat which is supposed to be reflected in the genetic constitution of its diverse populations Gera *et al.* (1999). According to Gutterman (2000) seed germination can be greatly affected by maternal factors (day length, light quality, moisture availability and altitude).

Results of present investigation were in line with the study carried out by Dhiman (2018), they germinated seeds in nursery conditions which were collected from 36 plus trees of Toon in Punjab and Himachal Pradesh and observed seedling survival ranging from 62.50 to 85.58 %. Significant variation in germination percent among seed sources found in present study is in conformity with the findings of Rawat and Bakshi (2011) in *Pinus wallichiana*, Gera *et al.* (1999) in *D. sissoo*, Uppal and Singh (2010) in *T. ciliata*, Luna *et al.* (2006) in *A. lebbeck*, and Kumar *et al.* (2004) in *Acacia catechu*. Shu *et al.* (2012) also reported variation for germination percent in *M. officinalis* which could be due to the genetic characters sources

population. Significant variation in survival percent reported by Singh *et al.* (2006) in *C. ausralis*, Banyal and Sharma (2015) in *Cedrus deodara* and Aslam *et al.* (2014) in *P.wallichiana*.

4.3.3 Variation in seedling height (cm) of four months old half sibs:

Table 10 Variation in seedling height showed that have some provenances that have non-significant differences except P₁, P₂, P₃, P₄, P₅, P₆, P₇, P₈, P₉ and P₁₀ after four months.

*Maximum seedling height was obtained from P₁ (30.40 cm) and minimum seedling height was obtained from P₁₁ (10.27 cm).

In P₁ (Nauni) provenance maximum seedling height was recorded in T₃ (33.91 cm) which was statistically at par with T₄ (33.17 cm) whereas minimum seedling height was recorded from T₂ (27.31 cm) which was statistically at par with T₁ (27.65 cm).

In P₂ (Hamirpur) provenance highest seedling height was obtained in T₃ (33.91cm) which was significantly higher than all trees, while minimum seedling height was recorded from T₅ (18.67 cm) which was statistically at par with T₁ (20.78 cm).

In P₃ (Thakurduara) provenance maximum seedling height was obtained in T₁ (21.50 cm) which was significantly higher while minimum seedling height was recorded from T₅ (17.18cm) which was statistically at par with T₂ (18.17 cm).

In P₄ (Ghumarwin) provenance maximum seedling height was recorded in T₁ (21.50 cm) which was statistically at par with T₂ (20.72 cm) whereas minimum seedling height was recorded from T₅ (19.53 cm) which was statistically at par with T₃ (20.72 cm).

In P₅ (Nurpur) provenance highest seedling height was recorded in T₃ (15.85cm) which was statistically at par with T₂ (14.41 cm) whereas minimum seedling height was recorded from T₅ (11.36 cm) which was statistically at par with T₄ (11.15 cm).

In P₆ (Nainikhad) provenance maximum seedling height was recorded in T₅ (24.32cm) which was significantly higher whereas minimum seedling height was recorded from T₁ (16.44cm) which was statistically at par with T₂ (17.58cm).

In P₇ (Una) provenance maximum seedling height was recorded in T₄ (28.95 cm) which was statistically at par with T₁ (28.12 cm) and T₅ (27.76 cm) whereas minimum

seedling height was recorded from T₃ (24.36 cm) which was statistically at par with T₂ (27.02cm).

Table 10: Variation in seedling height (cm) of four months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	27.65	27.31	33.91	33.17	29.97	30.40
P₂	Hamirpur	20.78	21.91	23.40	25.85	18.67	22.12
P₃	Thakurduara	21.50	18.17	19.76	18.54	17.18	19.03
P₄	Ghumarwin	23.51	22.95	20.72	21.65	19.53	21.67
P₅	Nurpur	15.26	14.41	15.85	11.15	11.36	13.60
P₆	Nainikhad	16.44	17.58	20.08	22.17	24.32	20.12
P₇	Una	28.12	27.02	24.36	28.95	27.76	27.24
P₈	Rajpur	26.64	20.60	19.72	20.76	23.44	22.23
P₉	Kathgodam	20.81	20.36	22.44	18.91	9.86	18.48
P₁₀	Naini	10.92	11.41	18.53	26.27	17.50	16.92
P₁₁	Nagina	10.17	11.36	10.27	9.85	9.70	10.27
P₁₂	Sarsawa	11.58	11.16	13.95	11.97	11.10	11.95
CD_{0.05}							
Between provenances				: 1.28			
Within provenances				: 2.28			

In P₈ (Rajpur) provenance maximum seedling height was recorded in T₁ (26.64 cm) which was all significantly different whereas minimum seedling height was recorded from T₃ (19.72 cm) which was statistically at par with T₂ (20.60 cm).

In P₉ (Kathgodam) provenance maximum seedling height was recorded in T₃ (22.44cm) which was significantly different whereas minimum seedling height was recorded from T₅ (9.86cm).

In P₁₀ (Naini) provenance maximum seedling height was recorded in T₄ (26.27cm) which was significantly different whereas minimum seedling height was recorded from T₁ (10.92cm) which was statistically at par with T₂ (11.41cm).

In P₁₁ (Nagina) provenance seedling height varied from 9.8 cm in T₄ to 11.36 cm in T₂ and no variation in seedling height was observed in P₁₁ provenance.

In P₁₂ (Sarsawa) provenance maximum seedling height was recorded in T₃ (13.95cm) which was all the significantly different whereas minimum seedling height was recorded from T₅ (11.10cm).

In P₁ best trees were T₃, T₄ and T₅, where as in P₂ best trees were T₄, T₃ and T₂. In P₃ best performing trees were T₁, T₃ and T₂ where as in P₄ best trees were T₁, T₂ and T₄. In P₅ best performing trees were T₃, T₁ and T₂, where as in P₆ best trees were T₅, T₄ and T₃. In P₇ best performing trees were T₄, T₁ and T₅, where as in P₈ best trees were T₁, T₅ and T₄. In P₉ best performing trees were T₃, T₁ and T₃, where as in P₁₀ best performing trees were T₄, T₂ and T₅. In P₁₁ best performing trees were T₂, T₁ and T₃, where as in P₁₂ best performing trees were T₃, T₄ and T₁.

4.3.4 Variation in seedling height (cm) of eight months old half sibs:

In P₁ (Nauni) provenance maximum seedling height was recorded in T₄ (55.67 cm) which was statistically at par with T₁ (54.77 cm) whereas minimum seedling height was recorded from T₅ (48.56cm) which was statistically at par with T₂ (52.17 cm).

In P₂ (Hamirpur) provenance maximum seedling height was recorded in T₅ (44.41 cm) which was significantly different from other provenances whereas minimum seedling height was recorded from T₁ (31.05cm) which was statistically at par with T₄ (33.94 cm).

In P₃ (Thakurduara) provenance maximum seedling height was recorded in T₁ (44.35cm) which was significantly higher whereas minimum seedling height was recorded from T₅ (29.20cm) which was statistically at par with T₂ (35.15 cm).

In P₄ (Ghumarwin) provenance maximum seedling height was recorded in T₅ (32.01 cm) which was statistically at par with T₄ (31.76 cm) whereas minimum seedling height was recorded from T₃ (26.43 cm) which was statistically at par with T₂ (28.15 cm).

In P₅ (Nurpur) provenance maximum seedling height was recorded in T₂ (38.57 cm) which was significantly different whereas minimum seedling height was recorded from T₅ (29.95 cm) which was statistically at par with T₄ (30.44 cm).

In P₆ (Nainikhad) provenance maximum seedling height was recorded in T₅ (38.36 cm) which was significantly different whereas minimum seedling height was recorded from T₁ (27.05 cm) which was statistically at par with T₂ (31.71 cm).

In P₇ (Una) provenance maximum seedling height was recorded in T₅ (46.47 cm) which was significantly different whereas minimum seedling height was recorded from T₃ (37.60 cm) which was statistically at par with T₂ (40.12 cm).

Table 11: Variation in seedling height (cm) of eight months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	54.77	52.17	52.40	55.67	48.56	52.71
P₂	Hamirpur	31.05	41.48	42.49	33.94	44.41	38.68
P₃	Thakurduara	44.35	35.15	36.87	41.58	29.20	37.43
P₄	Ghumarwin	29.96	28.15	26.43	31.76	32.01	29.66
P₅	Nurpur	23.12	38.57	33.11	30.44	29.95	31.04
P₆	Nainikhad	27.05	31.71	33.61	34.90	38.36	33.13
P₇	Una	42.03	40.12	37.60	41.03	46.47	41.45
P₈	Rajpur	38.47	32.92	29.23	36.26	37.42	34.86
P₉	Kathgodam	34.86	28.06	30.44	31.57	22.05	29.40
P₁₀	Naini	31.43	30.37	41.73	38.89	40.22	36.53
P₁₁	Nagina	14.49	15.63	14.62	14.32	15.47	14.91
P₁₂	Sarsawa	17.01	16.69	15.01	15.32	16.29	16.06
CD_{0.05}							
Between provenances					: 1.66		
Within provenances					: 3.71		

In P₈ (Rajpur) provenance maximum seedling height was recorded in T₁ (38.47cm) which was significantly different whereas minimum seedling height was recorded from T₃ (29.23cm) which was statistically at par with T₂ (32.92cm).

In P₉ (Kathgodam) provenance maximum seedling height was recorded in T₁ (34.86cm) which was significantly different whereas minimum seedling height was recorded from T₅ (22.05cm) which was statistically at par with T₂ (28.06cm).

In P₁₀ (Naini) provenance maximum seedling height was recorded in T₃ (41.73cm) which was statistically at par with T₅ (40.22cm) whereas minimum seedling height was recorded from T₂ (30.37cm) which was statistically at par with T₁ (31.43cm).

In P₁₁ (Nagina) provenance seedling height recorded in T₂ was 15.63cm which was statistically at par whereas minimum seedling height was recorded from T₄ (14.32) which was statistically at par with T₁ (14.49).

In P₁₂ (Sarsawa) provenance there was no tree to tree variation in T₁ (17.01 cm) which was statistically at par and minimum seedling height was recorded from T₃ (15.01).

In P₁ best trees were T₄, T₁ and T₃, where as in P₂ best trees were T₅, T₃ and T₂. In P₃ best performing trees were T₁, T₄ and T₃ where as in P₄ best trees were T₅, T₄ and T₁. In P₅ best performing trees were T₂, T₃ and T₄, where as in P₆ best trees were T₅, T₄ and T₃. In P₇

best performing trees were T₅, T₁ and T₄, where as in P₈ best trees were T₁, T₂ and T₄. In P₉ best performing trees were T₁, T₃ and T₄, where as in P₁₀ best performing trees were T₄, T₂ and T₅. In P₁₁ best performing trees were T₂, T₅ and T₃, where as in P₁₂ best performing trees were T₁, T₂ and T₅.

Table 11 shows that maximum seedling height was obtained from P₁ (52.71cm) and minimum seedling height was obtained from P₁₁ (14.91cm).

4.3.5 Variation in seedling height (cm) of one year old half sibs:

*Variation in seedling height (cm) after one year is presented in Table 12 and maximum seedling height was obtained from P₁ (129.04 cm) followed by P₃ (126.54 cm).

In P₁ (Nauni) provenance maximum seedling height after one year was recorded in T₅ (144.40cm) which was significantly different whereas minimum seedling height was recorded from T₁ (109.67cm) which was statistically at par with T₂ (111.93cm).

In P₂ (Hamirpur) provenance maximum seedling height was recorded in T₃ (137.30cm) which was significantly different whereas minimum seedling height was recorded from T₅ (100.21cm) which was statistically at par with T₂ (112.09cm).

In P₃ (Thakurduara) provenance maximum seedling height was recorded in T₄ (142.84cm) which was statistically at par with T₃ (140.06cm and T₅ (142.88cm) whereas minimum seedling height was recorded from T₂ (101.94cm) which was statistically at par with T₁ (104.99cm).

In P₄ (Ghumarwin) provenance maximum seedling height was recorded in T₂ (84.66cm) which was significantly higher from other provenances whereas minimum seedling height was recorded from T₄ (68.28cm) which was statistically at par with T₁ (79.56 cm).

In P₅ (Nurpur) provenance maximum seedling height was recorded in T₃ (70.80cm) which was significantly different whereas minimum seedling height was recorded from T₁ (44.21cm) which was statistically at par with T₄ (47.64cm).

In P₆ (Nainikhad) provenance maximum seedling height was recorded in T₅ (81.85cm) which was significantly different whereas minimum seedling height was recorded from T₁ (58.11cm) which was statistically at par with T₃ (59.81cm).

In P₇ (Una) provenance maximum seedling height was recorded in T₁ (93.43cm) which was significantly different whereas minimum seedling height was recorded from T₃ (78.05cm) which was statistically at par with T₂ (78.40cm).

Table 12: Variation in seedling height (cm) of one year old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	109.67	111.93	140.47	138.74	144.40	129.04
P₂	Hamirpur	112.09	126.05	137.30	122.22	100.21	119.58
P₃	Thakurduara	104.99	101.94	140.06	142.84	142.88	126.54
P₄	Ghumarwin	79.56	84.66	72.91	68.28	80.33	77.15
P₅	Nurpur	44.21	61.48	70.80	47.64	49.74	54.77
P₆	Nainikhad	58.11	65.19	59.81	75.42	81.85	68.08
P₇	Una	93.43	78.40	78.05	90.32	80.74	84.19
P₈	Rajpur	87.10	83.11	77.67	75.81	85.16	81.77
P₉	Kathgodam	62.90	66.08	72.38	69.80	49.49	64.13
P₁₀	Naini	54.94	63.17	80.97	77.15	73.75	70.00
P₁₁	Nagina	45.82	54.14	55.66	49.51	55.79	52.18
P₁₂	Sarsawa	17.01	16.69	15.01	15.32	16.29	16.06
CD_{0.05} Between provenances : 3.44 Within provenances : 7.69							

In P₈ (Rajpur) provenance maximum seedling height was recorded in T₁ (87.10cm) which was statistically at par with T₅ (142.88cm) whereas minimum seedling height was recorded from T₄ (75.81cm) which was statistically at par with T₄ (77.67cm).

In P₉ (Kathgodam) provenance maximum seedling height was recorded in T₃ (72.38cm) which was statistically at par with T₄ (69.80cm) whereas minimum seedling height was recorded from T₅ (49.49cm) which was statistically at par with T₁ (62.90cm).

In P₁₀ (Naini) provenance maximum seedling height was recorded in T₃ (80.97cm) which was significantly different whereas minimum seedling height was recorded from T₁ (54.94cm) which was statistically at par with T₂ (63.17cm).

In P₁₁ (Nagina) provenance maximum seedling height was recorded in T₅ (55.79cm) which was statistically at par with T₂ (54.14cm) T₃ (55.66cm) whereas minimum seedling height was recorded from T₁ (45.82cm) which was statistically at par with T₄ (49.51cm).

In P₁₂ (Sarsawa) provenances no significant differences were observed seedling height and minimum seedling height was recorded from T₃ (15.01cm).

In P₁ best trees were T₅, T₃ and T₄, where as in P₂ best trees were T₃, T₂ and T₄. In P₃ best performing trees were T₅, T₄ and T₃ where as in P₄ best trees were T₂, T₅ and T₃. In P₅ best performing trees were T₃, T₂ and T₄, where as in P₆ best trees were T₅, T₄ and T₂. In P₇ best performing trees were T₁, T₄ and T₅, where as in P₈ best trees were T₃, T₄ and T₅. In P₉ best performing trees were T₃, T₄ and T₂, where as in P₁₀ best performing trees were T₃, T₄ and T₅. In P₁₁ best performing trees were T₅, T₃ and T₂, where as in P₁₂ best performing trees were T₁, T₂ and T₅.

4.3.6 Variation in collar diameter (mm) after four months

*Table 13 present collar diameter after four months and maximum collar diameter was obtained from P₁ (3.25 mm) followed by P₅ (3.21 mm) and minimum collar diameter was obtained from P₁₁ (0.91 mm).

In P₁ (Nauni) provenance maximum collar diameter was recorded in T₁ (3.63 mm) which was statistically at par with T₃ (3.38 mm) whereas minimum collar diameter was recorded from T₅ (2.98 mm) which was statistically at par with T₄ (3.05 mm).

In P₂ (Hamirpur) provenance maximum collar diameter was recorded in T₅ (3.09 mm) which was statistically at par with T₃ (3.38 mm) whereas minimum collar diameter was recorded from T₁ (2.25 mm) which was statistically at par with T₂ (2.40 mm).

In P₃ (Thakurduara) provenance maximum collar diameter was recorded in T₁ (2.65 mm) which was significantly different whereas minimum collar diameter was recorded from T₄ (1.58 mm) which was statistically at par with T₄ (1.64 mm).

In P₄ (Ghumarwin) provenance maximum collar diameter was recorded in T₅ (2.78 mm) which was statistically at par with T₂ (2.38 mm) T₄ (2.66 mm) whereas minimum collar diameter was recorded from T₃ (1.59 mm) which was statistically at par with T₁ (2.17 mm).

In P₅ (Nurpur) provenance maximum collar diameter was recorded in T₅ (3.78 mm) which was statistically at par with T₂ (3.63 mm) and T₄ (3.65 mm) whereas minimum collar diameter was recorded from T₃ (2.38 mm) which was statistically at par with T₁ (2.63 mm).

Table 13: Variation in collar diameter (mm) of four months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	3.63	3.19	3.38	3.05	2.98	3.25
P₂	Hamirpur	2.25	2.40	2.93	2.77	3.09	2.69
P₃	Thakurduara	2.65	1.91	1.97	1.58	1.64	1.95
P₄	Ghumarwin	2.17	2.38	1.59	2.66	2.78	2.32
P₅	Nurpur	2.63	3.63	2.38	3.65	3.78	3.21
P₆	Nainikhad	3.63	3.1	3.11	3.06	2.96	3.19
P₇	Una	2.80	2.15	2.10	2.62	2.55	2.45
P₈	Rajpur	2.73	2.34	2.50	2.29	2.94	2.56
P₉	Kathgodam	2.18	2.68	2.47	3.12	1.80	2.45
P₁₀	Naini	1.94	1.87	2.12	2.95	2.43	2.26
P₁₁	Nagina	0.91	0.87	0.82	0.83	1.10	0.91
P₁₂	Sarsawa	1.16	1.17	1.17	1.06	1.27	1.17
CD_{0.05} Between provenances : 0.21 Within provenances : 0.48							

In P₆ (Nainikhad) provenance maximum collar diameter was recorded in T₁ (3.63 mm) which was statistically at par with T₂ (3.18 mm) whereas minimum collar diameter was recorded from T₅ (2.96 mm) which was statistically at par with T₄ (3.06 mm).

In P₇ (Una) provenance maximum collar diameter was recorded in T₁ (2.80 mm) which was statistically at par with T₄ (2.62 mm) whereas minimum collar diameter was recorded from T₃ (2.10 mm) which was statistically at par with T₂ (2.15 mm).

In P₈ (Rajpur) provenance maximum collar diameter was recorded in T₅ (2.94 mm) which was statistically at par with T₂ (2.34 mm) whereas minimum collar diameter was recorded from T₄ (2.29 mm) which was statistically at par with T₂ (2.34 mm).

In P₉ (Kathgodam) provenance maximum collar diameter was recorded in T₄ (3.12 mm) which was significantly different whereas minimum collar diameter was recorded from T₅ (1.80 mm) which was statistically at par with T₁ (2.18 mm).

In P₁₀ (Naini) provenance maximum collar diameter was recorded in T₄ (2.95 mm) which was significantly different whereas minimum collar diameter was recorded from T₂ (1.87 mm) which was statistically at par with T₁ (1.94 mm).

In P₁₁ (Nagina) provenance maximum collar diameter was recorded in T₅ (1.10 mm) which was statistically at par with T₁ (0.91 mm) whereas minimum collar diameter was recorded from T₃ (0.82 mm) which was statistically at par with T₄ (0.83 mm).

In P₁₂ (Sarsawa) provenance no significant differences in collar diameter was recorded and value varied from T₁ (1.27 mm) which was statistically at par with collar diameter recorded from T₄ (1.06 mm).

In P₁ best trees were T₁, T₃ and T₂, where as in P₂ best trees were T₅, T₃ and T₂. In P₃ best performing trees were T₁, T₃ and T₂ where as in P₄ best trees were T₅, T₄ and T₂. In P₅ best performing trees were T₅, T₄ and T₃, where as in P₆ best trees were T₁, T₂ and T₃. In P₇ best performing trees were T₁, T₅ and T₄, where as in P₈ best trees were T₅, T₁ and T₃. In P₉ best performing trees were T₄, T₂ and T₂, where as in P₁₀ best performing trees were T₄, T₅ and T₃. In P₁₁ best performing trees were T₅, T₁ and T₂, where as in P₁₂ best performing trees were T₅, T₂ and T₃.

4.3.7 Variation in collar diameter (mm) of eight months old half sibs:

*Table 14 present collar diameters after 4 months and maximum collar diameter was obtained from P₁ (6.70 mm) which was statistically at par with P₇ and P₂ and minimum collar diameter was obtained from P₁₂ (3.90 mm).

In P₁ (Nauni) provenance maximum collar diameter was recorded in T₁ (7.83 mm) which was statistically at par with T₂ (7.03 mm) whereas minimum collar diameter was recorded from T₅ (5.72 mm) which was statistically at par with T₃ (6.42 mm).

In P₂ (Hamirpur) provenance maximum collar diameter was recorded in T₁ (7.65 mm) which was significantly different whereas minimum collar diameter was recorded from T₄ (5.65 mm) which was statistically at par with T₃ (5.82 mm).

In P₃ (Thakurduara) provenance maximum collar diameter was recorded in T₁ (7.10 mm) which was significantly different whereas minimum collar diameter was recorded from T₄ (5.17 mm) which was statistically at par with T₅ (5.24 mm).

In P₄ (Ghumarwin) provenance maximum collar diameter was recorded in T₅ (6.19 mm) which was statistically at par with T₂ (5.72 mm) whereas minimum collar diameter was recorded from T₁ (5.19 mm) which was statistically at par with T₄ (5.37 mm).

In P₅ (Nurpur) provenance maximum collar diameter was recorded in T₅ (6.45 mm) which was statistically at par with T₂ (6.35 mm) whereas minimum collar diameter was recorded from T₁ (4.62 mm) which was statistically at par with T₃ (5.14 mm).

In P₆ (Nainikhad) provenance maximum collar diameter was recorded in T₄ (5.56 mm) which was statistically at par with T₂ (5.22 mm) and T₃ (5.22 mm) whereas minimum collar diameter was recorded from T₁ (2.04 mm) which was statistically at par with T₅ (2.38 mm).

In P₇ (Una) provenance maximum collar diameter was recorded in T₁ (7.52 mm) which was significantly different whereas minimum collar diameter was recorded from T₄ (5.50 mm) which was statistically at par with T₃ (5.81 mm).

In P₈ (Rajpur) provenance maximum collar diameter was recorded in T₁ (6.50 mm) which was statistically at par with T₄ (6.26 mm) and T₅ (6.11mm) whereas minimum collar diameter was recorded from T₃ (4.49 mm) which was statistically at par with T₂ (5.41mm).

In P₉ (Kathgodam) provenance maximum collar diameter was recorded in T₃ (6.88 mm) which was significantly different whereas minimum collar diameter was recorded from T₅ (4.68 mm) which was statistically at par with T₂ (5.63 mm).

In P₁₀ (Naini) provenance maximum collar diameter was recorded in T₄ (5.79 mm) which was statistically at par with T₃ (5.56 mm) whereas minimum collar diameter was recorded from T₂ (4.02 mm) which was statistically at par with T₁ (4.09 mm).

Table 14: Variation in collar diameter (mm) of eight months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	7.83	7.03	6.42	6.50	5.72	6.70
P₂	Hamirpur	7.65	5.87	5.82	5.65	6.34	6.27
P₃	Thakurduara	7.10	5.34	5.43	5.17	5.24	5.66
P₄	Ghumarwin	5.19	5.72	5.46	5.37	6.19	5.59
P₅	Nurpur	4.62	6.35	5.14	5.66	6.45	5.65
P₆	Nainikhad	2.04	5.22	5.22	5.56	2.38	4.09
P₇	Una	7.52	6.58	5.81	5.50	6.03	6.29
P₈	Rajpur	6.50	5.41	4.49	6.26	6.11	5.75
P₉	Kathgodam	5.68	5.63	6.88	5.99	4.68	5.77
P₁₀	Naini	4.09	4.02	5.56	5.79	4.83	4.86
P₁₁	Nagina	3.85	4.35	4.48	4.63	4.37	4.33
P₁₂	Sarsawa	3.51	3.85	3.93	4.14	4.08	3.90
CD_{0.05} Between provenances : 0.63 Within provenances : 1.40							

In P₁₁ (Nagina) provenance maximum collar diameter was recorded in T₄ (4.63 mm) which was statistically at par with T₃ (4.48 mm), T₅ (4.37 mm) and T₂ (4.35 mm) whereas minimum collar diameter was recorded from T₁ (3.85 mm) which was statistically at par with T₂ (4.35 mm).

In P₁₂ (Sarsawa) provenance no significant differences collar diameter and recorded as T₄ (4.14 mm) in was statistically at par with minimum collar diameter recorded from T₁ (3.51mm).

In P₁ best performing trees were T₁ and T₂, where as in P₂ best trees were T₁, T₅ and T₂. In P₃ best performing trees were T₁, T₃ and T₂ where as in P₄ best trees were T₅, T₂ and T₃. In P₅ best performing trees were T₅, T₂ and T₄, where as in P₆ best trees were T₄, T₂ and T₃. In P₇ best performing trees were T₁, T₂ and T₅, where as in P₈ best trees were T₁, T₄ and T₅. In P₉ best performing trees were T₃, T₄ and T₁, where as in P₁₀ best performing trees were T₄, T₂ and T₅. In P₁₁ best performing trees were T₄, T₃ and T₅, where as in P₁₂ best performing trees were T₄, T₂ and T₃.

4.3.8 Variation in collar diameter (mm) of one year old half sibs:

*Table 15 present collar diameter (mm) after one year and maximum collar diameter was obtained from P₁ (9.03 mm) followed by P₅ (8.63 mm) and minimum collar diameter was obtained from P₆ (4.86 mm) which was statistically at par with P₁₁ (5.32 mm)

In P₁ (Nauni) provenance maximum collar diameter was recorded in T₁ (11.58 mm) which was significantly different whereas minimum collar diameter was recorded from T₅ (7.51 mm) which was statistically at par with T₃ (8.21 mm).

In P₂ (Hamirpur) provenance maximum collar diameter was recorded in T₃ (8.08 mm) which was statistically at par with T₁ (7.86 mm) and T₂ (7.62 mm) whereas minimum collar diameter was recorded from T₄ (4.78 mm) which was statistically at par with T₅ (5.64 mm).

In P₃ (Thakurduara) provenance maximum collar diameter was recorded in T₃ (8.49 mm) which was statistically at par with T₁ (8.01 mm) whereas minimum collar diameter was recorded from T₅ (5.85 mm) which was statistically at par with T₂ (6.38 mm).

In P₄ (Ghumarwin) provenance maximum collar diameter was recorded in T₅ (9.34 mm) which was significantly different whereas minimum collar diameter was recorded from T₃ (6.37 mm) which was statistically at par with T₁ (6.94 mm).

In P₅ (Nurpur) provenance maximum collar diameter was recorded in T₄ (10.69 mm) which was statistically at par with T₅ (10.30 mm) whereas minimum collar diameter was recorded from T₁ (7.01 mm) which was statistically at par with T₂ (7.07 mm).

Table 15: Variation in collar diameter (mm) of one year old half sibs

Code No.	Tree No. Provenances	T ₁	T ₂	T ₃	T ₄	T ₅	Mean
P ₁	Nauni	11.58	9.49	8.21	8.36	7.51	9.03
P ₂	Hamirpur	7.86	7.62	8.08	4.78	5.64	6.79
P ₃	Thakurduara	8.01	6.38	8.49	6.67	5.85	7.08
P ₄	Ghumarwin	6.94	8.09	6.37	7.33	9.34	7.61
P ₅	Nurpur	7.01	7.07	8.08	10.69	10.30	8.63
P ₆	Nainikhad	2.04	6.98	6.72	6.18	2.38	4.86
P ₇	Una	6.62	7.89	6.41	8.20	9.07	7.64
P ₈	Rajpur	7.95	7.98	5.34	6.53	6.81	6.92
P ₉	Kathgodam	6.87	6.23	6.54	8.33	5.31	6.66
P ₁₀	Naini	6.67	5.70	7.76	8.06	5.60	6.76
P ₁₁	Nagina	5.17	5.41	4.92	6.43	4.66	5.32
P ₁₂	Sarsawa	6.56	5.22	5.84	7.50	4.51	5.93
CD _{0.05} Between provenances : 0.88 Within provenances : 1.96							

In P₆ (Nainikhad) provenance maximum collar diameter was recorded in T₂ (6.98 mm) which was statistically at par with T₃ (6.72 mm) and T₄ (6.18 mm) whereas minimum collar diameter was recorded from T₁ (2.04 mm) which was statistically at par with T₅ (2.38 mm).

In P₇ (Una) provenance maximum collar diameter was recorded in T₅ (9.07 mm) which was statistically at par with T₄ (8.20 mm) whereas minimum collar diameter was recorded from T₃ (6.41 mm) which was statistically at par with T₁ (6.62 mm).

In P₈ (Rajpur) provenance maximum collar diameter was recorded in T₂ (7.98 mm) which was statistically at par with T₁ (7.95 mm) whereas minimum collar diameter was recorded from T₃ (5.34 mm).

In P₉ (Kathgodam) provenance maximum collar diameter was recorded in T₄ (8.33 mm) which was significantly different from other provenances whereas minimum collar diameter was recorded from T₅ (5.31 mm).

In P₁₀ (Naini) provenance maximum collar diameter was recorded in T₄ (8.06 mm) which was statistically at par with T₃ (7.76 mm) whereas minimum collar diameter was recorded from T₅ (5.60 mm) which was statistically at par with T₂ (5.70 mm).

In P₁₁ (Nagina) provenance maximum collar diameter was recorded in T₄ (6.43 mm) which was significantly different whereas minimum collar diameter was recorded from T₅ (4.66 mm) which was statistically at par with T₃ (4.92 mm).

In P₁₂ (Sarsawa) provenance maximum collar diameter was recorded in T₄ (7.50 mm) which was significantly different whereas minimum collar diameter was recorded from T₅ (4.51 mm) which was statistically at par with T₂ (5.22 mm).

In P₁ best trees were T₁, T₂ and T₄ where as in P₂ best trees were T₃, T₁ and T₂. In P₃ best performing trees were T₂, T₁ and T₄ where as in P₄ best trees were T₅, T₂ and T₄. In P₅ best performing trees were T₄, T₅ and T₃, where as in P₆ best trees were T₂, T₃ and T₄. In P₇ best performing trees were T₅, T₄ and T₂, where as in P₈ best trees were T₁, T₂ and T₅. In P₉ best performing trees were T₄, T₁ and T₃, where as in P₁₀ best performing trees were T₄, T₃ and T₁. In P₁₁ best performing trees were T₄, T₂ and T₁, where as in P₁₂ best performing trees were T₄, T₁ and T₃.

4.3.9 Variation in number of leaves of four months old half sibs:

*Table 16 presents number of leaves in seedling after 4 months and maximum number of leaves after 4 months was obtained from P₈ (45.32) which was statistically at par with P₇, P₆, P₄ and P₁ respectively and minimum was obtained from P₁₂ (27.44) which was statistically at par with P₁₁.

In P₁ (Nauni) provenance maximum number of leaves was recorded in T₁ (46.80) which was statistically at par with minimum number of leaves recorded from T₃ (37.07).

In P₂ (Hamirpur) provenance maximum number of leaves was recorded in T₃ (45.40) which was statistically at par with P₂, P₄ and P₅ whereas minimum number of leaves was recorded from T₂ (20.75).

In P₃ (Thakurduara) provenance maximum number of leaves was recorded in T₁ (43.72) which was statistically at par with minimum number of leaves that was recorded from T₅ (35.62).

In P₄ (Ghumarwin) provenance maximum number of leaves was recorded in T₂ (52.93) which was the significantly different whereas minimum number of leaves was recorded from T₄ (38.60) which was statistically at par with T₅ (38.80).

Table 16: Variation in number of leaves of four months old half sibs

Code No.	Tree No. Provenances	T ₁	T ₂	T ₃	T ₄	T ₅	Mean
P ₁	Nauni	46.80	38.27	37.07	40.80	42.87	41.16
P ₂	Hamirpur	38.20	20.75	45.40	37.73	35.07	35.43
P ₃	Thakurduara	43.72	38.34	39.27	36.14	35.62	38.62
P ₄	Ghumarwin	42.40	52.93	36.53	38.60	38.80	41.85
P ₅	Nurpur	38.00	43.87	30.20	43.60	33.73	37.88
P ₆	Nainikhad	39.40	49.22	45.34	34.60	38.22	41.36
P ₇	Una	43.29	46.34	43.26	40.14	43.91	43.39
P ₈	Rajpur	50.46	44.41	44.78	41.50	45.47	45.32
P ₉	Kathgodam	37.98	44.09	47.40	46.07	29.20	40.95
P ₁₀	Naini	31.00	31.07	36.60	44.93	38.67	36.45
P ₁₁	Nagina	30.33	32.93	25.40	22.33	26.87	27.57
P ₁₂	Sarsawa	32.75	27.78	22.71	26.47	27.48	27.44
CD _{0.05}							
Between provenances				: 4.63			
Within provenances				: 10.35			

In P₅ (Nurpur) provenance maximum number of leaves was recorded in T₂ (43.87) which was statistically at par with T₄ (43.60) whereas minimum number of leaves was recorded from T₃ (30.20) which was statistically at par with T₅ (33.73).

In P₆ (Nainikhad) provenance maximum number of leaves was recorded in T₂ (49.22) which was statistically at par with minimum number of leaves recorded from T₄ (34.60) which was statistically at par with T₅ (38.22).

In P₇ (Una) provenance no significant differences and maximum number of leaves was recorded in T₂ (46.34) which was statistically at par with minimum number of leaves was recorded from T₄ (40.14) which was statistically at par with T₃ (43.26).

In P₈ (Rajpur) provenance no significant differences in maximum number of leaves recorded in T₁ (50.46) which was statistically at par with minimum number of leaves recorded from T₄ (41.50).

In P₉ (Kathgodam) provenance maximum number of leaves was recorded in T₃ (47.40) which was statistically at par with T₂ (44.09) and T₄ (43.07) whereas minimum number of leaves was recorded from T₅ (29.20) which was statistically at par with T₁ (37.98).

In P₁₀ (Naini) provenance maximum number of leaves was recorded in T₄ (44.93) whereas minimum number of leaves was recorded from T₁ (31.00) which was statistically at par with T₂ (31.07).

In P₁₁ (Nagina) provenance maximum number of leaves was recorded in T₂ (32.93) which was statistically at par with minimum number of leaves from T₄ (22.33).

In P₁₂ (Sarsawa) provenance maximum number of leaves was recorded in T₁ (32.75) which was at par with minimum number of leaves from T₃ (22.71).

In P₁ best tree were T₁, T₅ and T₄ where as in P₂ best trees were T₃, T₁ and T₄. In P₃ best performing trees were T₁, T₃ and T₂ where as in P₄ best trees were T₅, T₂ and T₄. In P₅ best performing trees were T₂, T₄ and T₃, where as in P₆ best trees were T₂, T₃ and T₁. In P₇ best performing trees were T₂, T₅ and T₃, where as in P₈ best trees were T₁, T₅ and T₃. In P₉ best performing trees were T₃, T₄ and T₂, where as in P₁₀ best performing trees were T₄, T₅ and T₂. In P₁₁ best performing trees were T₂, T₁ and T₅, where as in P₁₂ best performing trees were T₁, T₅ and T₄.

4.3.10 Variation in number of leaves of eight months old half sibs

*Table 17 present variation in number of leaves after eight months and maximum number of leaves after eight months was obtained from P₈ (63.95cm) which was statistically at par with P₁ and P₂ and minimum was obtained from P₃ (43.59) which was statistically at par with P₄.

In case of P₁ (Nauni) provenance maximum number of leaves was recorded in T₁ (68.73) which was significantly different whereas minimum number of leaves was recorded from T₃ (41.47) which was statistically at par with T₂ (45.40).

In P₂ (Hamirpur) provenance number of leaves was obtained in T₂ (70.72) which was statistically at par with T₃ (66.20) whereas minimum number of leaves was recorded from T₄ (50.67) which was statistically at par with T₁ (54.33).

In P₃ (Thakurduara) provenance maximum number of leaves was recorded in T₃ (49.55) which was statistically at par with T₂ (48.65) and T₄ (49.27) whereas minimum number of leaves was recorded from T₅ (34.14) which was statistically at par with T₁ (34.35).

In P₄ (Ghumarwin) provenance maximum number of leaves was recorded in T₂ (60.28) which was statistically at par with T₅ (55.40) whereas minimum number of leaves was recorded from T₄ (41.38) which was statistically at par with T₂ (42.80).

In P₅ (Nurpur) provenance maximum number of leaves was recorded in T₄ (55.71) which was statistically at par with T₁ (50.32), T₃ (55.00) and T₅ (53.17) whereas minimum number of leaves were recorded from T₂ (34.66).

Table 17: Variation in number of leaves of eight months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	68.73	45.40	41.47	58.67	52.73	53.40
P₂	Hamirpur	54.33	70.72	66.20	50.67	60.03	60.39
P₃	Thakurduara	36.35	48.65	49.55	49.27	34.14	43.59
P₄	Ghumarwin	48.24	60.28	42.80	41.38	55.40	49.62
P₅	Nurpur	50.32	34.66	55.00	55.71	53.17	49.77
P₆	Nainikhad	41.24	62.66	55.55	53.41	52.46	53.06
P₇	Una	66.74	50.40	62.16	50.28	63.19	58.55
P₈	Rajpur	70.95	62.67	59.24	71.68	55.20	63.95
P₉	Kathgodam	59.44	56.22	54.39	74.04	61.12	61.04
P₁₀	Naini	48.65	55.05	56.31	59.01	57.29	55.26
P₁₁	Nagina	51.98	46.78	64.19	59.01	54.80	55.35
P₁₂	Sarsawa	50.93	57.40	53.13	51.21	48.61	52.26
CD_{0.05}							
Between provenances				: 6.05			
Within provenances				: 13.54			

In P₆ (Nainikhad) provenance maximum number of leaves was recorded in T₂ (62.66) which was statistically at par with P₃, P₄ and P₅ whereas minimum number of leaves was recorded from T₁ (41.24).

In P₇ (Una) provenance maximum number of leaves was recorded in T₁ (66.74) which was statistically at par with T₃ (62.16) and T₅ (63.19) whereas minimum number of leaves was recorded from T₄ (50.28) which was statistically at par with T₂ (50.40).

In P₈ (Rajpur) provenance maximum number of leaves was recorded in T₄ (71.68) which was statistically at par with T₁ (70.95) whereas minimum number of leaves was recorded from T₅ (55.20) which was statistically at par with T₃ (59.24).

In P₉ (Kathgodam) provenance maximum number of leaves was recorded in T₄ (74.04) which was significantly different whereas minimum number of leaves was recorded from T₃ (54.39) which was statistically at par with T₂ (56.22).

In P₁₀ (Naini) provenance no significant differences were observed maximum number of leaves was recorded in T₄ (59.01) which was statistically at par with minimum number of leaves recorded from T₁ (48.65).

In P₁₁ (Nagina) provenance maximum number of leaves was recorded in T₃ (64.19) which was statistically at par with T₄ (59.01) whereas minimum number of leaves was recorded from T₂ (46.78) which was statistically at par with T₁ (51.98).

In P₁₂ (Sarsawa) provenance no significant differences in maximum number of leaves recorded in T₂ (57.40) which was statistically at par with minimum number of leaves recorded from T₅ (48.61).

In P₁ best trees were T₁, T₄ and T₅ where as in P₂ best trees were T₂, T₃ and T₅. In P₃ best performing trees were T₃, T₄ and T₂ where as in P₄ best trees were T₂, T₅ and T₁. In P₅ best performing trees were T₂, T₄ and T₃, where as in P₆ best trees were T₂, T₃ and T₄. In P₇ best performing trees were T₁, T₅ and T₃, where as in P₈ best trees were T₄, T₁ and T₂. In P₉ best performing trees were T₄, T₅ and T₁, where as in P₁₀ best performing trees were T₄, T₅ and T₂. In P₁₁ best performing trees were T₃, T₄ and T₅, where as in P₁₂ best performing trees were T₂, T₃ and T₄.

4.3.11 Variation in number of branches of one year old half sibs

Table 18 shows provenances that have significant variation in number of branches after one year for P₁, P₂, P₉, and P₁₁ provenances.

*Table 18 present number of branches after one year and maximum number of branches was obtained from P₁ (25.97) and minimum was obtained from P₃ (7.79).

In P₁ (Nauni) provenance maximum number of branches was recorded in T₂ (32.27) which was significantly different whereas minimum number of branches was recorded from T₅ (22.60) which was statistically at par with T₃ (23.53).

In P₂ (Hamirpur) provenance maximum number of branches was recorded in T₅ (18.43) which was significantly different whereas minimum number of branches was recorded from T₄ (10.99) which was statistically at par with T₁ (13.99).

In P₃ (Thakurduara) provenance maximum number of branches was recorded in T₅ (9.67) which was statistically at par with minimum number of branches recorded from T₄ (5.97).

In P₄ (Ghumarwin) provenance maximum number of branches was recorded in T₅ (13.13) which was statistically at par with minimum number of branches recorded from T₁ (9.09).

In P₅ (Nurpur) provenance maximum number of branches was recorded in T₄ (12.40) which was statistically at par with minimum number of branches recorded from T₁ (8.73).

In P₆ (Nainikhad) provenance maximum number of branches was recorded in T₂ (12.67) which was statistically at par with minimum number of branches was recorded from T₃ (10.67).

In P₇ (Una) provenance maximum number of branches was recorded in T₃ (15.33) which was statistically at par with number of branches recorded from T₁ (8.68).

In P₈ (Rajpur) provenance maximum number of branches was recorded in T₂ (16.27) which was statistically at par with minimum number of branches recorded from T₃ (11.33).

In P₉ (Kathgodam) provenance maximum number of branches was recorded in T₂ (18.60) which was statistically at par with T₁ (14.40), T₄ (15.07) and T₅ (15.07) whereas minimum number of branches was recorded from T₅ (10.07) which was statistically at par with T₃ (12.73).

Table 18: Variation in number of branches of one year old half sibs

Code No.	Tree No. Provenances	T ₁	T ₂	T ₃	T ₄	T ₅	Mean
P ₁	Nauni	26.33	32.27	23.53	25.13	22.60	25.97
P ₂	Hamirpur	13.99	15.02	14.94	10.99	18.43	14.67
P ₃	Thakurduara	8.54	6.97	7.80	5.97	9.67	7.79
P ₄	Ghumarwin	9.09	9.31	9.59	12.31	13.13	10.69
P ₅	Nurpur	8.73	10.93	9.13	12.40	11.87	10.61
P ₆	Nainikhad	11.47	12.67	10.67	11.47	12.27	11.71
P ₇	Una	8.67	13.33	15.33	12.12	12.41	12.37
P ₈	Rajpur	14.40	16.27	11.33	15.07	15.07	14.43
P ₉	Kathgodam	13.73	18.60	12.73	13.20	10.07	13.67
P ₁₀	Naini	10.87	11.33	12.13	12.93	10.53	11.56
P ₁₁	Nagina	8.27	10.20	11.40	15.47	8.93	10.85
P ₁₂	Sarsawa	16.36	16.40	13.72	12.04	14.98	14.70
CD _{0.05}							
Between provenances				: 2.10			
Within provenances				: 4.70			

In P₁₀ (Naini) provenance maximum number of branches was recorded in T₄ (12.93) which was statistically at par with minimum number of branches was recorded from T₅ (10.53).

In P₁₁ (Nagina) provenance maximum number of branches was recorded in T₄ (15.47) which was statistically at par with T₁ (10.87), T₄ (11.33) and T₃ (12.13) whereas minimum number of branches was recorded from T₁ (8.27) which was statistically at par with T₅ (8.93).

In P₁₂ (Sarsawa) provenance maximum number of branches was recorded in T₂ (16.40) which was statistically at par with minimum number of branches was recorded from T₄ (12.04).

In P₁ best trees were T₂, T₁ and T₄ where as in P₂ best trees were T₅, T₂ and T₃. In P₃ best performing trees were T₅, T₁ and T₃ where as in P₄ best trees were T₅, T₄ and T₃. In P₅ best performing trees were T₄, T₅ and T₂, where as in P₆ best trees were T₂, T₅ and T₁. In P₇ best performing trees were T₃, T₂ and T₅, where as in P₈ best trees were T₂, T₄ and T₅. In P₉ best performing trees were T₂, T₁ and T₄, where as in P₁₀ best performing trees were T₄, T₃ and T₂. In P₁₁ best performing trees were T₄, T₃ and T₂, where as in P₁₂ best performing trees were T₂, T₁ and T₃.

4.3.12 Variation in leaf length (cm) of four months old half sibs

Table 19 shows provenance that are having non-significant variation in leaf length after four months for P₁, P₂, P₃, P₇ and P₁₁.

*Variation in leaf length (cm) after 4 months is presented in Table 19 and maximum leaves length after four months was obtained from P₁ (5.19 cm) which was statistically at par P₅ (5.06 cm) and minimum leaf length was obtained from P₆ (3.19 cm) followed by P₃ (3.55 cm).

In P₁ (Nauni) provenance maximum leaf length was recorded in T₁ (5.44 cm) which was statistically at par with minimum leaf length recorded from T₂ (4.95 cm).

In P₂ (Hamirpur) provenance maximum leaf length was recorded in T₅ (4.13 cm) which was statistically at par with minimum leaf length was recorded from T₂ (3.55 cm).

In P₃ (Thakurduara) provenance maximum leaf length was recorded in T₃ (4.00 cm) which was statistically at par with minimum leaf length recorded from T₁ (3.23 cm).

In P₄ (Ghumarwin) provenance maximum leaf length was recorded in T₁ (4.74 cm) which was statistically at par with T₃ (3.39 cm) whereas minimum leaf length was recorded from T₅ (3.15 cm) which was statistically at par with T₂ (3.66 cm).

In P₅ (Nurpur) provenance maximum leaf length was recorded in T₂ (5.90 cm) which was significantly different whereas minimum leaf length was recorded from T₄ (4.41cm) which was statistically at par with T₅ (4.53 cm).

In P₆ (Nainikhad) provenance maximum leaf length was recorded in T₁ (3.63 cm) which was significantly different whereas minimum leaf length was recorded from T₅ (2.98 cm) which was statistically at par with T₄ (3.05 cm).

In P₇ (Una) provenance maximum number of leaves was recorded in T₅ (5.05 cm) which was significantly different whereas minimum number of leaves was recorded from T₃ (3.51cm) which was statistically at par with T₁ (3.95 cm).

In P₈ (Rajpur) provenance maximum leaf length was recorded in T₂ (5.36 cm) which was significantly different whereas minimum leaf length was recorded from T₅ (3.33cm) which was statistically at par with T₁ (3.51cm) and T₄ (3.61cm).

Table 19: Variation in leaf length (cm) of four months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	5.44	4.95	5.09	5.24	5.23	5.19
P₂	Hamirpur	4.07	3.55	3.71	3.94	4.13	3.88
P₃	Thakurduara	3.23	3.27	4.00	3.60	3.66	3.55
P₄	Ghumarwin	4.74	3.66	4.39	3.89	3.15	3.97
P₅	Nurpur	5.04	5.90	5.44	4.41	4.53	5.06
P₆	Nainikhad	3.63	3.19	3.11	3.05	2.98	3.19
P₇	Una	3.95	4.26	3.51	4.05	5.05	4.16
P₈	Rajpur	3.51	5.36	4.38	3.61	3.33	4.04
P₉	Kathgodam	4.23	5.04	4.13	3.54	4.12	4.21
P₁₀	Naini	5.37	5.02	3.88	4.04	4.53	4.57
P₁₁	Nagina	3.45	3.37	3.59	4.82	4.91	4.03
P₁₂	Sarsawa	3.54	3.75	3.86	3.47	3.19	3.56
CD_{0.05} Between provenances : 0.43 Within provenances : 0.95							

In P₉ (Kathgodam) provenance maximum leaf length was recorded in T₂ (5.04 cm) which was statistically at par with T₁ whereas minimum leaf length was recorded from T₄ (3.54 cm) which was statistically at par with T₅ (4.12cm) and T₃.

In P₁₀ (Naini) provenance maximum leaf length was recorded in T₁ (5.37cm) which was statistically at par with T₂ (5.02 cm) whereas minimum leaf length was recorded from T₃ (3.88 cm) which was statistically at par with T₄ (4.04 cm).

In P₁₁ (Nagina) provenance maximum leaf length was recorded in T₅ (4.91cm) which was statistically at par with minimum leaf length recorded from T₂ (3.37cm).

In P₁₂ (Sarsawa) provenance maximum leaf length was recorded in T₃ (3.86 cm) which was statistically at par minimum leaf length was recorded from T₅ (3.19 cm).

In P₁ best trees were T₁, T₄ and T₅ where as in P₂ best trees were T₅, T₁ and T₄. In P₃ best performing trees were T₅, T₃ and T₄ where as in P₄ best trees were T₁, T₃ and T₄. In P₅ best performing trees were T₂, T₁ and T₃, where as in P₆ best trees were T₁, T₂ and T₃. In P₇ best performing trees were T₅, T₂ and T₄, where as in P₈ best trees were T₂, T₃ and T₄. In P₉ best performing trees were T₂, T₁ and T₃, where as in P₁₀ best performing trees were T₁, T₂ and T₅. In P₁₁ best performing trees were T₅, T₄ and T₃, where as in P₁₂ best performing trees were T₃, T₂ and T₁.

4.3.13 Variation in leaf length (cm) of eight months old half sibs:

*Table 20 present variation in leaf length (cm) after 8 months and maximum leaf length was obtained from P₉ (9.60 cm) followed by P₈ (9.52 cm) and P₆ (9.06cm) and minimum leaf length was obtained from P₆ (4.79 cm).

In P₁ (Nauni) provenance maximum number of leaves was recorded in T₂ (8.19 cm) which was statistically at par with T₄ (7.89 cm) and T₃ (7.91cm) whereas minimum number of leaves was recorded from T₅ (6.89 cm) which was statistically at par with T₁ (7.05 cm).

In P₂ (Hamirpur) provenance maximum number of leaves was recorded in T₃ (9.95 cm) which was statistically at par with T₂ (9.49 cm) whereas minimum number of leaves was recorded from T₄ (7.53 cm) which was statistically at par with T₁ (8.08 cm).

In P₃ (Thakurduara) provenance maximum leaf length was recorded in T₄ (6.54 cm) which was significantly different whereas minimum leaf length was recorded from T₅ (4.23 cm) which was statistically at par with T₃ (5.41cm).

In P₄ (Ghumarwin) provenance maximum leaf length was recorded in T₁ (7.48 cm) which was significantly different whereas minimum leaf length was recorded from T₄ with mean value of (5.35 cm) which was statistically at par with T₅ (5.65 cm).

In P₅ (Nurpur) provenance maximum leaf length was recorded in T₂ (8.27cm) which was statistically at par with T₁ (7.83 cm) whereas minimum leaf length was recorded from T₅ (6.38 cm) which was statistically at par with T₃ (6.43 cm).

In P₆ (Nainikhad) provenance maximum leaf length was recorded in T₁ (5.63 cm) which was statistically at par with T₂ (5.19 cm) and T₄ (5.05 cm) whereas minimum leaf length was recorded from T₅ (4.90 cm) which was statistically at par with T₃ (4.19cm).

In P₇ (Una) provenance maximum leaf length was recorded in T₁ (7.72 cm) which was statistically at par with T₂ (7.29 cm) and T₅ (7.68 cm) whereas minimum leaf length was recorded from T₃ (7.08 cm) which was statistically at par with T₄ (7.10 cm).

Table 20: Variation in leaf length (cm) of eight months old half sibs

Code No.	Tree No. Provenances	T₁	T₂	T₃	T₄	T₅	Mean
P₁	Nauni	7.05	8.19	7.91	7.89	6.43	7.49
P₂	Hamirpur	8.08	9.49	9.95	7.53	9.03	8.82
P₃	Thakurduara	5.70	5.58	5.41	6.54	4.23	5.50
P₄	Ghumarwin	7.48	5.75	6.35	5.35	5.65	6.12
P₅	Nurpur	7.83	8.27	6.43	6.57	6.38	7.09
P₆	Nainikhad	5.63	5.19	4.19	5.05	4.90	4.90
P₇	Una	7.72	7.29	7.08	7.10	7.68	7.37
P₈	Rajpur	9.93	9.51	7.97	9.38	8.49	9.06
P₉	Kathgodam	8.96	8.80	9.37	10.73	10.15	9.60
P₁₀	Naini	9.17	8.46	9.94	10.36	9.66	9.52
P₁₁	Nagina	7.65	6.69	7.74	7.46	8.82	7.67
P₁₂	Sarsawa	7.05	8.25	8.97	8.19	9.29	8.35
CD_{0.05}							
Between provenances				: 0.58			
Within provenances				: 1.29			

In P₈ (Rajpur) provenance no significant variation in leaf length was observed however maximum leaves length was recorded in T₁ (9.93cm) which was statistically at par with minimum leaves length recorded from T₃ (7.97cm).

In P₉ (Kathgodam) provenance maximum leaves length was recorded in T₄ (10.73 cm) which was statistically at par with T₅ (10.15 cm) whereas minimum leaves length was

recorded from T₂ with mean value of (8.80 cm) which was statistically at par with T₁ (8.96 cm).

In P₁₀ (Naini) provenance maximum leaves length was recorded in T₄ (10.36 cm) which was statistically at par with T₃ (9.94 cm) and T₅ (9.66 cm) whereas minimum leaves length was recorded from T₂ (8.46 cm) which was statistically at par with T₁ (9.17cm).

In P₁₁ (Nagina) provenance maximum leaves length was recorded in T₅ (8.82 cm) which was significantly different whereas minimum leaves length was recorded from T₂ (6.69 cm) which was statistically at par with T₄ (7.46 cm).

In P₁₂ (Sarsawa) provenance maximum leaves length was recorded in T₅ (9.29 cm) which was significantly different whereas minimum leaves length was recorded from T₁ (7.05 cm) which was statistically at par with T₂ (8.25 cm).

In P₁ best trees were T₂, T₃ and T₄ where as in P₂ best trees were T₃, T₂ and T₅. In P₃ best performing trees were T₄, T₁ and T₂ where as in P₄ best trees were T₁, T₃ and T₂. In P₅ best performing trees were T₂, T₁ and T₄, where as in P₆ best trees were T₁, T₂ and T₃. In P₇ best performing trees were T₁, T₅ and T₃, where as in P₈ best trees were T₁, T₂ and T₅. In P₉ best performing trees were T₄, T₅ and T₃, where as in P₁₀ best performing trees were T₃, T₅ and T₄. In P₁₁ best performing trees were T₅, T₃ and T₁, where as in P₁₂ best performing trees were T₅, T₃ and T₄.

4.3.14 Variation in leaf length (cm) of one year old half sibs:

There are some provenances that are non-significant except P₁, P₂, P₃, P₄, P₈, P₁₀ and P₁₁.

*Table 21 present leaf length and maximum leaf length after one year was obtained from P₁₀ (12.76cm) followed by P₁₂ (11.92 cm) and minimum leaf length was obtained from P₆ (6.15cm).

In P₁ (Nauni) provenance maximum leaves length was recorded in T₁ (12.77cm) which was significantly different whereas minimum leaves length was recorded from T₄ (10.07cm).

In P₂ (Hamirpur) provenance maximum leaves length was recorded in T₃ (11.78cm) which was significantly different whereas minimum leaves length was recorded from T₁ (9.84 cm).

In P₃ (Thakurduara) provenance maximum leaves length was recorded in T₁ (11.22cm) which was statistically at par with T₂ (10.98 cm) and T₅ (11.11cm) whereas minimum leaves length was recorded from T₃ (8.36 cm) which was statistically at par with T₄ (10.91cm).

In P₄ (Ghumarwin) provenance maximum leaves length was recorded in T₅ (12.74cm) which was significantly different whereas minimum leaves length was recorded from T₁ (10.45cm) which was statistically at par with T₃ (10.97cm).

In P₅ (Nurpur) provenance maximum leaves length was recorded in T₄ (12.00 cm) which was significantly different whereas minimum leaves length was recorded from T₃ (11.05 cm) which was statistically at par with T₅ (11.10 cm).

Table 21: Variation in leaf length (cm) of one year old half sibs

Code No.	Tree No. Provenances	T ₁	T ₂	T ₃	T ₄	T ₅	Mean
P ₁	Nauni	12.77	12.25	10.93	10.07	12.26	11.65
P ₂	Hamirpur	9.84	10.00	11.78	9.91	11.26	10.56
P ₃	Thakurduara	11.22	10.98	8.36	10.91	11.11	10.52
P ₄	Ghumarwin	10.45	11.71	10.97	12.11	12.74	11.60
P ₅	Nurpur	11.64	11.23	11.05	12.00	11.10	11.40
P ₆	Nainikhad	6.83	6.79	6.15	6.05	4.98	6.15
P ₇	Una	11.04	10.83	11.72	11.13	11.83	11.31
P ₈	Rajpur	11.74	11.73	10.46	11.40	9.58	10.98
P ₉	Kathgodam	10.79	10.80	10.64	10.52	10.34	10.62
P ₁₀	Naini	11.58	13.25	14.11	13.14	11.71	12.76
P ₁₁	Nagina	10.37	10.45	10.71	12.62	11.40	11.11
P ₁₂	Sarsawa	11.46	11.18	12.32	12.94	11.72	11.92
CD _{0.05}							
Between provenances				: 0.27			
Within provenances				: 0.61			

In P₆ (Nainikhad) provenance maximum leaves length was recorded in T₁ (6.63cm) which was statistically at par with T₂ (6.79 cm), T₃ (6.15 cm) and T₄ (6.05cm) whereas minimum leaves length was recorded from T₅ (4.98 cm).

In P₇ (Una) provenance maximum leaves length was recorded in T₅ (11.83cm) which was statistically at par with T₃ (11.72cm) and T₄ (11.13cm) whereas minimum leaves length was recorded from T₂ (10.83cm) which was statistically at par with T₁ (11.04cm).

In P₈ (Rajpur) provenance maximum leaves length was recorded in T₁ (11.74cm) which was statistically at par with T₂ (11.73cm) whereas minimum leaves length was recorded from T₅ (9.58cm) which was statistically at par with T₃ (10.46cm).

In P₉ (Kathgodam) provenance maximum leaves length was recorded in T₂ (10.80cm) which was statistically at par with T₁ (10.79cm) and T₃ (10.64cm) whereas minimum leaves length was recorded from T₅ (10.34cm) which was statistically at par with T₄ (10.52cm).

In P₁₀ (Naini) provenance maximum leaves length was recorded in T₃ (14.11cm) which was significantly different whereas minimum leaves length was recorded from T₁ (11.58cm) which was statistically at par with T₅ (11.71cm).

In P₁₁ (Nagina) provenance maximum leaves length was recorded in T₄ (12.62cm) which was significantly different whereas minimum leaves length was recorded from T₁ (10.37) which was statistically at par with T₂ (10.45cm).

In P₁₂ (Sarsawa) provenance maximum leaves length was recorded in T₄ (12.94cm) which was significantly different whereas minimum leaves length was recorded from T₂ (11.18cm) which was statistically at par with T₁ (11.46cm).

In P₁ best trees were T₁, T₅ and T₃ where as in P₂ best trees were T₃, T₅ and T₂. In P₃ best performing trees were T₁, T₅ and T₂ where as in P₄ best trees were T₅, T₄ and T₂. In P₅ best performing trees were T₄, T₂ and T₃, where as in P₆ best trees were T₁, T₂ and T₃. In P₇ best performing trees were T₅, T₃ and T₄, where as in P₈ best trees were T₁, T₂ and T₄. In P₉ best performing trees were T₂, T₁ and T₃, where as in P₁₀ best performing trees were T₃, T₂ and T₄. In P₁₁ best performing trees were T₄, T₃ and T₂, where as in P₁₂ best performing trees were T₄, T₃ and T₅.

In overall performance, the progenies of seed sources selected from Himachal Pradesh, Uttarakhand and Uttar Pradesh state exhibited outstanding growth in terms of seedling height, collar diameter and number of leaves and leaf length per plant selected from three provenances. The trend is same both for provenances and among the genotypes within provenances except for the leaf length trait.

Present investigation was in line with Dhiman (2018), who studied nursery performance of 36 plus trees of Toon in Punjab and Himachal Pradesh and observed seedling



a. Extracted sample using Increment borer



b. Cold water extraction of wood samples



c. Alcohol: benzene extraction using Soxhlet

Pate 3. Extraction method s of wood extractives

height, collar diameter and number of leaves per seedling and ranged from 8.65 to 8.69 cm, 2.40 to 5.60 mm and 43.75 to 66.25, respectively. Present investigation was compatible with Isik (1986), who reported that families of *Pinus brutia* from the higher elevation produced smaller seedlings than the families of middle and lower elevation. Juvenile growth traits are controlled by genetic structure, environment and the seedlings from the seeds of plus trees of all 12 selected seed sources were raised under the similar nursery conditions, so variation observed among seed sources as well as among the genotypes might be attributed to genetic potential of individual progenies and the variations noticed in seed traits. Similar results were also reported by (Kaushik, 1993) for collar diameter, seedling height in *T. ciliata* and Rana *et al.* (2009) for seedling height collar diameter and number of leaves in *T. ciliata*. Uppal and Singh (2010) also reported significant variation for collar diameter, shoot length, root length and number of leaves in *T. ciliata*. Sneizko and Stewart (1986) reported variation among provenances and within provenances for seedling height in *Acacia albida* in Zimbabwe. Similarly, significant variation among progenies for growth traits was reported in *Cedrus doedara* by Banyal and Sharma (2015) and in *M. officinalis* by Shu *et al.* (2012).

4.4 WOOD CHEMICAL STUDIES

a) Moisture content (%) and maximum moisture content (%):

The data on variation in moisture content (%) and maximum moisture content (%) for both sapwood and heartwood in Toon wood samples from different provenances are presented in Table 4.32. The effect of provenances on these parameters was found to be significant. In case of sapwood, moisture content (%) was found to be the maximum in Nauni (58.98 %) which was at par with Nainikhad (56.08 %) whereas minimum was found in Ghumarwin (29.05 %). Maximum moisture content (%) was found to be highest in Nauni (179.89) which was statistically at par with Ghumarwin (175.23 %) and Rajpur (174.22 %). The minimum value was estimated in Kathgodam (138.55 %) which was statistically at par with Nainikhad (148.31 %), Naini (144.23 %) provenances.

In case of heartwood, moisture content (%) was found maximum in Hamirpur (54.95 %) which was statistically at par with Nainikhad (54.28 %), Rajpur (49.56 %) and Kathgodam (48.60 %) and minimum was found in Sarsawa (41.28 %) which was at par with Thakurduara (41.42 %), Nurpur (44.15 %), Una (42.83 %), Naini (47.97 %) and Nagina (42.05 %). Maximum moisture content (%) was found to be highest in Nagina (168.22 %)

which was statistically at par with Hamirpur (161.91 %) and Una (167.40 %) and minimum was found in (127.65 %) which was statically at par with Nurpur (134.40 %), Nainikhad (138.23 %) and Rajpur (138.84 %) provenances.

Table 22: Variation in moisture content (%) and maximum moisture content (%) in sapwood and heartwood of different provenances

Code No.	Provenances	Sapwood		Heartwood	
		Moisture content (%)	Maximum moisture content (%)	Moisture content (%)	Maximum moisture content (%)
P ₁	Nauni	58.98	179.89	49.28	158.02
P ₂	Hamirpur	45.66	149.38	54.95	161.91
P ₃	Thakurduara	40.69	167.27	41.42	127.65
P ₄	Ghumarwin	29.05	175.23	47.23	148.39
P ₅	Nurpur	52.33	168.39	44.15	135.40
P ₆	Nainikhad	56.08	148.31	54.28	138.23
P ₇	Una	34.98	164.22	42.83	167.40
P ₈	Rajpur	50.71	174.22	49.56	138.84
P ₉	Kathgodam	49.90	138.55	48.60	151.60
P ₁₀	Naini	33.97	144.23	47.97	156.29
P ₁₁	Nagina	44.74	154.46	42.05	168.22
P ₁₂	Sarsawa	40.13	146.30	41.28	119.27
Mean		44.77	159.20	48.71	147.60
SE (d)		2.18	5.89	3.56	7.89
CD _{0.05}		4.88	9.78	5.58	11.22

Wood is hygroscopic in nature and extent of its hygroscopicity depends upon the cellular components of wood. The water in wood is held in cellular cavities and cell wall. The water in cell wall is of more concern as it influences various wood properties including shrinkage and swelling. The moisture content and maximum moisture content in living trees vary by species and also due to sapwood and heartwood content, wood porosity and cellular composition. In the present study the significant variation in maximum moisture content of different Toon provenances have been recorded. This variation may be due to the variation in micro-climate, site quality and size of vessels. Wood moisture generally vary within stems, commonly peaking towards the outer edges in the radial direction and declining towards the heartwood, leading to different moisture contents between heartwood and heartwood and sapwood (Rackzkowaki *et al.*, 2000; Spicer and Gartner, 2001) The moisture content variables have shown significant variations among core samples collected from different populations of *Dipterocarpus indicus* (Nageeb *et al.*, 2010).

Yadavrao (2018) recorded 23.85 % mean moisture content and 138.96 % average maximum moisture content in Toon wood samples, which were procured from different local markets across Himachal Pradesh. Likewise, Kumar (2004) estimates moisture content (53.67 %) different DBH classes and different levels of height in Toon wood under agrisilviculture system at Solan district of Himachal Pradesh. The similar results have been reported by Baha (2002) in *Leucaena leucocephala* and Sharma and Sharma (2005) in *Robinia pseudoacacia*. Getahun *et al.* (2014) have found variation in initial moisture content within tree in *Pinus Patula* which showed decreasing trend from bottom to top of tree.

b) Specific gravity of sapwood and heartwood

The data pertaining to variation in specific gravity of sapwood and heartwood of different Toon provenances are presented in Table 23. Statistical analysis carried out on data for specific gravity was found to be significant at 5 per cent level of significance. Specific gravity of sapwood was found to be the maximum in Hamirpur (0.502) and the minimum in Una (0.381).

In case of heartwood, the specific gravity was recorded to be the maximum in Rajpur (0.549) which was statistically at with Thakurduara (0.544) and Kathgodam (0.543) provenances, whereas the minimum value was recorded in Nagina (0.385) which was significantly different from other provenances.

Wood density is the oldest and most widely used criterion for depicting the strength of wood and is said to be influenced by moisture, structure, extractives, and chemical composition (Tsoumis, 1991). It even varies among trees of the same species, as well as within a tree. Wood specific gravity is considered as one of the most informative property about the physic- mechanical behavior of wood used for timber, pulp and paper production (Lima *et al.*, 2000; Raymond and Muneri, 2001). The average values for heartwood specific gravity was (10.15 %) greater than those for sapwood and greater values for heartwood are due to accumulations of polyphenols and other extractives, which are not normally found in sapwood (Hiller *et al.*, 1972).

Yadavrao (2018) recorded higher value of mean specific gravity (0.511) in Toon wood samples, which were procured from different local markets across Himachal Pradesh,

as compared to present study (0.455). Kumar (2004) studied Toon wood specific gravity for different DBH classes and different levels of height under agrisilviculture system in Solan district of Himachal Pradesh and estimated means for specific gravity was 0.537. Morales (1987) have found highly significant differences in specific gravity between the 220 species from Mexican forests. By analyzing above table of sapwood and heartwood density, it has been observed that provenances with low elevations have more specific gravity as compared to higher elevation.

Table 23: Variation in sapwood and heartwood specific gravity of different provenances

Code No.	Provenances	Specific gravity	
		Sapwood	Heartwood
P ₁	Nauni	0.453	0.495
P ₂	Hamirpur	0.442	0.439
P ₃	Thakurduara	0.502	0.544
P ₄	Ghumarwin	0.449	0.477
P ₅	Nurpur	0.483	0.522
P ₆	Nainikhad	0.475	0.466
P ₇	Una	0.418	0.428
P ₈	Rajpur	0.477	0.549
P ₉	Kathgodam	0.455	0.543
P ₁₀	Naini	0.466	0.511
P ₁₁	Nagina	0.381	0.385
P ₁₂	Sarsawa	0.459	0.479
Mean		0.455	0.487
SE (d)		0.006	0.005
CD _{0.05}		0.013	0.011

The most probable reason for this is stressed conditions and variable site factors. Similar findings have been reported by Kennedy and Smith (1959) in *Populus trichocarpa* as the site changed from good to poor, the specific gravity has shown increase from 0.331 to 0.383. Awang and Taylor (1993) have reported that values obtained for specific gravity at drier sites (0.6) were substantially higher than those at wetter sites (0.4) in *Acacia mangium*. Zobel and Buijtenen (1989) have also compared specific gravity in Sitka spruce of North and south provenances and found that faster growing more southerly Sitka spruce provenances produced denser timber compared to slow growing more northerly provenances. Cox *et al.* (2001) have reported that specific gravity is heritable and the differences between wood are due to the genetic make-up. They have found significant variations in the specific gravity of *Shorea acuminata*, *S. ovalis*, *S. leprossula* and *Dryobalanops aromatica*. Similarly Martinez *et*

al. (2009) have recorded that wood density was more significantly correlated with precipitation and aridity than temperature. As high of wood density is achieved through reductions in cell size and increase in the proportion of wall relative to lumen and density is independent of vessel traits. Nageeb *et al.* (2010) have shown significant variations in wood density of core samples collected from *Dipterocarpus indicus* of different populations. Igartua *et al.* (2003) have studied basic density at breast height of 35 years old *Eucalyptus globulus* for parameter prediction of the whole tree and Wahlgren and Fassnachat (1959) have suggested that increment cores extracted at breast height could be safely used to estimate whole tree density. Sidhu and Dhillon (2007) have measured specific gravity (at DBH) and noticed significant differences with respect to locations.

c) Water and chemical soluble extractives (%)

The data on variation in water and chemical soluble extractives of Toon wood sample from different provenances are presented in Table 24. Statistical analysis carried out on all the parameters was found to be significant at 5% level of significance. Among the different provenances, the maximum cold water soluble extractives per cent was found in Una (6.87 %) which was statistically at par with Thakurduara (6.20 %), Nagina (6.64 %) and Sarsawa (6.43 %), whereas, the minimum value was recorded in the Nainikhad (4.05 %) which was statistically at par with Hamirpur (4.90%), Nurpur (5.10%), Rajpur (4.19 %), Kathgodam (4.72%) and Naini (5.08 %) provenances.

Maximum hot water soluble extractives per cent were recorded in Hamirpur (9.75%) which was statistically at par with Nauni (9.50%), Nainikhad (9.57%), Kathgodam (9.53%) and Nagina (9.31%). The minimum value was found in Rajpur (7.34 %) which was at par with Sarsawa (7.53%) and Ghumarwin provenances.

Maximum alcohol-benzene soluble extractive per cent was found in Sarsawa (9.06%) which was statistically at par with Nauni (8.40%) and Thakurduara (8.37%) whereas minimum was found in Nurpur (6.10%) which was statistically at par with Ghumarwin (6.27%), Nainikhad (6.13%), Kathgodam (6.83%) and Nagina (6.33%). Extractive contents consist of lipids (terpenoids, fat, wax and fatty acids) and phenolics, (single phenolics, stilbenes, lignans, flavonoids, tannin). The most amounts of ingredients can be found in core wood, wood rays, root wood, branches formation and at the bark. The above mentioned

ingredients define wood colour, smell and durability as well as quality of pulping and drying and also the gluing properties (Lange and Schwager, 1997).

Yadavrao (2018) recorded a mean of (4.71 %) cold water soluble extractives (7.85 %) hot water soluble extractives and (8.33 %) alcohol-benzene soluble extractives in Toon wood samples, which were procured from different local markets across Himachal Pradesh.

Table 24: Variation in water and chemical soluble extractives (%) of different provenances

Code No.	Provenances	Cold water soluble extractives (%)	Hot water soluble extractives (%)	Alcohol-benzene soluble extractive (%)
P ₁	Nauni	5.63	9.50	8.40
P ₂	Hamirpur	4.90	9.75	7.57
P ₃	Thakurduara	6.20	8.31	8.37
P ₄	Ghumarwin	5.84	7.61	6.27
P ₅	Nurpur	5.10	8.32	6.10
P ₆	Nainikhad	4.05	9.57	6.13
P ₇	Una	6.87	8.57	8.11
P ₈	Rajpur	4.19	7.34	7.63
P ₉	Kathgodam	4.72	9.53	6.83
P ₁₀	Naini	5.08	8.12	7.13
P ₁₁	Nagina	6.64	9.31	6.33
P ₁₂	Sarsawa	6.43	7.53	9.06
Mean		4.45	8.59	7.44
SE (d)		1.95	1.81	1.09
CD_{0.05}		1.19	1.09	0.89

Pari *et al.* (1997) have studied nine Indonesian species and found solubility in cold water, hot water and alcohol -benzene (1:2) which ranged from 4.33 to 7.41 per cent, 4.67 to 9.47 per cent and 1.99 to 9.21 per cent, respectively. The difference in solubility is due to hydrolysis and corresponding increase in solubility of wood substances during the boiling with water. The content, type and position of extractives affect the strength properties of wood (Narayanamurti and Verma, 1964). Water solubility of wood represents the low molecular weight compounds and polysaccharides. Hot water soluble extractives are more than cold water due to the reason that hot-water extraction eliminates greater quantities of materials and extracts some inorganic extractive (Shebani *et al.*, 2008). Sodium hydroxide solubility shows the extent of fungal decay in wood. As fungal decay causes increase in sodium hydroxide solubility. Alcohol-benzene solubility of wood is an important character



a. Holocellulose



b. Lignin

Plate 4. Holocellulose and Lignin

represent extractive present in wood which affect the quality of pulp. The components which are generally soluble in alcohol-benzene are oleoresins, fats and waxes. Alton *et al.* (1990) reported that heartwood contained significantly more extractives than sapwood. The variation is water soluble and chemical soluble extractives of toon wood is in conformity with the studies conducted by Shirsat (2001) in *Acacia nilotica*, Liang (2004) in *Acacia mangium*, Mahdavi *et al.* (2004) in *Eucalyptus camaldulensis*, Kumar *et al.* (2004) in *Dalbergia sissoo*, Shilva *et al.* (2004) in *Eucalyptus camaldulensis*, Kumar *et al.* (2005) in *Dalbergia sissoo*, Shilva *et al.* (2006) in *Eucalyptus grandis*, Morais *et al.* (2005) in *Pinus oocarpa*.

d) Holocellulose and lignin content %

The data represent in Table 25 revealed significant variations in holocellulose and lignin per cent of different Toon provenances.

Table 25: Variation in holocellulose and lignin content % of different provenances

Code No.	Provenances	Holocellulose (%)	Lignin (%)
P ₁	Nauni	65.10	28.50
P ₂	Hamirpur	70.47	16.83
P ₃	Thakurduara	70.13	28.33
P ₄	Ghumarwin	69.70	22.33
P ₅	Nurpur	69.67	20.33
P ₆	Nainikhad	72.00	22.00
P ₇	Una	70.53	24.00
P ₈	Rajpur	71.33	20.17
P ₉	Kathgodam	72.00	22.00
P ₁₀	Naini	74.50	21.83
P ₁₁	Nagina	70.67	19.33
P ₁₂	Sarsawa	68.17	25.67
Mean		70.36	22.61
SE (d)		1.77	0.74
CD _{0.05}		3.67	1.53

Among all provenances, holocellulose per cent was found to be maximum in Naini (74.50 %) which was statistically at par with Nainikhad (72.00%), Rajpur (71.33%) and Kathgodam (72.00 %) whereas, minimum was found in Nauni (65.10 %) which was statistically at par with Sarsawa (68.17 %) provenances.

The lignin per cent was found to be the maximum in Nauni (28.50 %), while the minimum value was recorded in Hamirpur (16.83 %) which was statistically at par with Nagina (19.33 %) provenances.

Cellulose and hemicellulose together described as holocellulose is used to denote the polysaccharides in wood. The holocellulose content is a quantitative indication of fibrous raw material influencing consideration of its suitability for pulp. Whereas, lignin is a phenolic substance consisting of an irregular array of variously bonded hydroxyl- and methoxy-substituted phenyl-propane units, which is distributed throughout the secondary cell wall with highest concentration in middle lamella and is responsible for providing stiffness to the cell wall. It also serves to bond individual cells together in the middle lamella region (Alen, 2000). Photographs of holocellulose and lignin after extraction are shown on Plate 6.

Yadavrao (2018) documented 69.76 % holocellulose and 23.51% lignin content in Toon wood, which were procured from different local markets across Himachal Pradesh. Alton *et al.* (1990) have reported that sapwood contained more holocellulose than heartwood. Among different provenances, significant variations have been noticed where, holocellulose ranged from 67.05-73.82 per cent and lignin content ranged from 21.03-25.95 %. The results are in conformity with studies of Bealeam and Harkin (1975) in *Eucalyptus hybrid*, Pari *et al.* (1997) in nine Indonesia species, Kumar (2000) in *Dalbergia sissoo*, Kumar *et al.* (2005) in *Dalbergia sissoo*, Fakharian *et al.* (2005) in *Alnus glutinosus* and Lopez *et al.* (2008) in *Leucaena leucocephala*. Kumar *et al.* (2005) have estimated lignin content and holocellulose content of *Dalbergia sissoo* ranged from 23.90-30.50 % and 66.00-6.55 %, respectively. Kaushal *et al.* (2012) have estimated lignin content of 21.45 percent in *Toona ciliata* wood.

4.5 GENETIC STUDIES

4.5.1 Morphological traits

Genetic estimates for the morphological characters between different of *Toona ciliata* have been studied and is presented in Table 26.

Variability estimates with regard to genotypic coefficient of variability (%), Phenotypic Coefficient of Variability (%), heritability (%), genetic advance and genetic gain (%) for the phenotypic characters is discussed as below.

Genotypic coefficient of variability (%):

Maximum GCV (%) was estimated for crown area with value (18.71 %), while the minimum value was estimated for tree diameter (2.27%).

Phenotypic coefficient of variability (%):

Table 26 also depicted the similar pattern with the crown area having maximum phenotypic coefficient of variability (31.91%) and minimum value for tree diameter (5.03%).

Table 26: Genetic estimates for different phenotypic characters of *Toona ciliata*

Studied characters	Coefficient of variability		Heritability (h ²)	Genetic advances	Genetic gain (%)
	Genotypic	Phenotypic			
Tree height (m)	10.19	19.24	0.28	2.68	11.12
Tree diameters (cm)	2.27	5.03	0.20	0.68	2.11
Crown spread (m)	9.46	15.66	0.37	1.31	11.78
Clear bole height (m)	7.90	10.36	0.58	0.34	12.40
Crown area (m ²)	18.71	31.91	0.34	8.23	22.59

Heritability:

The maximum value for heritability (Broad sense) was for the clear bole height (0.58) while minimum value was estimated for tree diameter (0.20).

Genetic advances:

Maximum value of the genetic advance was obtained for crown area with (8.23), while the minimum genetic advances were found for clear bole height with of (0.34).

Genetic gain (%):

Genetic gain was estimated to be highest for crown area with value (22.59%) and the least was estimated for tree diameter with value (2.11 %).

4.5.2 Nursery growth performance

Genotypic coefficient of variability (%):

Maximum GCV (%) was estimated for seedling height after one year with value (42.60 %), while the minimum value was estimated for tree leaf length after one year (8.57%).

Phenotypic coefficient of variability (%):

Table 27 also depicted the similar pattern with the crown area having maximum phenotypic coefficient of variability (43.02%) and minimum value for collar diameter of one year (5.03%).

Heritability:

The maximum value for heritability (Broad sense) was for the seedling height after one year (0.98) while minimum value was estimated for seedling survival (0.29).

Table 27: Genetic estimates for seedlings (half sib) from different provenances

Characters studies		Coefficient of variability		Heritability (h ²)	Genetic advance	Genetic gain (%)
		Genotypic	Phenotypic			
Germination energy index (%) after four months		9.89	16.63	0.35	9.20	12.12
Seedling Survival (%)		9.36	17.37	0.29	7.38	10.40
Seedling height (cm)	after four months	32.09	33.34	0.93	12.41	63.61
	after eight months	32.00	32.75	0.95	21.25	64.41
	after one year	42.60	43.02	0.98	68.31	86.88
Collar diameter (mm)	after four months	31.30	33.71	0.86	1.42	59.86
	after eight months	16.82	23.22	0.52	1.36	25.10
	after one year	25.75	0.54	0.54	1.98	28.48
Number of leaves	after four months	16.74	23.72	0.50	9.28	24.36
	after eight months	13.38	20.33	0.43	9.92	18.14
	after one year	33.95	40.43	0.71	7.78	58.73
Leaf length (cm)	after four months	15.50	21.12	0.54	0.97	23.44
	after eight months	21.36	23.88	0.80	2.93	39.34
	after one year	8.57	12.67	0.46	1.27	11.93

Genetic advances:

Maximum value of the genetic advance was obtained for seedling height after one year with (68.31), while the minimum genetic advances were found for leaf length after four months with of (0.97).

Genetic gain (%):

Genetic gain was estimated to be highest for seedling height after four months with value (86.88%) and the least was recorded for seedling survival (%) after four months with value (10.40%).

Higher values for phenotype coefficient of variation as compared to genotypic coefficient of variation in variation in corresponding germination and seedling growth characters indicating that these characters was greatly influenced by the field environment. The heritability and expected genetic gain were also observed to be high to moderate for these characters. According to Robinson *et al.* (1949), heritability of 0-0.3 is low, 0.4-0.6 moderate, and 0.6 and above high.

In present study height, collar diameter, number of branches and root length has very low heritability and genetic gain indicating non-additive type of gene action. Low heritability with moderate genetic advances observed in seedling height, stem length and canopy spread indicates environmental control on the expression of the traits (Goodger *et al.*, 2004).

Dhiman (2018) reported coefficient of phenotypic and genotypic variability, and broad sense heritability ranging from 9.60 to 37.5 %, 9.36 to 36.48 % and 0.88 to 0.95, respectively, for seed traits and nursery growth performance of 36 plus trees of Toon in Punjab and Himachal Pradesh. This result is similar with the findings of Cornelius (1994) who observed that heritability estimates for traits of most forest tree species are low to moderate largely due to environmental effects.

4.6 CORRELATION STUDIES

4.6.1 Morphological and phenotypic traits

The value for simple correlation coefficient between different morphological characteristics and phenotypic characteristics of Toon trees is present in Table 28. Out of 21 combination of simple correlation, 1 combination was found to be positively correlated at 1 per cent level of significance. The remaining 20 values were found to be non-significant.

Tree height showed non-significant positive correlation with tree diameter, clear bole height and number of flowers per inflorescences respectively (0.217, 0.391 and 0.287) while a non-significant negative correlation exists between crown spreads (-0.094), crown area (-0.055) and leaf area (-0.299).

Tree diameter showed non-significant positive correlation with crown spread (0.292), clear bole height (0.511), crown area (0.272) and number of flower per inflorescences (0.301), while a non-significant negative correlation with leaf area (-0.389).

Crown spread showed highly positive significant correlation with crown area (0.992), while non-significant negative correlation with clear bole height (-0.063) and leaf area (0.282).

Clear bole height showed non-significant positive correlation with number of flowers per inflorescences (0.238) while non-significant negative correlation with crown area (-0.031) and leaf area (- 0.401).

Table 28: Simple correlations for different morphological character of *Toona ciliata*

Morphological character	Tree height (m)	Tree diameter (cm)	Crown spreads (m)	Clear bole height (m)	Crown area (m)	Leaf area (cm ²)	Number of flowers per inflorescences
Tree height(m)	1.000	0.217	-0.094	0.391	-0.055	-0.299	0.287
Tree diameters(cm)		1.000	0.292	0.511	0.272	-0.389	0.301
Crown spreads (m)			1.000	-0.063	0.992**	-0.282	0.255
Clear bole height (m)				1.000	-0.031	-0.401	0.238
Crown area (m)					1.000	-0.323	0.190
Leaf area (cm ²)						1.000	-0.336
Number of flowers per inflorescences							1.000

** Significant at the 0.01 level 2-(tailed).

Crown area showed non-significant positive correlation with number of flower per inflorescences (0.190) while non-significant negative correlation with leaf area (-0.323).

Leaf area showed non-significant negative correlation with number of flower per inflorescences (-0.336).

Crown spread showed highly significant correlation with seed length, seed germination and number of branches, whereas it has significant negative correlation with 100 seeds weight which is in confirmation with Kumar *et al.* (2004) in *Acacia catechu*.

Tree diameter also showed highly significant correlation with crown spread at all the levels. Kumar (2004) estimated correlation between different morphological characters of Toon trees under agrisilviculture system in Solan district of Himachal Pradesh and high correlation was reported between DBH and height (0.82), DBH and clean bole height (0.98), height and clean bole height (0.79) and clean bole height and crown area (0.61). These findings are in confirmation with Gera and Gera (2006) in *Acacia catechu*, Luna *et al.* (2006) in *Albizia lebbeck*, Kumar *et al.* (2004) in *Acacia catechu* and Selvan (1999) in *Acacia catechu*.

In the present study, tree height showed highly significant positive correlation with tree diameter and crown spread at all the levels i.e. genotype, phenotypic and environment level. These findings are in confirmation with Gera and Gera (2000) in *Acacia catechu*, Luna *et al.* (2006) in *Albizia lebbeck*, Kumar *et al.* (2004) in *Acacia catechu*, Selvan (1999) in *Acacia catechu* and Handa (1994) in *Alnus nitida*, whereas tree height showed highly significant correlation at genotypic levels with 100 seeds weight, seed length and collar

diameter. These findings are in contradiction with Kumar *et al.* (2004) in *Acacia catechu*, which showed significant but negative correlation between same characters.

4.6.2 Seed characters

Correlation analysis as depicted in revealed that seed weight showed non-significant positive correlation with seed germination (0.037), non-significant positive correlation with seed viability after (3-months and after 6-months) respectively (0.160 and 0.140).

Seed germination (%) showed highly significantly positive correlation with seed viability (%) after 3-months (0.438) and after 6-months (0.333).

Seed viability (%) after 3-months showed highly significantly positive correlation with after 6-months (0.989).

In the present study 100 seeds weight showed significantly negative correlation with seed germination which is in confirmation with Luna *et al.* (2006) in *Acacia catechu* and Gargi *et al.* (2011) in *Terminalia tomentosa*. It showed highly significant correlation at all the levels with collar diameter and significant correlation at environment level. This is in confirmation with Bhat and Chauhan (2002) in *Albizia lebbeck*.

Table 29: Simple correlation of seed characters of different provenances

Seed characters		Seeds weight (gm)	Seeds germination (%)	Seeds storage and viability (%)	
				After 3-months	After 6-months
Seeds weight (gm)		1.000	0.037	0.160	0.140
Seeds germination (%)			1.000	0.438**	0.333**
Seeds storage and viability (%)	6-month			1.000	0.989**
	3-month				1.000

** Correlation is significant at the 0.01 level of significance (2-tailed)

Seed length showed significant negative correlation with seed germination which is in confirmation with Luna *et al.* (2006) in *Albizia lebbeck*, Gera and Gera (2000) in *Acacia nilotica* and Bhat and Chauhan (2002) in *Albizia lebbeck* showed non-significant correlation between the same characters.

4.6.3 Nursery growth performances

Germination energy index (%) showed a non-significant negative correlation with seedling survival (-0.092), non-significant positive correlation with seedling height, collar

diameter, number of branches, respectively (0.185, 0.099, 0.166), while highly negative and significant correlation with leaf length (-0.343) at 1 per cent level of significance.

Seedling survival (%) showed a non-significant positive correlation with seedling height (0.156), collar diameter (0.173) and number of branches (0.098), respectively, while highly positively and significant correlation with leaf length (0.331) at 1 per cent level of significant.

Seedling height (cm) showed highly positively and significant correlation with collar diameter (0.344) and non-significant positively correlation with number of branches (0.202), while highly negative and significant correlation with leaf length (-0.295) at 1 per cent level of significant.

Table 30: Simple correlations for nursery growth performances of different provenances

Parameters	Germination energy index (%)	Seedling survival (%)	Seedling height (cm)	Collar diameter (mm)	Number of branches	Leaf length (cm)
Germination energy index (%)	1.000	-0.092	0.185	0.099	0.166	-0.343**
Seedling survival (%)		1.000	0.156	0.173	0.098	0.331**
Seedling height (cm)			1.000	0.344**	0.202	-0.295*
Collar diameter (mm)				1.000	0.419**	0.099
Number of branches					1.000	0.114
Leaf length (cm)						1.000
*correlation is significant at the 0.05 level (2-tailed)						
** correlation is significant at the 0.01 level (2-tailed)						

Collar diameter (mm) showed highly positively and significant correlation with number of branches (0.419), while non-significant positive correlation with leaf length (0.099).

Number of branches showed non-significant positive correlation with leaf length (0.114).

In case of seedling height it showed highly significant correlation with collar diameter and number of branches. Dhiman (2018) estimated correlation coefficient among seed traits, germination and nursery growth performance for 36 plus trees of Toon in Punjab and Himachal Pradesh and observed significant positive correlation of 100 seeds weight with seed germination (0.54), survival percentage (0.34), seedling height (0.51), collar diameter (0.29) and number of leaves per plant (0.43), and seed germination was also significantly correlated

with survival percent (0.82), seedling height (0.48), collar diameter (0.31) and number of leaves per plant (0.31). This was in confirmation with Bhatt and Chauhan (2002) in *Albizia lebbeck* and such condition may facilitate indirect selection for desired traits of the species. Collar diameter also showed highly significant correlation with number of branches as such types of association between seedling traits have been studied by many workers like Selvan (1999) in *Acacia catechu*, Chauhan and Verma (1993) in *Acacia catechu* and Srivastava (1995) in *Bauhaniya variegata*.

4.6.4 Wood chemical characteristic

In the present investigation the relationship between chemical characteristics and moisture content of wood have been analyzed and discussed. The data on simple correlation coefficient analysis are shown in Table 31.

Table 31: Correlation coefficient between wood chemical characteristics

WCC	H mc	S mc	H M mc	S M mc	H SG	S SG	C W	H W	AB	Holo C	Lignin C
H mc	1.000	0.926**	0.587*	0.636*	0.475	0.207	0.697*	0.772**	0.616*	0.507	0.665*
S mc		1.000	0.436	0.543	0.399	0.329	0.677*	0.810**	0.581*	0.361	0.744**
H M mc			1.000	0.828**	0.572	-0.153	0.720**	0.455	0.836**	0.535	0.556
S M mc				1.000	0.745**	0.042	0.807**	0.700*	0.799**	0.477	0.743**
H SG					1.000	0.531	0.598*	0.610*	0.286	0.381	0.602*
S SG						1.000	0.110	0.489	-0.314	-0.304	0.423
CW							1.000	0.720**	0.727**	0.594*	0.799**
HW								1.000	0.556	0.213	0.943**
AB									1.000	0.423	0.668*
Holo C										1.000	0.167
Lignin C											1.000

*Significant at the 0.05 level (2-tailed)

**Significant at the 0.01 level (2-tailed)

WCC- Wood chemical characteristics

Hme- Heartwood Moisture content

S mc- Sapwood Moisture content

H Mmc-Heartwood Maximum

Moisture content

S Mmc- Sapwood Maximum moisture content

H SG- Heartwood Specific gravity

S SG- Sapwood Specific gravity

CW- Cold water soluble extractives

HW-Hot Water Soluble extractives

AB- Alcohol: Benzene soluble extractives

Holo C – Holocellulose content

Lignin C- Lignin content

The value for simple correlation coefficients between chemical characters and moisture content of Toon tree are presented in Table 31. Out of 55 combination of simple correlation, 15 combinations were found to be significantly positive correlated.

The study revealed that heartwood moisture content was positively correlated with sap wood moisture content (0.926) at 1% level of significance. It was also observed that heartwood moisture content was positively correlated with heartwood maximum moisture

content (0.587), sapwood maximum moisture content (0.636), cold water soluble extractive (0.697), hot water soluble extractive (0.772), Alcohol benzene soluble extractive (0.616) and lignin content (0.665). It was also observed that sapwood moisture content was positively correlated with cold water moisture content (0.677), hot water soluble extractive (0.810), alcohol benzene soluble extractive (0.581) and lignin content (0.744).

Heartwood maximum moisture content showed highly positive correlation with sapwood maximum moisture content (0.828), cold water soluble extractive (0.720) and alcohol benzene soluble extractive (0.836) whereas non-significant negative correlation with sapwood specific gravity (0.153).

Sapwood maximum moisture content was highly positive correlation with sapwood specific gravity (0.745), cold water soluble extractive (0.807), hot water soluble extractive (0.700), alcohol benzene soluble extractive (0.799) and lignin content (0.743).

Heartwood specific gravity was positive specific gravity with cold water soluble extractive (0.598), hot water soluble extractive (0.610) and lignin content (0.602). Rink and Phelps (1988) have recorded significant correlation between heartwood and sapwood specific gravity (0.28). Sapwood specific gravity was non-significant negative correlated with alcohol benzene extractive (0.314) and holocellulose extractive (0.304). Latib *et al.* (2014) have found non-significant correlation with tree portion and water soluble extractive and they have also noticed that holocellulose content have not been related significantly with tree portion.

Cold water soluble extractive was highly positively correlated with hot water soluble extractive (0.720), alcohol benzene extractive (0.727), holocellulose extractive (0.594) and lignin content (0.799).

Hot water soluble extractive was positively correlated with lignin (0.943) and alcohol benzene soluble extractive was positive correlated (0.668). On this aspect, other findings include significant negative correlation was reported by Lekha (1999) for *Acacia catechu*, Kumar *et al.* (2005) for *Dalbergia sissoo*, Silva *et al.* (2006) for *Eucalyptus* and Nimkar (2002) for *Pinus roxburghii*. Other interaction was confined as non- significant and the same has been noticed by Ona *et al.* (1997) in *Eucalyptus camaludulensis*.

Schuman (1973) has found no correlation between specific gravity and total TAPPI extractive content, but Hiller *et al.* (1972) showed positive correlation with wood colour.

Correlation coefficient is an important tool which helps determining associations among different parameters under considerations. Wood is an orthotropic material which has different properties in different planes and these properties are interlinked to each other and giving rise to unique behavior of wood. In hardwoods, wood density is determined by its anatomical structure, cell wall thickness, fiber width, vessel with and density can differ markedly in fiber properties and cell wall dimensions which affected by wood density (Butterfield, 2006). Schumann (1973), Manwiller (1979), Alton *et al.* (1990), Vargees *et al.* (2000), Nisgoski *et al.* (2011) and Kiaei and Samriha (2011).

Chapter-5

SUMMARY AND CONCLUSION

The present investigations entitled “**Studies on provenance variation in *Toona ciliata* M. Roem**” was carried out in the Department of Tree Improvement and Genetic Resources, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP). Twelve provenances were selected from three states of India for the study. The study was carried out to fulfill the following objectives:

1. Morphological characterisation of *Toona ciliata* provenances in three states.
2. Variation in seed traits and seedling attributes.
3. Provenance variations in wood characteristics.

The populations of *Toona ciliata* across the three states were surveyed on the basis of available literature the samples represented ten plus trees were randomly selected from each of the twelve provenances. Observations on phenotypic traits were recorded separately for every tree at each provenance. These observations showed that there exists considerable genetic variation among selected provenances.

- ❖ Among all selected provenances, P₁ (Nauni) showed its superiority for tree height, and clear bole height and P₉ (Kathgodam) for crown spread and crown area.
- ❖ Leaf area was found maximum P₇ (371.82cm²) whereas minimum P₉ (222.58cm²). Leaf base (P₄, P₁₀, P₁₁ and P₁₂) of all provenances were categorized into three category oblique (P₁, P₂, P₃ and P₉), acute (and rounded (P₅, P₆, P₇ and P₈). The leaflet margin of four provenances (P₁, P₁₀, P₁₁ and P₁₂) was categorized as entire, four provenances (P₂, P₃, P₇ and P₈) were observed toothed and wavy for the remaining four provenances (P₄, P₅, P₆ and P₉).
- ❖ Duration of flowering and Number of flowers per inflorescences April to May, March to April and May to June, maximum (497.14) in P₁₂ Sarsawa while lowest number of inflorescences P₇ (376.22).
- ❖ Seeds were collected separately from each individual tree in all provenances for observing different seed traits viz., seed weight 100 seeds weight, seed colour and seed germination. Maximum seed weight was recorded in P₈ (Rajpur) provenance,

whereas minimum 100 seeds weight was recorded in P₂ (Hamirpur) provenances. In case of seed germination maximum value was obtained in P₁ (Nauni) provenance. Seed storage and viability percent after three month and six month. The maximum seed viability was recoded in P₄ (68.00) P₂ (51.00%), while minimum was found in P₆ (40.67%) (31.67%) respectively. Majority of seeds collected from selected trees reported light brown seed.

- ❖ On the basis of progeny performances most of the provenances differ significantly on individual genotype basis for seedling height, collar diameter and number of leaves/per seedling.
- ❖ Variability and genetic estimates for tree height, tree diameter and crown spread and crown area showed low genotypic coefficient of variability, low to moderate genetic gain and high heritability. With respect to seedling traits all characters except number of branches showed low genotypic coefficient of variability, low or moderate genetic gain and low heritability. For phenotypic traits high genotypic and phenotypic coeffiecnt of variabilty was observed for crown spread and tree height with high heritability and moderate gain which make them suitable for selection.
- ❖ The Toon wood samples extracted from different provenances showed highest sapwood and moisture content and maximum moisture content (58.98 %) and (179.89 %) in Nauni and minimum in Ghumarwin (29.05 %) and Kathgodam (23.11%), respectively.
- ❖ The maximum percentage of specific gravity, sapwood and heartwood content of *Toona ciliata* were recorded in Thakurduara (0.502 %) and Rajpur (0.549 %), respectively, whereas the minimum sapwood (0.381 %) and (0.385 %) heartwood specific gravity were recorded in Nagina, respectively.
- ❖ Heartwood maximum moisture content showed highly positive correlation with sapwood maximum moisture content, cold water soluble extractive (0.720) and alcohol-benzene soluble extractive (0.836) whereas non-significant negative correlation with sapwood specific gravity (0.153). Sapwood maximum moisture content was highly positive correlated with sapwood specific gravity (0.745), cold water soluble extractive (0.807), hot water soluble extractive (0.700), alcohol benzene soluble extractive (0.799) and lignin content (0.743).
- ❖ Heartwood specific gravity was positively correlated with specific gravity with cold water soluble extractive (0.598), hot water soluble extractive (0.610) and lignin

content (0.602). Sapwood specific gravity was having non-significant negative correlation with alcohol benzene extractive (0.314) and holocellulose extractive (0.304).

- ❖ Cold water soluble extractive was highly positively correlated with hot water soluble extractive (0.720), alcohol-benzene extractive (0.727), holocellulose extractive (0.594) and lignin content (0.799). Hot water soluble extractive was positively correlated with lignin (0.943) and alcohol benzene soluble extractive was positive correlated (0.668).
- ❖ Highly significant correlation was found between 100 seed weight and collar diameter. Seedling height showed highly significant correlation with collar diameter and number of branches, whereas highly significant correlation exist between collar diameter and number of branched at genotypic and phenotypic levels.

CONCLUSIONS

On the basis of present investigations provenance variation on *Toona ciliata*, the following conclusion has been drawn:

1. P₁ (Nauni) provenance was found to be the best respect to the phenotypic characters followed by P₉ (Kathgodam) and P₁₀ (Naini) provenance. These trees may be used further selection to maintain for any tree improvement programme.
2. P₇ (Una) provenance was found to be the best respect to the leaf area traits followed by P₁₂ (Sarsawa) and P₁₁ (Nagina) provenance.
3. P₁₂ provenance was to be the best with respect to number of flowers per inflorescences which is closely accompanied by P₁₀ (Naini) provenance.
4. P₈ (Rajpur) provenances was to be the best with respect to seed characters which is closely accompanied by P₁₀ (Naini) provenance.
5. With the respect to seed germination percent P₁ (Nauni) provenance proved to be outstanding one among the all provenance.
6. On the basis of progeny performances most of the provenances showed significant variability for height, collar diameter and number of branch. For all these parameters studied at nursery P₁ (Nauni) provenances maintained its superiority over provenances followed by P₂ (Hamirpur), P₃ (Thakurduara) and P₈ (Rajpur).

7. On the basis of wood chemical characteristics, P₁₁ (Nagina), P₂ (Hamirpur), P₁₂ (Sarsawa), P₁₀ (Naini) and P₁ (Nauni) provenance showed highest cold water, hot water and alcohol –benzene soluble extractive, holocellulose and lignin percent respectively.
8. The specific gravity for sapwood and heartwood was recorded highest from P₃ (Thakurduara) and P₈ (Rajpur) provenance with elevation from 733 and 477m respectively.
9. Genotypic and phenotypic coefficient of variability was maximum for crown area, while the minimum value was estimated in tree diameter.
10. Maximum heritability (broad sense) was for the clear bole height, whereas genetic advance and genetic gains were highest for crown area.
11. Wood from the provenances viz: P₃ (Thakurduara), P₈ (Rajpur), P₁₂ (Sarsawa), P₅ (Nurpur), P₁₀ (Naini) and P₁ (Nauni) have shown higher specific gravity and holocellulose content. Therefore toon wood from these provenances can be considered superior for timber purpose.
12. Variability and genetic estimates for morphological and phenotypic traits of trees and seedling traits showed low genotypic coefficient of variability. High heritability was observed in morphological and phenotypic traits of trees and number of branches of seedlings, which can be utilized in selection process.

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APPENDIX -1

Table 1: Anova for variation in tree height (m) in different provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	9	155.6451	17.29389572	1.116893	1.975806	ns
Provenance	11	834.2421	75.84019366	4.897995	1.886684	sig
Error	99	1532.909	15.48392709			
Total	119	2522.796				

Table 2: Anova for variation in tree diameter (cm) in different provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	9	19.73041	2.192267	1.061525	1.975806	ns
Provenance	11	80.8904	7.353673	3.560747	1.886684	sig
Error	99	204.4553	2.065205			
Total	119	305.0761				

Table 3: Anova for variation in crown spread (m) in different provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	9	24.93177	2.770197	1.430321	1.975806	ns
Provenance	11	143.838	13.07619	6.751557	1.886684	sig
Error	99	191.7398	1.936766			
Total	119	360.5096				

Table 4: Anova for variation in clear bole height (m) in different provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	9	24.93177	2.770197	1.430321	1.975806	ns
Provenance	11	143.838	13.07619	6.751557	1.886684	sig
Error	99	191.7398	1.936766			
Total	119	360.5096				

Table 5: Anova for variation in crown area (m²) in different toon provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	9	838.3636	93.15151	1.051265	1.975806	ns
Provenance	11	6078.615	552.6014	6.236404	1.886684	sig
Error	99	8772.289	88.60898			
Total	119	15689.27				

Table 6: Anova for variation in leaf area index (cm²) in different provenances

Sources of variance	df	SS	MSS	F _{cal}	Significance
Treatment	11	19.487	17.044	2.315	0.04147
Error	24	17.584	7.733		
Total	35	36.071			

Table 7: Anova for variation in number of flowers per inflorescences in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	74,147.180	6,740.653	95.701	0.00000
Error	24	1,690.432	70.435		
Total	35	75,837.612			

Table 8: Anova for variation in seed weights (gm) in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	0.060	0.005	281.582	-0.00000
Error	24	0.000	0.000		
Total	35	0.061			

Table 9: Anova for variation in seed first germination (%) (Angular transformation is used) in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	942.855	85.714	35.172	0.00000
Error	24	58.488	2.437		
Total	35	1,001.342			

Table 10: Anova for variation in seed storage and viability after 3 month (Angular transformation is used) in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	416.925	37.902	2.987	0.01209
Error	24	304.528	12.689		
Total	35	721.453			

Table 11: Anova for variation in seed storage and viability after 6.month (Angular transformation is used) in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	215.281	19.571	2.997	0.01188
Error	24	156.730	6.530		
Total	35	372.011			

Table 12: Anova for variation in germination energy index (%) of different provenances

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	469.65	234.82	2.30	3.07	NS
Treatment	59	11587.77	196.40	1.92	1.43	SIG
Provenances	11	1813.97	164.91	1.61	1.87	NS
Treatment x Provenances P ₁	4	686.83	171.71	1.68	2.45	NS
P ₂	4	442.03	110.51	1.08	2.45	NS
P ₃	4	2416.79	604.20	5.91	2.45	SIG
P ₄	4	667.11	166.78	1.63	2.45	NS
P ₅	4	133.81	33.45	0.33	2.45	NS
P ₆	4	310.11	77.53	0.76	2.45	NS
P ₇	4	399.83	99.96	0.98	2.45	NS
P ₈	4	1711.11	427.78	4.18	2.45	SIG
P ₉	4	907.59	226.90	2.22	2.45	NS
P ₁₀	4	206.51	51.63	0.50	2.45	NS
P ₁₁	4	163.75	40.94	0.40	2.45	NS
P ₁₂	4	1728.32	432.08	4.22	2.45	SIG
Error	118	12071.65	102.3021			
Total	179	24129.07	234.82			

Table 13: Anova for variation in seedling survible (%) after four month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	981.14	490.57	4.55	3.07	SIG
Treatment	59	14180.42	240.35	2.23	1.43	SIG
Provenances	11	4035.64	366.88	3.40	1.87	SIG
Treatment x Provenances P ₁	4	686.83	171.71	1.59	2.45	NS
P ₂	4	211.09	52.77	0.49	2.45	NS
P ₃	4	2416.79	604.20	5.60	2.45	SIG
P ₄	4	667.11	166.78	1.55	2.45	NS
P ₅	4	47.41	11.85	0.11	2.45	NS
P ₆	4	1502.70	375.68	3.48	2.45	SIG
P ₇	4	550.45	137.61	1.28	2.45	NS
P ₈	4	1711.11	427.78	3.97	2.45	SIG
P ₉	4	907.59	226.90	2.10	2.45	NS
P ₁₀	4	106.51	26.63	0.25	2.45	NS
P ₁₁	4	15.15	3.79	0.04	2.45	NS
P ₁₂	4	1322.05	330.51	3.06	2.45	SIG
Error	118	12725.96	107.8471			
Total	179	27887.52				

Table 14: Anova for variation in seedling height (cm) after four month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2.00	12.55	6.28	2.03	3.07	NS
Treatment	59.00	7183.39	121.75	39.38	1.43	SIG
Provenances	11.00	5806.98	527.91	170.74	1.87	SIG
Treatment x Provenances P₁	4.00	112.16	28.04	9.07	2.45	SIG
P₂	4.00	87.89	21.97	7.11	2.45	SIG
P₃	4.00	33.14	8.29	2.68	2.45	SIG
P₄	4.00	31.45	7.86	2.54	2.45	SIG
P₅	4.00	58.46	14.61	4.73	2.45	SIG
P₆	4.00	125.50	31.38	10.15	2.45	SIG
P₇	4.00	36.89	9.22	2.98	2.45	SIG
P₈	4.00	96.01	24.00	7.76	2.45	SIG
P₉	4.00	297.35	74.34	24.04	2.45	SIG
P₁₀	4.00	469.94	117.48	38.00	2.45	SIG
P₁₁	4.00	5.10	1.27	0.41	2.45	NS
P₁₂	4.00	22.51	5.63	1.82	2.45	NS
Error	118.00	364.85	3.09			
Total	179.00	7560.79				

Table 15: Anova for variation in seedling height (cm) after eight month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	18.75	9.38	1.82	3.07	NS
Treatment	59	19978.30	338.62	65.80	1.43	SIG
Provenances	11	17519.74	1592.70	309.50	1.87	SIG
Treatment x Provenances P₁	4	91.67	22.92	4.45	2.45	SIG
P₂	4	407.78	101.94	19.81	2.45	SIG
P₃	4	415.06	103.77	20.16	2.45	SIG
P₄	4	43.43	10.86	2.11	2.45	NS
P₅	4	375.70	93.93	18.25	2.45	SIG
P₆	4	209.11	52.28	10.16	2.45	SIG
P₇	4	126.79	31.70	6.16	2.45	SIG
P₈	4	171.14	42.78	8.31	2.45	SIG
P₉	4	274.07	68.52	13.31	2.45	SIG
P₁₀	4	330.49	82.62	16.06	2.45	SIG
P₁₁	4	4.31	1.08	0.21	2.45	NS
P₁₂	4	9.03	2.26	0.44	2.45	NS
Error	118	607.22	5.15			
Total	179	20604.28				

NS-Non-significant

SIG- Significant

Table 16: Anova for variation in seedling height (cm) after twelve month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	16.28	8.14	0.36	3.07	NS
Treatment	59	199867.93	3387.59	149.91	1.43	SIG
Provenances	11	182031.90	16548.35	732.31	1.87	SIG
Treatment x Provenances P₁	4	3386.33	846.58	37.46	2.45	SIG
P₂	4	2382.72	595.68	26.36	2.45	SIG
P₃	4	5355.32	1338.83	59.25	2.45	SIG
P₄	4	507.26	126.82	5.61	2.45	SIG
P₅	4	1468.81	367.20	16.25	2.45	SIG
P₆	4	1259.33	314.83	13.93	2.45	SIG
P₇	4	618.89	154.72	6.85	2.45	SIG
P₈	4	282.43	70.61	3.12	2.45	SIG
P₉	4	959.68	239.92	10.62	2.45	SIG
P₁₀	4	1376.60	344.15	15.23	2.45	SIG
P₁₁	4	229.63	57.41	2.54	2.45	SIG
P₁₂	4	9.03	2.26	0.10	2.45	NS
Error	118	2666.51	22.60			
Total	179	202550.72				

NS Non-significant

SIG- Significant

Table 17: Anova for variation in collar diameter (mm) after four month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	0.21	0.11	1.21	3.07	NS
Treatment	59	102.29	1.73	19.72	1.43	SIG
Provenances	11	159.54	14.50	164.99	1.87	SIG
Treatment x Provenances P₁	4	0.84	0.21	2.38	2.45	NS
P₂	4	1.51	0.38	4.30	2.45	SIG
P₃	4	2.21	0.55	6.28	2.45	SIG
P₄	4	2.68	0.67	7.63	2.45	SIG
P₅	4	5.12	1.28	14.57	2.45	SIG
P₆	4	0.79	0.20	2.26	2.45	NS
P₇	4	1.12	0.28	3.17	2.45	SIG
P₈	4	0.89	0.22	2.54	2.45	SIG
P₉	4	3.00	0.75	8.55	2.45	SIG
P₁₀	4	2.36	0.59	6.70	2.45	SIG
P₁₁	4	0.16	0.04	0.45	2.45	NS
P₁₂	4	0.06	0.02	0.18	2.45	NS
Error	118	10.37	0.09			
Total	179	112.87				

Table 18: Anova for variation in collar diameter (mm) after eight month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	1.093	0.546	0.73	3.07	NS
Treatment	59	190.451	3.228	4.31	1.43	SIG
Provenances	11	-64.810	-5.892	-7.87	1.87	NS
Treatment x Provenances P ₁	4	7.431	1.858	2.48	2.45	SIG
P ₂	4	7.979	1.995	2.66	2.45	SIG
P ₃	4	7.891	1.973	2.63	2.45	SIG
P ₄	4	1.797	0.449	0.60	2.45	NS
P ₅	4	7.339	1.835	2.45	2.45	SIG
P ₆	4	35.626	8.907	11.89	2.45	SIG
P ₇	4	7.531	1.883	2.51	2.45	SIG
P ₈	4	7.927	1.982	2.65	2.45	SIG
P ₉	4	7.487	1.872	2.50	2.45	SIG
P ₁₀	4	7.970	1.993	2.66	2.45	SIG
P ₁₁	4	1.041	0.260	0.35	2.45	NS
P ₁₂	4	0.730	0.182	0.24	2.45	NS
Error	118	88.368	0.749			
Total	179	279.912				

Table 19: Anova for variation in collar diameter (mm) after twelve month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	6.326	3.163	2.14	3.07	NS
Treatment	59	390.209	6.614	4.48	1.43	SIG
Provenances	11	-145.032	-13.185	-8.93	1.87	NS
Treatment x Provenances P ₁	4	30.374	7.594	5.14	2.45	SIG
P ₂	4	26.546	6.637	4.49	2.45	SIG
P ₃	4	15.150	3.787	2.56	2.45	SIG
P ₄	4	15.856	3.964	2.68	2.45	SIG
P ₅	4	37.156	9.289	6.29	2.45	SIG
P ₆	4	71.453	17.863	12.10	2.45	SIG
P ₇	4	14.930	3.732	2.53	2.45	SIG
P ₈	4	14.513	3.628	2.46	2.45	SIG
P ₉	4	14.540	3.635	2.46	2.45	SIG
P ₁₀	4	15.471	3.868	2.62	2.45	SIG
P ₁₁	4	5.594	1.399	0.95	2.45	NS
P ₁₂	4	16.155	4.039	2.73	2.45	SIG
Error	118	174.268	1.477			
Total	179	570.802				

Table 20: Anova for variation in number of leaves after four month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	31.78	15.89	0.39	3.07	NS
Treatment	59	9628.88	163.20	3.98	1.43	SIG
Provenances	11	5353.83	486.71	11.88	1.87	SIG
Treatment x Provenances P₁	4	179.94	44.98	1.10	2.45	NS
P₂	4	984.03	246.01	6.00	2.45	SIG
P₃	4	124.81	31.20	0.76	2.45	NS
P₄	4	513.82	128.46	3.13	2.45	SIG
P₅	4	434.25	108.56	2.65	2.45	SIG
P₆	4	410.80	102.70	2.51	2.45	SIG
P₇	4	58.66	14.66	0.36	2.45	NS
P₈	4	126.52	31.63	0.77	2.45	NS
P₉	4	673.51	168.38	4.11	2.45	SIG
P₁₀	4	406.76	101.69	2.48	2.45	SIG
P₁₁	4	207.08	51.77	1.26	2.45	NS
P₁₂	4	154.88	38.72	0.94	2.45	NS
Error	118	4835.29	40.98			
Total	179	14495.94				

NS Non-significant

SIG- Significant

Table 21: Anova for variation in number of leaves after eight month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	4.605601	2.302801	0.03	3.07	NS
Treatment	59	13609.53	230.67	3.29	1.43	SIG
Provenances	11	5362.366	487.4878	6.96	1.87	SIG
Treatment x Provenances P₁	4	1409.093	352.2733	5.03	2.45	SIG
P₂	4	815.067	203.7668	2.91	2.45	SIG
P₃	4	705.7012	176.4253	2.52	2.45	SIG
P₄	4	790.1305	197.5326	2.82	2.45	SIG
P₅	4	908.1055	227.0264	3.24	2.45	SIG
P₆	4	715.8892	178.9723	2.55	2.45	SIG
P₇	4	709.3825	177.3456	2.53	2.45	SIG
P₈	4	627.8282	156.957	2.24	2.45	NS
P₉	4	716.9324	179.2331	2.56	2.45	SIG
P₁₀	4	188.9789	47.24472	0.67	2.45	NS
P₁₁	4	529.9529	132.4882	1.89	2.45	NS
P₁₂	4	130.102	32.52549	0.46	2.45	NS
Error	118	8269.581	70.0812	0.03	3.07	NS
Total	179	21883.72		3.29	1.43	SIG

Table 22: Anova for variation in number of branch after twelve month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	59.110	29.555	3.49	3.07	SIG
Treatment	59	4081.456	69.177	8.18	1.43	SIG
Provenances	11	3340.185	303.653	35.89	1.87	SIG
Treatment x Provenances P₁	4	173.323	43.331	5.12	2.45	SIG
P₂	4	85.006	21.252	2.51	2.45	SIG
P₃	4	24.156	6.039	0.71	2.45	NS
P₄	4	42.860	10.715	1.27	2.45	NS
P₅	4	31.771	7.943	0.94	2.45	NS
P₆	4	7.296	1.824	0.22	2.45	NS
P₇	4	70.464	17.616	2.08	2.45	NS
P₈	4	41.323	10.331	1.22	2.45	NS
P₉	4	115.173	28.793	3.40	2.45	SIG
P₁₀	4	11.403	2.851	0.34	2.45	NS
P₁₁	4	97.157	24.289	2.87	2.45	SIG
P₁₂	4	41.338	10.335	1.22	2.45	NS
Error	118	998.4631	8.461551			
Total	179	5139.03				

Table 23: Anova for variation in leaf length (cm) after four month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	0.51	0.25	0.73	3.07	NS
Treatment	59	92.68	1.57	4.50	1.43	SIG
Provenances	11	-170.34	-15.49	-44.41	1.87	NS
Treatment x Provenances P₁	4	0.41	0.10	0.29	2.45	NS
P₂	4	0.72	0.18	0.52	2.45	NS
P₃	4	1.19	0.30	0.85	2.45	NS
P₄	4	4.64	1.16	3.33	2.45	SIG
P₅	4	4.66	1.17	3.34	2.45	SIG
P₆	4	0.79	0.20	0.57	2.45	NS
P₇	4	3.88	0.97	2.78	2.45	SIG
P₈	4	8.47	2.12	6.07	2.45	SIG
P₉	4	3.49	0.87	2.50	2.45	SIG
P₁₀	4	4.77	1.19	3.42	2.45	SIG
P₁₁	4	7.08	1.77	5.08	2.45	SIG
P₁₂	4	0.82	0.20	0.59	2.45	NS
Error	118	41.15	0.35			
Total	179	134.33				

Table 24: Anova for variation in leaf length (cm) after eight month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	1.16	0.58	0.91	3.07	NS
Treatment	59	489.71	8.30	12.97	1.43	SIG
Provenances	11	1250.96	113.72	177.74	1.87	NS
Treatment x Provenances P ₁	4	6.45	1.61	2.52	2.45	SIG
P ₂	4	11.91	2.98	4.65	2.45	SIG
P ₃	4	8.25	2.06	3.22	2.45	SIG
P ₄	4	8.53	2.13	3.33	2.45	SIG
P ₅	4	9.41	2.35	3.68	2.45	SIG
P ₆	4	0.79	0.20	0.31	2.45	NS
P ₇	4	1.14	0.29	0.45	2.45	NS
P ₈	4	7.75	1.94	3.03	2.45	SIG
P ₉	4	8.04	2.01	3.14	2.45	SIG
P ₁₀	4	6.47	1.62	2.53	2.45	SIG
P ₁₁	4	6.98	1.74	2.73	2.45	SIG
P ₁₂	4	8.96	2.24	3.50	2.45	SIG
Error	118	75.50	0.64			
Total	179	566.37				

Table 25: Anova for variation in leaf length (cm) after twelve month

Source of variation	df	SS	MSS	F _{cal}	F _{tab}	Conclusion
Replication	2	2.53	1.26	1.28	3.07	NS
Treatment	59	205.12	3.48	3.53	1.43	SIG
Provenances	11	2221.11	201.92	204.74	1.87	NS
Treatment x Provenances P ₁	4	14.95	3.74	3.79	2.45	SIG
P ₂	4	9.70	2.42	2.46	2.45	SIG
P ₃	4	17.60	4.40	4.46	2.45	SIG
P ₄	4	9.86	2.46	2.50	2.45	SIG
P ₅	4	2.00	0.50	0.51	2.45	NS
P ₆	4	0.79	0.20	0.20	2.45	NS
P ₇	4	2.32	0.58	0.59	2.45	NS
P ₈	4	10.63	2.66	2.70	2.45	SIG
P ₉	4	0.45	0.11	0.11	2.45	NS
P ₁₀	4	14.09	3.52	3.57	2.45	SIG
P ₁₁	4	10.50	2.63	2.66	2.45	SIG
P ₁₂	4	6.00	1.50	1.52	2.45	NS
Error	118	116.37	0.99			
Total	179	324.02				

Table 26: Anova for variation in cold water soluble extractive in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	41.824	3.802	0.664	0.75722
Error	24	137.417	5.726		
Total	35	179.242			

Table 27: Anova for variation in hot water soluble extractive in different provenances.

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	35.915	3.265	0.666	0.75565
Error	24	117.676	4.903		
Total	35	153.592			

Table 28: Anova for variation in alcohol-benzene soluble extractive in different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	45.592	4.145	2.330	0.04034
Error	24	42.693	1.779		
Total	35	88.286			

Table 29: Anova for variation in moisture content (%) of sapwood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	7,541.083	685.553	3.203	0.00826
Error	24	5,136.338	214.014		
Total	35	12,677.421			

Table 30: Anova for variation in moisture content (%) of heartwood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	4,842.115	440.192	0.850	0.59571
Error	24	12,421.873	517.578		
Total	35	17,263.989			

Table 31: Anova for variation in maximum moisture content (%) of sap wood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	180,357.415	16,396.129	50.683	0.00000
Error	24	7,764.047	323.502		
Total	35	188,121.463			

Table 32: Anova for variation in maximum moisture content (%) of heartwood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	35,351.872	3,213.807	1.445	0.21703
Error	24	53,393.165	2,224.715		
Total	35	88,745.038			

Table 33: Anova for variation in specific gravity of sapwood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	0.195	0.018	1.808	0.10897
Error	24	0.235	0.010		
Total	35	0.429			

Table 34: Anova for variation in specific gravity of heartwood of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	0.195	0.018	1.808	0.10897
Error	24	0.235	0.010		
Total	35	0.429			

Table 35: Anova for variation in holocellulose content of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	0.195	0.018	1.808	0.10897
Error	24	0.235	0.010		
Total	35	0.429			

Table 36: Anova for variation in lignin content of different provenances

Source of variation	df	SS	MSS	F _{cal}	Significance
Treatment	11	406.222	36.929	0.512	0.87631
Error	24	1,730.833	72.118		
Total	35	2,137.056			

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Admission Number	:	F-2015-08-D
Major Advisor	:	Dr. Tara Gupta
Major Field	:	Forestry
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ABSTRACT

The present research entitled “**Studies on provenance variation in *Toona ciliata* M. Roem**” was carried out in the Department of Tree Improvement and Genetic Resources, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP). Field survey was carried out across the population of *Toona ciliata* through HP, UK and UP to select well represented twelve provenances viz., P₁ (Nauni), P₂ (Hamirpur), P₃ (Thakurduara), P₄ (Ghumarwin), P₅ (Nurpur), P₆ (Nainikhad), P₇ (Una), P₈ (Rajpur), P₉ (Kathgodam), P₁₀ (Naini), P₁₁ (Nagina) and P₁₂ (Sarsawa). The trees of approximately same age group were randomly selected and phenotypic characters viz., tree height, tree diameter, crown spread, clear bole height and crown area were recorded. The seeds were collected from individual trees for seed studies. The data analyzed by RBD and CRD revealed that there was significant variation in provenances and maximum seed germination percentage from Nauni provenance. In order to study variability status of individual mother trees selected under each provenance, progenies of individual tree were raised in Randomized Block Design to assess the growth performances w.r.t germination energy index (%), seedling survival (%) seedling height (cm), collar diameter (mm), number of leaves and branches and leaf length. Half sib progenies performances revealed significant variation within provenances suggesting for single tree selection. The genetic estimates suggested intensive selection as high heritability followed by high genetic gains were obtained for crown spread and tree height. Similarly high correlation for collar diameter with mother tree height and 100 seeds weight was observed. The study revealed significant variation in chemical characteristics of wood from different provenances of *Toona ciliata*. The wood chemical analysis revealed that highest sapwood moisture content (58.98 %) was observed from Nauni, whereas minimum (29.05 %) was recorded from Ghumarwin. The heartwood moisture content was observed highest (54.94 %) from Hamirpur. The study revealed that heartwood moisture content was positively correlated with sap wood moisture content. The maximum holocellulose (74.50%) and lignin (28.50%) contents were recorded from Naini and Nauni respectively while, minimum holocellulose (65.10%) and lignin (16.83 %) was noticed from Nauni and Hamirpur. The study revealed that heart wood moisture content was positively correlated with sap wood moisture content (0.926). It was also observed that heart wood moisture content was positively correlated with heartwood maximum moisture content (0.587), sapwood maximum moisture content (0.636), cold water soluble extractive (0.697), hot water soluble extractive (0.772), alcohol benzene soluble extractive (0.616) and lignin content (0.665). The moderate to high heritability and genetic gains were estimated for collar diameter and seedling height till one year age suggesting early selection.

Signature of the Major Advisor

Signature of the Student

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Narendra Singh