GENETIC VARIABILITY AND DIVERGENCE STUDIES FOR SEED AND SEEDLING TRAITS AMONG CANDIDATE PLUS TREES (CPTs) OF *Toona ciliata* M. ROEM.

Thesis

by

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CERTIFICATE - I

This is to certify that the thesis titled **"Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem."** submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY)** in the discipline of **FOREST BIOLOGY AND TREE IMPROVEMENT** of Dr. Yashwant Singh Parmar University of Horticulture and Forestry (Nauni) Solan (HP)-173230 is a bonafide research work carried out by **Mr. Rahul Kumar (NF-2023-09-M)** son of Sh. Rajkumar Bhatia under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Neri, Hamirpur
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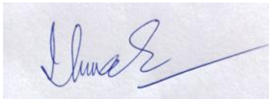
CERTIFICATE - II

This is to certify that the thesis entitled **"Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem."** submitted by **Mr. Rahul Kumar** son of **Shri Rajkumar Bhatia** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173 230, India in partial fulfilment of the requirements for the degree of **Master of Science** in the discipline of **Forestry (Forest Biology and Tree Improvement**) has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.



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Place: Neri, Hamirpur

Dated: **Rahul Kumar**

CONTENTS

ABBREVIATIONS USED

%	:	Per cent
=	:	Equal to
×	:	Multiplication
&	:	And
ANOVA	:	Analysis of Variance
CD	:	Critical difference
cm	:	Centimeter
CPTs	:	Candidate Plus trees
df	:	Degree of freedom
et al.	:	And others
Fig.	:	Figure
g	:	Gram
GCV		Genotypic coefficient of variation
H.P.	:	Himachal Pradesh
i.e.,	:	That is
m	:	Meter
mm	:	Millimeter
MSS	:	Mean sum of square
PCV	:	Phenotypic coefficient of variation
SS	:	Sum of square
viz.	:	*Videlicet*
YSP	:	Yashwant Singh Parmar

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Chapter- 1

INTRODUCTION

Understanding the diversity within and between tree populations is the fundamental key for setting priorities for the conservation and enhancement of tree genetic resources. All the differences among trees are the result of three factors i.e. genetic differences among trees, environment and interaction between different tree genotypes and their surroundings. Continuous development is feasible if variation exist in species. Variability is necessary for adaptation and improvement and the degree of variation determine the possibility of breeding programs to improve a species. High genetic variation within population and evolutionary histories can suggest future breeding initiatives (Namkoong, 1984). Variability study is the first step in any tree improvement programme which begins with a field survey and selection from the full range of species distribution. Once a superior and genetically diversified population has been obtained through a specific cycle of selection and development, the aim of tree breeder is to systematically utilize their genetic worth. (Zobel & Talbert, 1984).

The family Meliaceae exhibits a wide range of variation than any other trees families. *Toona ciliata* commonly known as Toon and Red Cedar belonging to family Meliaceae is one among such species which is largely preferred by the farmers to be grown on their fields and farms for its high-class timber value. (Orwa *et al.*2009). It is native to Australia and Asia but introduced elsewhere as a shade tree and for its fast-growing aspect and red timber.It is also known as Indian mahogany and it is found throughout the sub-Himalayan tract, Western Himalaya and valleys of the outer Himalayas including Manipur, Assam and Khasi Hills up to an elevation of 1600 meters (Troup, 1981). It is also distributed in the plains of Madhya Pradesh, Tamil Nadu and Karnataka thriving in moist locations such as ravines, stream bank or swamps. This species grows best in deep loamy soils with good moisture regimes, making it ideal for cultivated fields and roadside plantations in other states. The country like Himachal Pradesh, Uttar Pradesh and Uttarakhand.

Toona ciliata is a large, fast-growing deciduous or semi-deciduous tree with a wide crown that can reach up to the height of 20-30 m and girth of 1.83-3 m. (Orwa *et al.* 2009, Hua and Edmonds, 2008). The wood has a specific gravity of 0.57, with a density of 330-600 kg/cubic metres at 12 percent moisture content, easy to saw and straight-grained, somewhat irregular and light brown in colour (Troup, 1981).It is a light-demander and an early pioneer species in forest succession that spreads rapidly in cleared areas or in disturbed forests. The three other members of the genus Toona that grow in India and produce timber are *Toona febrifuga, Toona microcarpa* and *Toona serrata* (Edmonds, 1995). The bark of tree is dark grey and sometimes reddish-brown, smooth up to middle and rough afterwards, with shallow reticulate cracks exfoliating in irregular woody scales (Orwa *et al.* 2009).It is one of the alternatives to other timber species with quick growing ability.

The Meliaceae family is a large group of tropical woody species, comprising 50 genera and approximately 575 species, Toona species are amongst the most valuable timbers of tropics and in fact the backbone of forest-based industries in many countries throughout the world owing to its high-quality timber and for the ease with which they can be grown in plantations (Bufalino, 2012). Toon possesses important economic characteristics including a relatively short 15-year cycle; straight clean bole, good yields, high value in the internal and external markets (Murakami, 2008). The colour of the heartwood ranges from pinkish to dark reddish brown with a good natural texture whereas sapwood is pale yellow to brown by which it is easily demarcated from heartwood. The timber is rated as moderately durable.

The assessment of variation serves as a fundamental step in any tree breeding initiative. Forest tree improvement programs typically begin by evaluating the extent of existing variability across the full range of a species distribution, followed by the identification of seed sources that yield well-adapted trees (Suri, 1984). Seeds, which are the primary carriers of genetic information, manifest the full scope of genetic variability when germinated under uniform environmental conditions (Dubey *et al.* 2020). Therefore, seeds collected from superior or Candidate Plus Trees (CPTs) play a pivotal role in the success of both tree improvement and afforestation programs. Seed traits and germination behaviour are crucial for such programs, as they are often interrelated and governed by multiple genes. Variability in nursery-grown seedlings begins with differences in seed germination and initial growth stages. Attributes such as seed length, width, thickness, 100-seed weight, pod size and seed count per pod significantly influence germination performance (Selvan and Guleria, 2012). To ensure the effective establishment of large-scale plantations, strategic and scientifically guided seed source selection is essential. Historical evidence suggests that the most effective improvement programs have consistently relied on high-quality and genetically diverse seed sources (Zobel and Talbert, 1984; Jaishankar *et al.*2014).Therefore, the study entitled **"Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem."** has been carried out with the following objectives:

1. To study the extent of variation for seed and seedling traits among Candidate Plus Trees (CPTs) of *Toona ciliata*
2. To study the genetic divergence for seed and seedling traits among Candidate Plus Trees (CPTs) of *Toona ciliata*

Chapter- 2

REVIEW OF LITERATURE

The relevant literature pertaining to the different aspects of the present investigation entitled "Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem." has been reviewed under the following heads:

2.1 Morphological variation in seed and seedling growth parameters

2.2 Genetic variation and divergence studies in seed and seedling growth parameters

Variation refers to the differences among individuals that arise due to genetic factors and environmental influences. Investigating this variation is a critical first step in any breeding or improvement program. The success of such efforts largely depends on recognizing and utilizing the natural variation present in tree populations.

Various research on variation allow scientists to understand the natural diversity patterns, classify individuals by their provenance and assess the degree of variation within each group. These insights enable comparisons among individuals and help identify superior genotypes, which play a key role in tree improvement strategies.

According to Zobel and Talbert (1984), the selection of individuals based on natural variation is essential for successful tree breeding. They noted that the most significant, cost-effective and rapid improvements in forest tree breeding programs come from selecting the right species and their appropriate sources. Forest trees, known for their complexity and vast genetic diversity, provide great potential for evolutionary studies and improvement programs. Despite this, specific studies on *Toona ciliata* remain limited. In reference to this, the available literature on plus tree selection, seed source variation and juvenile growth characteristics in *Toona ciliata* has been reviewed and organized under following heads:

2.1 Morphological variation in seed and seedling growth parameters

Yadav *et al.* (2005) conducted a survey across Haryana and adjoining regions of Uttar Pradesh and Himachal Pradesh during January-February 2006 to collect seed material from candidate plus trees (CPTs) of shisham (*Dalbergia sissoo*). The selection of plus trees was based on key traits such as straightness, clear bole, strong apical dominance and a compact crown. A total of 81 trees were selected, showing significant variation in characteristics like plant height, bole clarity, straightness, 100-seed weight and germination rate. After two years, seedling height varied between 61.40 cm and 210.60 cm.

Gera and Gera (2006) reported highly significant variations among twenty genotypes of *Acacia catechu* from the Jammu region with respect to pod traits (including pod length, pod width and number of seeds per pod), seed traits (length, width and weight), germination percentage, growth parameters (such as seedling height, collar diameter and nodule number)and biomass traits (shoot and root biomass). They noted that germination and growth traits exhibited higher genotypic variance and genotypic coefficient of variation, indicating strong genetic control over these characteristics. Additionally, high heritability and genetic gain were observed for all traits, except for germination percentage

Singh *et al.* (2006) reported notable variation in seed traits such as seed breadth, seed length, seed weight, germination percentage , survival rate, along with various growth and biomass traits among 13 provenances of *Celtis australis* in the Central Himalayas. They also identified a significant positive correlation between seed morphological traits, particularly seed weight and the altitude of the seed source, as well as between seedling growth performance and altitude.

Rana *et al.* (2009) evaluated the progenies of 25 seed sources (plus trees) of *Toona ciliata* collected from various seed zones in Himachal Pradesh under both nursery and field conditions. The analysis of variance revealed significant differences for seedling height, collar diameter and number of leaves in the nursery. After 120 days of sowing, seedling height and collar diameter showed high broad-sense heritability along with substantial genetic advance. In the field trials, seed sources S1, S2, S5 and S6 demonstrated superior growth rates based on growth parameter values.

Divakara *et al.* (2010) reported significant variation in pod and seed characteristics among candidate plus trees (CPTs) of *Pongamia pinnata*. Among them, Genotype CPT-19 stood out with the highest values for traits such as pod length (65.64 mm), 100-pod weight (542.35 g), 2D surface area (351.18 mm^2), seed length (27.93 mm), 100-seed weight (202.89 g)and total oil content (44.33%). The study highlighted the presence of considerable genetic variability, suggesting its potential utility in future tree improvement programs.

Hidayat (2010) employed the comparison tree method to examine the morphological diversity of candidate plus trees (CPTs) of *Toona ciliata* collected from community forests across 16 districts in West and Central Java. Out of 96 CPTs, 24 were analyzed for their morphological and seed traits. Results from analysis of variance and dendrogram analysis showed no significant differences in these traits, suggesting limited morphological diversity. However, stem diameter, clear bole height and crown length showed a significant positive correlation with stem height, clear bole height, crown length and rainfall.

Shu *et al.* (2012) reported notable differences among 15 provenances of *Magnolia officinalis* in terms of seed traits, germination and growth characteristics. Among all traits, seed weight exhibited the greatest variation. Additionally, seed weight was found to have a significant positive correlation with both average annual temperature and rainfall, while showing a negative correlation with the latitude of the seed's origin

Sharma (2014) observed significant variability in cone and seed traits among 52 plus trees of *Cedrus deodara* selected from Himachal Pradesh. The traits studied included cone diameter, cone weight, seed length, number of seeds, seed breadth and seed weight. Strong and highly significant positive genetic correlations were found between seed length and seed breadth, seed length and seed weight, as well as seed breadth and seed weight, highlighting the importance of these traits in selecting high-yielding genotypes.

Wu *et al.* (2014) examined seedling cultivation practices across 151 families of *T. ciliata*. The analysis of variance revealed significant differences among treatments and families for the traits studied. The genotypic coefficients of variation were recorded as 32.96% for plant height, 24.27% for stem diameter and 48.23% for number of leaves. Heritability estimates were high, 0.96 for height, 0.81 for diameter and 0.91 for number of leaves. The strong positive phenotypic correlations among traits indicated that selection based on one trait could effectively predict performance in the others within *Toona ciliata* families.

Medeiros *et al.* (2015) assessed the germination of Australian cedar (*Toona ciliata* M. Roem) seeds using three different substrates and two photoperiod conditions, while also examining the impact of salt stress induced by sodium chloride (NaCl) on seed viability and vigor. The findings revealed that a 24-hour light photoperiod had no effect on final germination rates and that paper as a substrate resulted in the highest germination percentage.

Singh and Gupta (2017) studied seed source variation in *Toona ciliata* across ten locations in Himachal Pradesh. Significant differences were observed in 100-seed weight (0.18–0.31 g), seed colour and germination percentage (0.33–27.78%). Nainikhad, Parwanoo, Rajgarh, Palampur, Mandi, Nagni and Jaunaji showed higher seed weights, while Parwanoo, Mandi and Jaunaji had the highest germination rates. Dark brown was the most common seed colour. The study confirmed notable variability in seed traits among different sources.

Pei and Yang (2017) studied *Toona ciliata* seedlings from 18 different provenances to support breeding efforts and the selection of superior provenances. They regularly monitored the height and ground diameter of one-year-old seedlings. The genotypic coefficient of variation (GCV) was found to be 43.31% for seedling height. Longitude was identified as the primary factor influencing geographic variation in these traits. Both height and diameter growth followed a "slow-fast-slow" pattern, forming an "S"-shaped growth curve. The seedling growth cycle of *Toona ciliata* was categorized into three stages: early, rapid and late growth, with the timing of these stages varying across different provenances.

Dhiman (2018) applied the baseline technique to identify six phenotypically superior genotypes of *Toona ciliata* from twelve different locations in Punjab and Himachal Pradesh, aiming to assess the extent and nature of variability in seed and seedling growth traits. Tree characteristics such as height, clear bole height and girth had average values of 13.20 m, 3.79 m and 94.54 cm, respectively. The correlation analysis revealed strong, positive and highly significant relationships between seed weight and germination percentage, germination and survival percentage, seedling height and collar diameter, indicating that improvement in one trait would likely lead to enhancement in the associated trait. Additionally, high values of genotypic coefficient of variation, phenotypic coefficient of variation and heritability for seed traits suggested that these traits are primarily governed by additive genetic factors.

Reeja *et al.* (2018) studied the variability in seed traits of *Prosopis juliflora* across thirty seed sources in South India. The findings showed that seed sources from Tuticorin, Rameshwaram, Ramnadand Keezhakarai exhibited considerable variation in all evaluated seed characteristics, including 2D surface area, perimeter, length, width, aspect ratio, 100-seed weight, pod length, number of seeds per pod, seed viability and germination percentage. The Sivaganga source had the longest pods, measuring 23.05 cm, while Rameshwaram pods had the highest number of seeds per pod (29.00). The highest viability was observed in seeds from Tuticorin (94.50%), followed by Tirunelveli (93.00%), Rameshwaram and Ramnad (92.00%). Germination percentage was also highest in seeds from Rameshwaram (92.00%) and Pollachi (90.5%), Theni (88.00%), Coimbatore (87.50%)and Ramnad (87.50%) following closely.

Warrier *et al.* (2018) conducted research on the genetic variation of *Melia dubia*, selecting 33 plus trees based on their phenotypic traits to identify promising seed sources for the production of high-quality planting material for forestry and related programs. The study revealed significant genetic diversity among the selected trees in terms of fruit and stone characteristics. Among them, the Nagondapalli source recorded the highest 100-fruit weight (1.00 kg), while Kollegal 10 had the highest 100-seed weight (280 g). Additionally, Kodipuram showed the highest number of filled locules and the greatest germination percentage.

Prabakaran *et al.* (2019) investigated the variability in seed traits, oil content and azadirachtin levels in *Azadirachta indica* by screening seeds from 34 Plus Trees (PTs) collected across Karnataka and Tamil Nadu. The study revealed significant differences among the PTs for both seed and biochemical characteristics. NPT 7 recorded the highest 100-seed weight (30.00 g) and 100-kernel weight (12.00 g), while NPT 34 exhibited the highest oil content (42.81%). The highest azadirachtin content was found in NPT 11 (0.972%), followed closely by NPT 17 (0.970%). All seed and biochemical traits showed high broad-sense heritability and high genetic gain. Additionally, seed weight and kernel weight were significantly correlated with azadirachtin content.

Pramono *et al.* (2019) examined the variation in seed size and its impact on germination and seedling growth in *Swietenia macrophylla*. Seeds were collected from mahogany plantations in Panjang, Bogor, Indonesia and categorized into five classes based on their size. The study found that seed size was influenced by both the fruit size and the seed's position within the fruit. Seeds measuring less than 6 cm exhibited lower germination rates compared to those longer than 6 cm. Additionally, seed size had a noticeable effect on the early growth of seedlings.

Dubey *et al.* (2020) investigated seed source variation in *Aquilaria malaccensis* by analysing seed traits across nineteen representative sources from Mizoram, Nagaland, Assam, West Bengal and Tripura. The study focused on evaluating capsule and seed characteristics, including capsule length (ranging from 25.24 to 32.53 mm), capsule width (14.25 to 18.14 mm), capsule thickness (10.73 to 14.84 mm) and 100-capsule weight (215.67 to 291.68 g). Seed traits assessed included seed length (13.65 to 16.61 mm), seed width (4.42 to 5.06 mm), number of seeds per capsule and 100-seed weight (10.35 to 12.40 g).

Singh (2021) selected twelve provenances of *Toona ciliata* from Himachal Pradesh, Uttarakhandand Uttar Pradesh for seed collection, based on phenotypic traits such as tree height, trunk diameter, crown diameter, clear bole height and crown area. The study found that tree height ranged from 18.47 m to 28.70 m, tree diameter varied between 29.97 cm to 33.19 cm, crown diameter ranged from 9.74 m to 12.84 m and clear bole height varied from 2.33 m to 2.99 m. Crown area values were observed between 27.44 m^2 and 48.73 m^2.

Singh (2021) conducted a comprehensive investigation to assess the genotypic variation in *Toona ciliata* M. Roem for growth and physiological traits.

The study focused on twenty-four half-sib progenies collected from eight distinct seed sources—Talwara, Kamahi Devi, Ludhiana, Sujanpur, Salouni, Chabutra, Shah Talai, and Suhari Takoli. The findings revealed substantial genetic variability among the seed sources and genotypes for key morphological and physiological attributes. Notably, seed sources such as Salouni (S5), Chabutra (S6), and Kamahi Devi (S2) exhibited superior average performance across multiple traits. On a genotype level, progenies including S6G16 (Chabutra), S5G15 and S5G13 (Salouni), and S2G4 (Kamahi Devi) consistently excelled and recorded the highest index score of 15 for critical morphological parameters such as plant height, clear bole height, collar diameter, and stem straightness.

Dhiman (2021) investigated the variation in seed and seedling growth traits of *T. ciliata*, identifying 36 superior genotypes from twelve different locations across Punjab and Himachal Pradesh. The study revealed high genotypic and phenotypic variability, along with high heritability for seed traits, indicating the influence of additive gene action. Additionally, treating seeds with hot and cold water for 48 hours proved effective in breaking dormancy and improving germination rates.

Khobragade *et al.* (2022)in their study on the impact of seed size and weight on the germination of *Terminalia bellirica*, found that larger seeds exhibited the highest germination rate (85%), followed by medium-sized seeds at 80%, while smaller seeds showed the lowest rate at 67%. The findings indicated a clear trend where germination percentage significantly declined with a decrease in seed size and weight.

Javaid *et al.* (2022) selected twenty-two Candidate Plus Trees of *Toona ciliata* from different zones of the Jammu region based on their superior phenotypic traits. The study revealed significant variation in the fruit and seed characteristics among the selected trees. Seed length with wings ranged from 10.44 mm to 12.61 mm. The 100-seed weight (excluding wings) showed considerable variation across seed sources, ranging from 0.12 g to 0.36 g. Additionally, seed width varied between 2.2 mm and 3.08 mm, while seed length ranged from 4.83 mm to 6.82 mm.

Mayavel *et al.* (2023) studied provenance variation in seed morphometry, germination and seedling growth traits of *Azadirachta indica* (Neem). Candidate Plus Trees (CPTs) were selected from six distinct agro-climatic zones of Tamil Nadu based on superior growth performance and higher fruit yield. The study revealed significant differences among provenances in various seed traits, including seed length, width, perimeter, areaand 100-seed kernel weight. Germination traits such as germination percentage, mean daily germination, germination value, germination time, peak value, time spread of germination and germination index also varied notably. Additionally, significant variation was observed in seedling parameters like shoot and root length, collar diameter, shoot and root fresh weight, as well as shoot and root dry weight.

Nabi *et al.* (2023) reported significant variation in pod and seed traits among nine seed sources of *Robinia pseudoacacia* Linn., with morphological differences in seeds and seedlings being statistically significant ($p<0.05$). Seed source S2 demonstrated superior performance in pod and seed characteristics, while S8 and S9 showed the lowest values for pod length (60.98 mm), pod width (11.13 mm) and seed number per pod (4.55). The maximum pod length (72.66 mm), pod width (13.57 mm) and seeds per pod (7.92) were also observed. S2 recorded the highest seed weight at 24.05 g, which was statistically like S4 (24.02 g), followed by S6 (24.00 g), whereas S7 had the lowest seed weight at 22.66 g. The observed variation appeared to be largely under genetic control and exhibited spatial patterning.

2.2) Genetic variation and divergence studies in seed and seedling growth parameters.

Singh and Pokhriyal (2001) examined pod and seed trait variation in *Dalbergia sissoo* collected from six distinct seed sources and observed significant differences in pod length, pod width, number of seeds per pod and seed weight, reflecting substantial genetic variability. The study emphasized the value of selecting superior seed sources for plantation efforts, as seed traits play a vital role in determining seedling vigor and overall growth performance. These findings are considered essential for tree improvement and agroforestry programs aimed at boosting productivity and promoting ecological stability.

Sehgal *et al.* (2005) collected seeds of *Toona ciliata* from 50 trees across 10 seed sources in Himachal Pradesh to study genetic variation and estimate variability in seed traits, germination behaviour and nursery growth parameters both between and within families. Significant variation was observed among and within seed sources for seed length, seed breadth and 100-seed weight. Germination traits like germination energy and seedling survival also showed statistically significant differences across and within seed sources, although germination percentage did not vary significantly. Analysis of variance indicated significant differences for all nursery traits at both the between- and within-family levels, except for leaf length, which showed non-significant variation within families. Germination energy had the highest phenotypic (30.84%) and genotypic (30.46%) coefficients of variation, with broad-sense heritability of 97.50% and a genetic gain of 61.90%. Leaf area heritability was 84.14% at the half-sib family level and 84.87% at the individual plant level, while the number of nodes showed the highest heritability (84.42%) for within-family selection. Overall, genetic gain was greater through family selection than within-family selection for all traits studied.

Kumar (2005) conducted a study on biomass estimation and wood properties of *Toona ciliata* within an agrisilviculture land use system. Trees were selected through stratified random sampling and grouped into eight diameter classes. Using a Randomized Block Design (RBD), data on volume, biomass and mean annual increment (MAI) were analyzed. The results indicated that as the diameter at breast height (DBH) increased, so did tree age and clean bole length, with tree height following a similar upward trend.

Uppal and Singh (2010) investigated the impact of seed source variation on seed and seedling traits of *Toona ciliata* in Himachal Pradesh and reported significant differences in seed characteristics, nursery germination percentage, growth and biomass traits. The study revealed that root and shoot lengths were largely influenced by genetic factors, with high estimates of heritability, genetic gain and genetic advance. In contrast, germination percentage was more affected by environmental conditions. Heritability was highest for root length, while it was relatively low for seed weight and germination percentage. The researchers concluded that seedling height and number of leaves, due to their high heritability and genetic advance, are reliable traits for selecting superior progenies.

Rawat and Bakshi (2011) observed notable variability in cone and seed characteristics among twenty seed sources of *Pinus wallichiana* at FRI Dehradun. Significant differences were recorded in cone traits such as length, diameter and weight, as well as in seed traits including length, width, thickness, 100-seed weight and seed volume. Germination parameters like germination percentage, germination value, energy, energy index and germination period also varied significantly. Additionally, variations were found in cotyledon number, shoot length and root length among the different seed sources.

Thakur and Dhuppe (2015) found notable variations among different provenances of *Albizia lebbeck* across all evaluated traits, including fresh and dry weights of shoots and roots, as well as fresh and dry shoot-to-root ratios. The study recorded high genotypic (22.10%) and phenotypic (20.70%) coefficients of variation specifically for root fresh weight. Significant heritability (98.0%) was observed for both root and shoot dry weights, while root fresh weight demonstrated a substantial genetic gain of 40.07%.

Thakur and Thakur (2015) conducted a variability assessment on twenty-seven mother trees of *Melia azedarach* and reported that collar diameter (heritability 0.96, genetic gain 64.37%), root length (0.93 and 57.72%) and the root-to-shoot length ratio (0.91 and 51.83%) exhibited high heritability coupled with substantial genetic gain. Plant height was found to have a strong and significant positive genotypic and phenotypic correlation with the number of branches (0.85 and 0.82) and collar diameter (0.84 and 0.81). Additionally, collar diameter showed a positive and significant correlation with the number of branches (0.83 and 0.74) and number of leaves (0.70 and 0.65), indicating strong genetic associations among these traits.

Sharma *et al.* (2018) carried out a study to assess the early growth performance of 16 improved genotypes of *Melia dubia* under the low hill conditions of Himachal Pradesh. Growth data were recorded over a period of three months and analyzed for traits like seedling height, diameter and associated genetic parameters. The findings revealed significant variation in height among the seedlings of different genotypes, with genotypes 231 and 241 exhibiting superior performance across the evaluated traits.

Singh *et al.* (2018) collected *Toona ciliata* seeds from ten different locations and evaluated their morphological traits at three sites to assess the extent and pattern of variation. The study found that both the number of flowers and the inflorescence length exhibited low genotypic coefficients of variability and low to moderate genetic gain, but high heritability values (0.41 and 0.62, respectively). This indicates that these traits are primarily controlled by additive genetic factors and are suitable for selection. Additionally, a strong positive correlation ($r = 0.94$) was observed between flower number and inflorescence length, while leaflet number and fruit setting showed a weak negative correlation ($r = -0.24$).

Loushambam *et al.* (2018) assessed forty-two genotypes of *Melia dubia* for multiple growth traits, including plant height, total biomass, leaf area and fibre quality. In the first experiment, genotype MD013 recorded the highest values for plant height (3.83 m), biomass (17.26 kg per tree) and leaf area (3.21 cm^2). In the second experiment, genotype MD058 exhibited the maximum plant height (3.83 m), biomass (16.76 kg per tree) and leaf area (3.05 cm^2).

Parthiban *et al*. (2019) conducted a progeny evaluation of 23 *Toona ciliata* genotypes from the Western Ghats and found significant variation in height, DBH, and volume. Progeny TC02 showed early superiority with higher height (4.95 m), DBH (6.45 cm), and volume (0.010 m^3). Growth traits had higher PCV than GCV, and heritability was low due to juvenile evaluation. Volume and clear bole height showed strong positive correlations, making them reliable selection indices. D^2 analysis grouped the progenies into seven clusters, with Cluster V showing maximum intra-cluster distance.

Gupta *et al.* (2020) carried out a study to estimate genetic parameters in progenies of *Acacia nilotica*, selecting superior trees from twenty locations with five randomly chosen trees at each site. The results indicated that the phenotypic coefficient of variation (PCV) exceeded the genotypic coefficient of variation (GCV) for all traits, suggesting a considerable environmental impact on trait expression. Traits such as dry root weight, root/shoot ratio, internodal length and seedling height exhibited high heritability estimates, while germination percentage had the lowest. The analysis further identified seedling biomass as the major contributor to genetic divergence.

Kundal *et al.* (2020) assessed the growth performance of 24 half-sib genotypes of *Toona ciliata* under field conditions. The findings revealed that for all measured traits, the phenotypic coefficient of variation (PCV) exceeded the genotypic coefficient of variation (GCV), indicating environmental influence. Additionally, both collar diameter and stem straightness showed significant positive correlations—at both phenotypic and genotypic levels—with plant height.

Thakur *et al.* (2020) investigated genetic variability, heritability, genetic advance and correlations for pod and seed characteristics in *Bauhinia variegata* L. The study found that seed weight per pod and number of seeds per pod exhibited the highest phenotypic coefficient of variability (PCV), while seed width and seed length showed the lowest PCV. Moderate genotypic coefficient of variability (GCV) was observed for seed weight per pod, whereas traits such as pod width, seed width, seed length, pod length and number of seeds per pod displayed low GCV values. Among all traits, seed width, seed length and seed weight per pod recorded the highest heritability. Both genotypic and phenotypic correlations revealed that all traits were significantly and positively associated with one another at both levels.

Rahman and Islam (2020) examined 20 mulberry genotypes to assess their phenotypic, morphological and yield-related traits, along with genotypic and phenotypic variability, heritability, genetic advance and genetic gain. Their findings indicated that the phenotypic coefficient of variation (PCV) was slightly higher (97.68%) than the genotypic coefficient of variation (96.99%), suggesting some environmental influence on trait expression.

Singh *et al.* (2020) investigated variability in seed sources of Shisham (*Dalbergia sissoo*) collected from 15 locations across Punjab, Haryana and Rajasthan. The study found significant differences in all pod traits, including germination percentage and germination value, as well as key growth parameters such as shoot length, root length and both shoot and root dry biomass. The low heritability estimates for seedling growth traits indicated limited transmission of these traits to progeny. The researchers concluded that the clustering of seed sources was primarily influenced by their inherent genotypic potential rather than their geographical origin.

Singh (2021) carried out a study on provenance variation in *Toona ciliata* M. Roem., focusing on traits such as germination energy index (%), seedling survival (%), seedling height (cm) and collar diameter (mm). The genetic analysis indicated that traits like crown spread and tree height exhibited high heritability along with high genetic gain, suggesting that intensive selection could be highly effective. Moreover, a strong correlation was observed between collar diameter and both the height of the mother tree and the 100-seed weight.

Panjoria (2021) examined genetic variability in twenty Candidate Plus Trees (CPTs) of *Acacia catechu*, with ten CPTs selected from each of the Una and Hamirpur districts. The study evaluated one-year-old seedlings for growth and genetic traits. Significant variation was observed among the CPTs for pod, seed and nursery growth attributes. Genotypic correlations were found to be stronger than their phenotypic counterparts and D^2 analysis indicated substantial genetic diversity among the *A. catechu* CPTs.

Kumar *et al.* (2021) investigated seed source variation in *Celtis australis* by collecting seeds from ten different locations across the Indian Himalayas to identify promising germplasm for enhancing productivity and climate resilience. After four years of growth, genotypic variation in traits such as height, collar diameter and total biomass exceeded the corresponding environmental variation. Among the sources, Tehri exhibited the greatest growth performance (Height: 4.88 m; Diameter: 9.69 cm), closely followed by Solan (Height: 4.81 m; Diameter: 8.64 cm), while the Dehradun seed source showed the lowest growth (Height: 3.46 m; Diameter: 5.19 cm). Tehri provenance also demonstrated superior potential for climate change mitigation and adaptation compared to the other seed sources.

Danu *et al.* (2021) investigated the growth performance and genetic parameters of *Melia azedarach* and found significant differences in height and diameter growth among the various families. Notably, the families from

Sumedang-31 and Bogor demonstrated superior performance, with 11 families exhibiting exceptional growth in both traits.

Nayana *et al.* (2021) evaluated the early growth performance of *Melia dubia* clones by recording collar diameter and plant height over a period of nine months. The results revealed significant variation in height and collar diameter among the clones. The tallest growth was observed in clone IFGTBC10 (269.70 cm), followed by IFGTBC8 (233.56 cm). Notable collar diameters were also recorded in clones IFGTBC8 (1.79 cm) and IFGTBC10 (1.71 cm).

Mohanraj et al. (2022) studied genetic diversity in sixteen *Toona ciliata* progenies using D^2 clustering and grouped them into five clusters. The highest intra-cluster and inter-cluster distances were found in Cluster II and between Clusters III and IV, respectively. Volume index contributed most (81.66%) to genetic divergence.

Mayavel *et al.* (2023) carried out a provenance variation study on *Azadirachta indica* to evaluate traits contributing to the development of superior planting material. Thirty Candidate Plus Trees (CPTs) were selected from six different agroclimatic zones of Tamil Nadu. The study recorded significant variability across all examined traits. Seed length ranged from 1.16 cm to 1.89 cm, width from 0.61 cm to 0.85 cm and circumference from 3.09 cm to 4.61 cm. The weight of 100 seeds varied between 10.35 g and 37.85 g. Collar diameter ranged from 2.87 mm to 5.75 mm. Shoot length varied between 19.27 cm and 35.27 cm and root length ranged from 15.85 cm to 33.87 cm. Additionally, shoot dry weight ranged from 0.30 g to 1.77 g, root fresh weight from 5.25 g to 11.75 g and root dry weight from 0.44 g to 1.93 g.

Chapter-3

MATERIALS AND METHODS

The current study entitled "**Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *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, College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh during 2024-2025. The descriptions of the materials and methods used, the sites selected for the experiments and the methodology chosen for the study are explained under the following headings.

3.1 EXPERIMENTAL SITE
3.2 EXPERIMENTAL MATERIALS
3.3 OBSERVATIONS RECORDED
3.4 STATISTICAL ANALYSIS

3.1EXPERIMENTAL SITE

The experiment was conducted in the experimental farm and laboratory of College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh. The experimental farm is situated at Khaggal, Hamirpur (HP). The site is located at 31°40'23.0"N latitude, 76°29'15.5"E longitude and 650 m elevation above the mean sea level (figure 3.1).

3.2 EXPERIMENTAL MATERIAL

The experimental material comprised of forty Candidate Plus Tress (CPTs) of *Toona ciliata* collected from three districts of Himachal Pradesh and one from Punjab namely, Kangra, Mandi, Hamirpur from Himachal Pradesh and Ludhiana from Punjab. Ten CPTs were selected from each district for the study. The experiment was laid out in Completely Randomized Design (CRD) with three replications. The details of CPTs along with physical description of sites are given in Table 1.

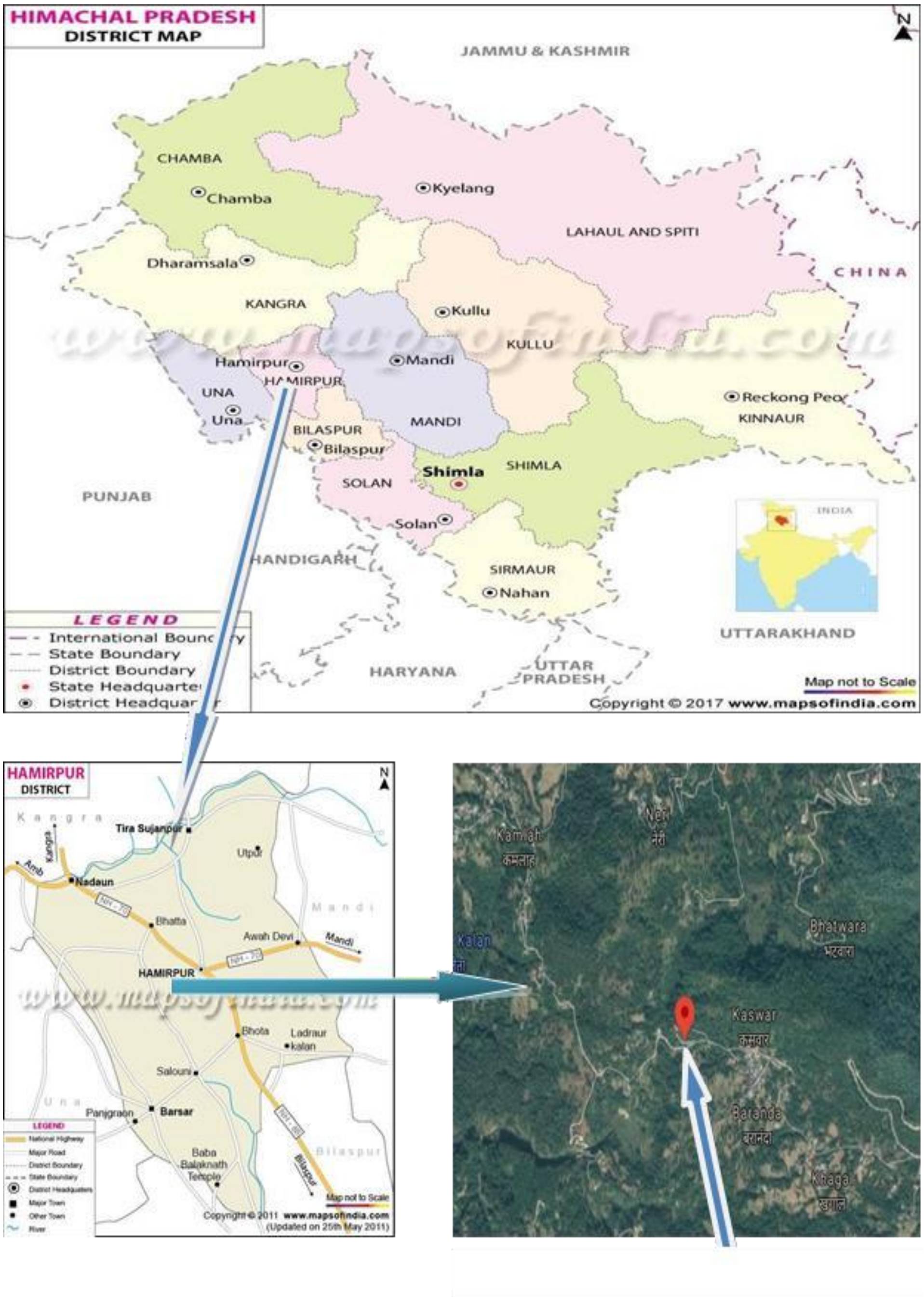


Figure 1: Location of study site

Table 1. Location of different Candidate Plus Trees (CPTs) of *Toona ciliata.*

CPTs	Location	District	Altitude	Latitude	Longitude
CPT1	Harsi	Kangra	729m	31°52'35"N	76°39'17"E
CPT2	Halehr	Kangra	581 m	31°53'28"N	76°37'21"E
CPT3	Jaisinghpur	Kangra	615m	31°53'56"N	76°35'59"E
CPT4	Sari Molag	Kangra	788m	31°54'05"N	76°39'57"E
CPT5	Dalu	Kangra	577m	31°53'51"N	76°36'49"E
CPT6	Dhaneri	Kangra	721m	31°53'17"N	76°38'56"E
CPT7	Maila	Kangra	693m	31°52'37"N	76°40'18"E
CPT8	Chambi	Kangra	632m	31°53'56"N	76°37'56"E
CPT9	Sanghol	Kangra	639m	31°53'22"N	76°38'21"E
CPT10	Kathla	Kangra	607m	31°53'06"N	76°37'58"E
CPT11	Khaggal	Hamirpur	711m	31º43’37”N	76º24’93”E
CPT12	Neri	Hamirpur	614m	31°42’43”N	76°21’48”E
CPT13	Dhaneta	Hamirpur	590m	31°40’04”N	76°21’57”E
CPT14	Masyana	Hamirpur	1100m	31°39’09”N	76°31’20”E
CPT15	Rangas	Hamirpur	500m	31°42’43”N	76°21’48”E
CPT16	Daruhi	Hamirpur	1150m	31°41’06”N	76°30’10”E
CPT17	Baleta Khurd	Hamirpur	650m	31°40’57”N	76°28’31”E
CPT18	Kamlah	Hamirpur	600m	31°40’45”N	76°28’43”E
CPT19	Kangoo	Hamirpur	650m	31°41’32”N	76°25’20”E
CPT20	Kashmir	Hamirpur	500m	31°37’52”N	76°24’06”E
CPT21	Sandhol	Mandi	650m	31°51'40"N	76°38'58"E
CPT22	Ghanala	Mandi	603m	31°52'11"N	76°38'27"E
CPT23	Datwar	Mandi	786m	31°51'09"N	76°38'27"E

CPT24	Khanoli	Mandi	790m	31°50'47"N	76°38'03"E
CPT25	Kakkar	Mandi	954m	31°49'21"N	76°36'29"E
CPT26	Palahi	Mandi	797m	31°50'03"N	76°33'45"E
CPT27	Kheri	Mandi	853m	31°51'59"N	76°36'46"E
CPT28	Bairi	Mandi	744m	31°51'59"N	76°35'36"E
CPT29	Bajrol	Mandi	777m	31°52'01"N	76°34'59"E
CPT30	Jangal Beri	Mandi	585m	31°52'31"N	76°34'10"E
CPT31	Khasi Kalan	Ludhiana	271m	30°55'47"N	75°56'52"E
CPT32	Tajpur	Ludhiana	263m	30°55'23"N	75°56'00"E
CPT33	Rawat	Ludhiana	264m	30°57'04"N	75°55'16"E
CPT34	Mundian	Ludhiana	278m	30°53'55"N	75°56'33"E
CPT35	Sahibana	Ludhiana	280m	30°53'52"N	75°58'10"E
CPT36	Mattewara	Ludhiana	268m	30°58'41"N	75°58'33"E
CPT37	Baura	Ludhiana	270m	30°57'36"N	76°02'09"E
CPT38	Kalewal	Ludhiana	269m	30°59'28"N	76°02'36"E
CPT39	Salempur	Ludhiana	253m	30°55'49"N	75°41'23"E
CPT40	Hambran	Ludhiana	255m	30°55'55"N	75°40'30"E

3.3 OBSERVATIONS RECORDED

3.3.1 Morphological parameters

- **Tree height (m):** It is the straight-line distance from leading tip of tree to ground level. The tree height was taken with the help Ravi's altimeter.
- **Clear bole height (m):** It is the distance from the base of the tree to the base of the first living branch. Clear bole height was taken with the help of Ravi's altimeter.

- **Diameter at breast height (cm):** Tree girth free from knots and disease were selected for study with the help of measuring tape at height of 1.37 m.

3.3.2 Seed parameters

- **Seed length (mm):** Randomly five seeds collected from each Candidate Plus Trees (CPTs) were measured for seed length with the help of digital vernier caliper and expressed in millimeter.
- **Seed width (mm):** Randomly five seeds collected from each Candidate Plus Trees (CPTs) were measured for seed width with the help of digital vernier caliper and expressed in millimeter.
- **100 Seed weight (gm)**: From each Candidate Plus Trees (CPTs) 100 seeds were randomly selected and weighed by using electronic balance.
- **Seed germination percentage (%):** The seeds collected from each Candidate Plus Trees (CPTs) were sown in polybags in three replications and germination percentage was recorded after one month.

$$\text{Seed germination percentage (\%)} = \frac{\text{Number of total germinated seeds}}{\text{Total number of seeds tested}} \times 100$$

3.3.3 Growth and biomass parameters

The data on growth parameters of seedlings were recorded after 2 months, four months and six months, while seedling biomass parameters were recorded after six months of sowing of seeds in nursery.

3.3.3.1 Growth parameters

- **Seedling height (cm):** The height of seedling was measured from root to the growing tip by using a measuring scale.
- **Shoot length (cm):** Shoot length was measured from collar diameter to apex of leading shoot with the help of scale and expressed in centimeter.
- **Root length (cm):** Root length was measured with the help of measuring scale and expressed in centimeter.
- **Seedling collar diameter (mm):** Seedling collar diameter was measured at collar region of the seedling by using digital vernier calliper

3.3.3.2 Biomass parameters

- **Seedling biomass (gm):** The root and shoot portions were separated at the collar region and following observation were recorded.
  a. **Shoot fresh weight (g):** The shoot fresh weight for each plant was recorded by using electronic balance.
  b. **Shoot dry weight (g):** Fresh shoots after weighing was dried in hot air oven till it attained constant weight and then dry weight was recorded using electronic balance.
  c. **Root fresh weight (g):** The root fresh weight for each plant was recorded by using electronic balance.
  d. **Root dry weight (g):** Fresh roots after weighing was dried in hot air oven till it attained constant weight and then dry weight was recorded using electronic balance.
  e. **Root/Shoot ratio:** Root and Shoot ratio was calculated on weight basis both by using the following formula-

$$\text{Fresh root/shoot ratio} = \frac{\text{Fresh weight of root (g)}}{\text{Fresh weight of shoot (g)}}$$

$$\text{Dry root/shoot ratio} = \frac{\text{Dry weight of root (g)}}{\text{Dry weight of shoot (g)}}$$

3.4 STATISTICAL ANALYSIS

3.4.1 Analysis of variation

The experimental data of all the tree characters studied were subjected to the statistical analysis for proper interpretation. Completely Randomized Design was applied for analysis. The analysis of variance (ANOVA) for CRD table was set up as under:

Analysis of variance for CRD (Completely Randomized Design)

Source of variation	Degree of freedom	Mean sum of square	Calculated F value
CPTs	V-1	Mv= MSS	MSS/MSE
Error	V(n-1)	Me= MSE	
Total	Vn-1		

The calculated F values were compared with tabulated F values. When the F test found significant, critical difference was calculated to find out the superiority of one genotype over the others.

The critical difference (CD) was calculated as under:

$CD_{0.05}$ = S.E.(d) x t $_{0.05}$ error degree of freedom

Where,

S.E. (d) (standard error of difference) $=\frac{\sqrt{2\ Me}}{r}$

$T_{0.05}$ error degree of freedom= t value at 5% level of significance.

All the traits which differed significantly were utilized for the estimation of the following genetic parameters:

i. Mean performance and genetic variability
ii. Heritability (in broad sense)
iii. Genetic advance (GA)
iv. Genetic gain (GG)
v. Correlation coefficients
vi. Genetic divergence

1. Mean performance and genetic variability:

The phenotypic and genotypic coefficients of variability were calculated as per the formula given by Burton and De Vane (1953).

a) Phenotypic coefficient of variation (PCV)

$$PCV\ (\%) = \frac{\sqrt{Phenotypic\ variance(V_g)}}{General\ mean\ of\ population(\bar{x})} \times 100$$

b) Genotypic coefficient of variation (GCV)

$$GCV\ (\%) = \frac{\sqrt{Genotypic\ variance(v_g)}}{General\ mean\ of\ population(\bar{x})} \times 100$$

Where,

Genotypic variance (Vg) = (Mg-Me)/r

Phenotypic variance (Vp) = (Vg+Ve)

2. **Heritability (in broad sense):**

Heritability in broad sense was calculated as per formula given by Burton and De Vane (1953) and Allard (1960).

$$H\ (\%) = \frac{\text{Genotypic variance (Vg)}}{\text{Phenotypic Variance (Vp)}} \times 100$$

3. **Genetic advance (GA) :**

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

$$\text{Genetic advance} = \frac{Vg}{Vp} \times \sqrt{Vp} \times k$$

Where;

k = Selection differential at five percent selection intensity.

k = 2.06 (Allard, 1960)

4. **Genetic gain (GG)**

Genetic gain expressed as per cent ratio of genetic advance and population mean was calculated by the method given by Johnson *et al.* (1955).

$$\text{Genetic gain (\%)} = \frac{\text{Genetic advance}}{\text{General mean of population } (\bar{X})} \times 100$$

5. **Correlation coefficients:**

Genotypic and phenotypic correlations were worked out as per Singh and Narayanam (2009).

$$\text{Genotypic correlation } (r_g) = \frac{G\ COVxy}{\sqrt{Vgx\ Vgy}}$$

$$\text{Phenotypic correlation } (r_p) = \frac{P\ COV_{xy}}{\sqrt{V_{px}\ V_{py}}}$$

Where;

G $Cov_{xy}$and P Cov_{xy} = genotypic and phenotypic covariance between x and y characters, respectively.

Vgx and Vpx= genotypic and phenotypic variance of x character

Vgy and Vpy= Genotypic and Phenotypic variance of y character

6. Genetic divergence (D^2 analysis):

The genetic divergence was estimated by Mahalanobis D^2 statistics (Mahalanobis, 1936) as suggested by Rao (1952). The calculation of D^2 values involved following steps:

i. A set of uncorrelated linear combinations (y's) were obtained by pivotal condensation of the common dispersion matrix Rao (1952) of the set of correlated variables (x's).

ii. Using the relationship between y's and x's the mean values of different genotypes for different characters (x_1 to x_{12}) were transformed into the mean values of asset of uncorrelated linear combinations (y_1-y_{12}).

iii. The D^2 values between i^{th} and j^{th} genotypes for K characters were calculated as under:

$$D^2ij = \sum_{i=1}^{K}(yit - yjt)$$

where,

Y_{it} is uncorrelated mean value of i^{th} genotype for 't' characters

Y_{jt} is uncorrelated mean value of j^{th} genotype for 't' characters

D^2ij is D^2 between i^{th} and j^{th} accessions

Group constellation:

Varieties were grouped into a number of clusters. D^2 being treated as the square of generalized distance, according to the method described by Tocher

(Rao, 1952). The criterion used in clustering by this method is that any two genotypes belonging to the same cluster should, at least on average, show a smaller D^2 value than those belonging to two different clusters. In other words, if variety V_1 and V_2 are close together and variety V3 is distant from both shown by this generalized distance, V_1 and V_2 from one cluster.

The average D^2 values of all possible genotype combinations in one cluster with those in the other were computed and its square root was used to represent the 'statistical distance' between two clusters.

Intra and inter cluster genetic distances:

For the measure of intra cluster D^2 values, the following formula was used.

$$\text{Intra-and inter cluster } D^2 = \frac{\sum D_i^2}{N}$$

$$N = n\,(n-1)/2$$

Where,

$\sum Di^2$ is the sum of D^2 values between all possible combinations (N) within and between clusters, respectively.

n = number of populations included in a cluster

Intra and inter cluster genetic distances (d) where computed square root of average intra and inter cluster D^2 values i.e $d = \sqrt{D^2}$

Chapter- 4

RESULTS AND DISCUSSION

The current study on "Genetic variability and divergence studies for seed and seedling traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem," was carried out to determine extent of variability within and between candidate plus trees. The results of the present investigation along with discussion are presented under following subheadings:

4.1 PHENOTYPIC VARIATION STUDIES

4.2 GENETIC VARIABILITY STUDIES

4.2.1 Analysis of variance

4.2.2 Mean performance of different Candidate Plus Trees (CPTs) for seed parameters

4.2.3 Variation studies in seed germination parameters among different Candidate Plus Trees (CPTs)

4.2.4 Mean performance of different Candidate Plus Trees (CPTs) for growth and biomass parameters

4.2.5 Genetic parameters of variability

4.3 CORRELATION COEFFICIENT ANALYSIS

4.4 GENETIC DIVERGENCE

4.1 STUDIES ON PHENOTYPIC VARIATION

Candidate Plus Trees showed notable variation for phenotypic traits. Variations for the various characteristics are presented in Table 2.

Table 2: Phenotypic variation among different Candidate Plus Trees (CPTs).

CPTs	Tree height (m)	Clear bole height (m)	Diameter at breast height (cm)
CPT-1	28.14	2.84	32.14
CPT-2	27.19	2.14	31.14
CPT-3	28.24	2.35	30.14
CPT-4	24.56	2.74	30.12
CPT-5	28.17	2.78	32.14
CPT-6	25.80	2.14	32.78
CPT-7	21.38	2.35	31.24
CPT-8	25.45	2.47	31.45
CPT-9	26.70	2.59	32.15
CPT-10	25.14	2.14	32.54
CPT-11	20.48	2.12	28.45
CPT-12	25.18	2.35	32.15
CPT-13	26.82	2.32	31.25
CPT-14	22.51	2.14	30.12
CPT-15	26.84	2.45	32.14
CPT-16	24.81	2.68	31.98
CPT-17	21.84	2.58	29.15
CPT-18	23.82	2.67	31.25
CPT-19	22.17	2.91	31.45
CPT-20	20.45	2.15	28.12
CPT-21	23.57	2.37	31.65
CPT-22	29.01	2.91	33.12
CPT-23	27.19	2.81	28.14
CPT-24	27.48	2.15	28.98
CPT-25	24.19	2.14	30.45
CPT-26	26.17	2.36	31.45
CPT-27	24.46	2.45	30.50
CPT-28	28.17	2.65	33.14
CPT-29	26.17	2.56	32.54

CPT-30	23.14	2.35	30.12
CPT-31	25.14	2.14	31.25
CPT-32	26.01	2.75	32.15
CPT-33	25.17	2.64	31.8
CPT-34	22.00	2.12	30.89
CPT-35	23.14	2.34	31.46
CPT-36	26.14	2.75	31.91
CPT-37	27.01	2.85	32.94
CPT-38	27.15	2.80	32.98
CPT-39	28.00	2.14	32.9
CPT-40	27.82	2.65	32.75

4.1.1 Tree height (m)

Highest tree height was noted for CPT-22 with a value of 29.01 m followed by CPT-3, CPT-5 and CPT-28 with values of 28.24m, 28.17m and 28.17m respectively. The minimum tree height was recorded for CPT-20 with value of 20.45m (Table 2).

4.1.2 Clear bole height (m)

Clear bole height was observed maximum in CPT-19 and CPT-22 with value of 2.91m followed by CPT-1and CPT-37 with mean value of 2.84m and 2.85m respectively. Whereas, the minimum clear bole height was noted in CPT-34 with value of 2.12m (Table 2).

4.1.3 Diameter at breast height (cm)

Perusal of Table 2 revealed that the highest diameter at breast height was noticed in CPT-28 with value of 33.14cm. whereas the lowest value was found for CPT-20 with the value of 28.12cm.

Significant variation was observed among different Candidate Plus Trees (CPTs) for growth parameters including tree height, clear bole height and diameter at breast height (DBH). The maximum tree height was recorded in CPT-22 (29.01m), followed by CPT-3, CPT-5 and CPT-28 each exceeding 28m. The lowest height was noted in CPT-20 (20.45m). Similarly, clear bole height ranged from 2.12m in CPT-34 to 2.91m in CPT-19 and CPT-22. For DBH, the highest value was recorded in CPT-28 (33.14cm), while the lowest was in CPT-20 (28.12cm). These results are similar with earlier findings by Singh (2021), who reported variation in tree height ranging from 18.47m to 28.70m and clear bole height between 2.33m and 3.19m among twelve provenances of *Toona ciliata*. Furthermore the present findings align with those of Kumari (2015), who observed DBH of *T. ciliata* values ranging from 25.5cm to 66.9cm.

4.2 GENETIC VARIABILITY STUDIES

4.2.1 Analysis of variance

At the 5 percent level of significance, analysis of variance (ANOVA) revealed significant differences for all the characters of candidate plus trees, including seed length, seed width, seed thickness, 100 seed weight, seedling height, shoot length, collar diameter, root length, fresh shoot weight, dry shoot weight, fresh root weight and dry root weight. This suggests that there is a wide range of variation among the CPTs (Appendix I).

4.2.2 Mean performance of different Candidate Plus Trees (CPTs) for seed parameters.

The data in Table 3 demonstrated differences in seed parameters across 40 Candidate Plus Trees. Plates 2 and 3 exhibit morphological variations in seed properties among CPTs.

4.2.2.1 Seed length with wings (mm)

Seeds collected from CPT-2 recorded maximum seed length (19.74mm), the values observed in CPT-1(18.14mm), CPT-5 (18.14mm), CPT-6 (18.18mm), CPT-7 (18mm) and CPT-25(18.57mm) were also found to be statistically at par with each other.

The lowest seed length was observed for CPT-33 with mean value of 12.17mm (Table3) (Plate 1).

4.2.2.2 Seed length without wings (mm)

The seed length was also calculated after dewinging the seeds to reflect the actual seed length.

Seeds collected from CPT-6 recorded maximum seed length (6.31mm) and was found statistically at par with CPT-14(6.24mm).

The minimum seed length was observed for CPT-8 with mean value of 5.04mm (Table 3).

4.2.2.3 Seed width (mm)

The seeds collected from CPT-26 revealed the maximum seed width with mean value of 4.71mm.

Seed collected from CPT-6 (4.37mm), CPT-25 (4.27mm) and CPT-27(4.34mm) were found statistically at par with each other for seed width.

Similarly, seed collected from CPT-1(4.04mm), CPT-2(4.17mm), CPT-5(4.03mm), CPT-12(4.04mm), CPT-30(4.07mm) and CPT-34(4.12mm) were statistically at par with each other.

On the other hand, the minimum seed width was exhibited by the seeds collected from CPT-4 with mean value 3.10mm. (Table 3) (Plate 1).

4.2.2.4 Seed thickness (mm)

The highest seed thickness was observed in CPT-17 (1.75mm), which was statistically comparable to CPT-20 and CPT-30, both recorded a mean thickness of 1.7mm.

Whereas, the minimum seed thickness was recorded for CPT-32 and CPT-21 with mean value of 1.25mm (Table 3).

4.2.2.5 100 seed weight (g)

This analysis revealed significant differences among the CPTs for 100 seed weight. The highest 100 seed weight among the different genotypes was recorded for CPT-5 with mean value of 0.31g.

100 seed weight of CPT-1 (0.28g), CPT-7 (0.28g), CPT-19 (0.29g) and CPT-38 (0.28g) was statistically at par with each other.

The lowest value was exhibited by the seeds collected from CPT-3and CPT-40 with mean value of 0.21g (Table 3).

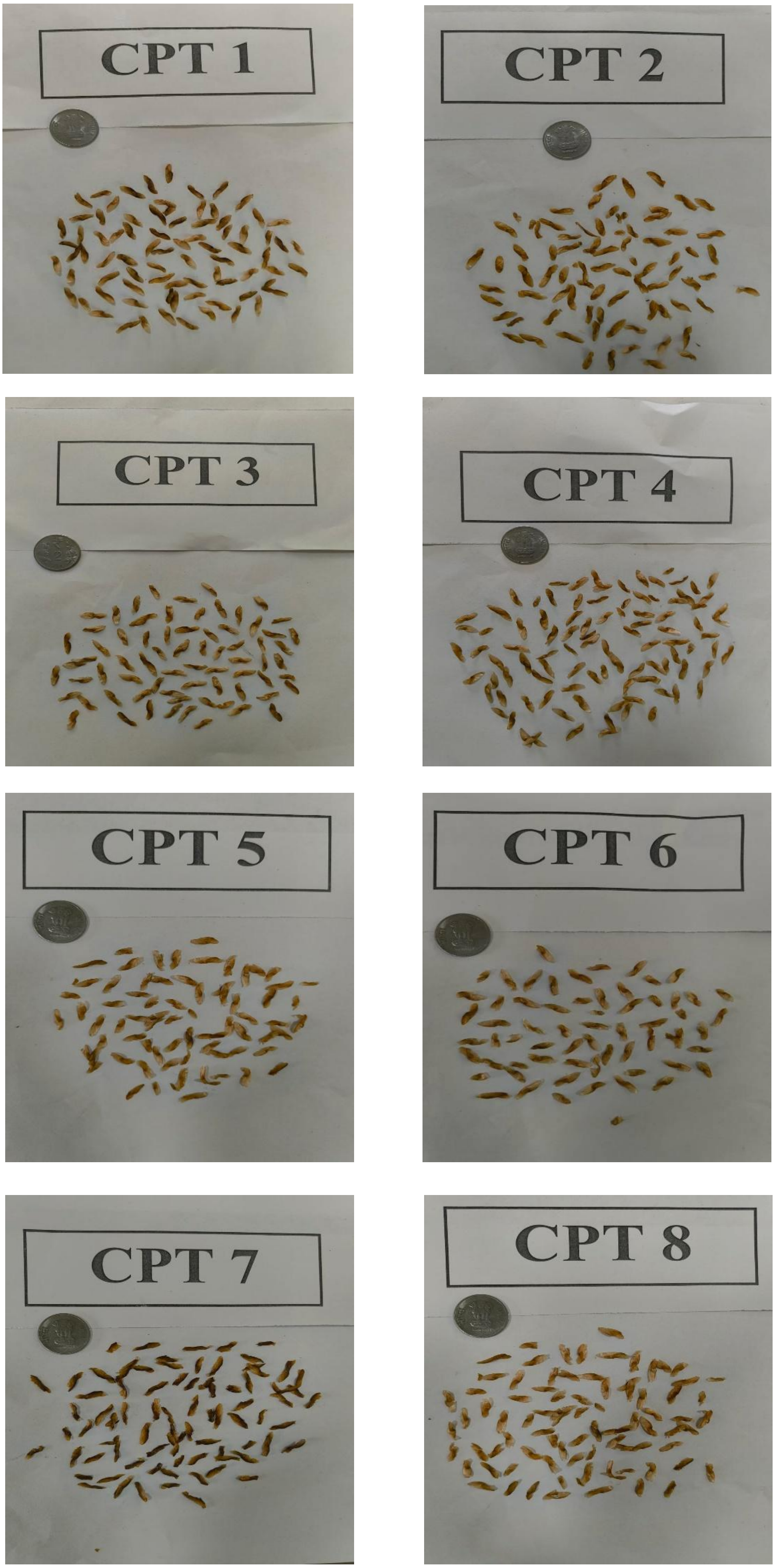
4.2.2.6 Seed germination percentage (%)

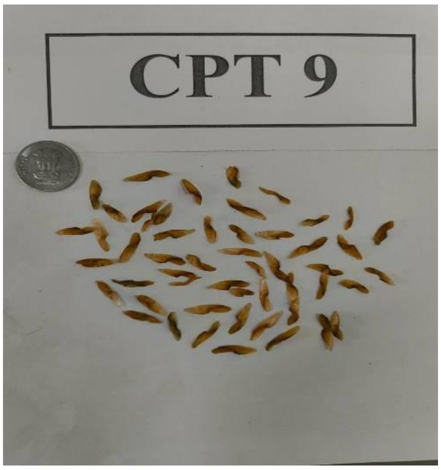
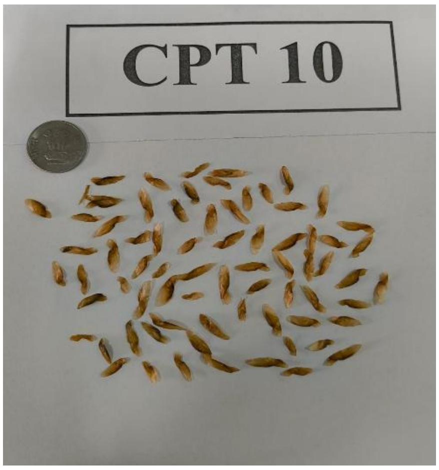
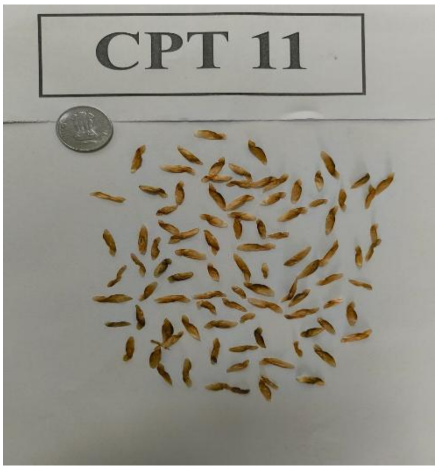
The data obtained during seed germination studies was analyzed for its variation among candidate plus trees, which revealed substantial variances between themselves.

Seed collected from CPT-4 (78.89%), CPT-13 (78.89%), CPT-18 (78.89%) registered the maximum germination percentage and was statistically at par with CPT-2 (77.78%) and CPT-10 (77.78%). These genotypes were statistically superior to the rest of the locations and were followed by CPT-1 (74.44%) and CPT-11 (73.33%).

Whereas CPT-34 (50%) and CPT-37 (50%) attained minimum seed germination percentage (Table 3).

Plate 1: Variation in seed morphology among different CPT's




CPT 9

CPT 10

CPT 11

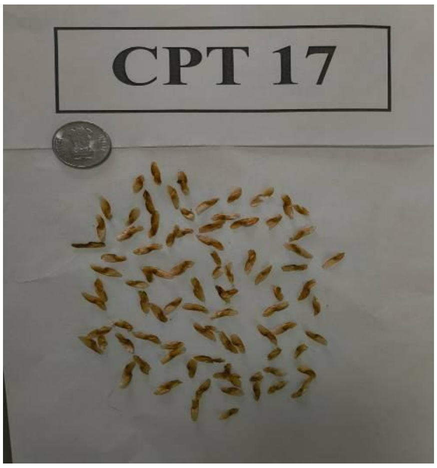
CPT 12

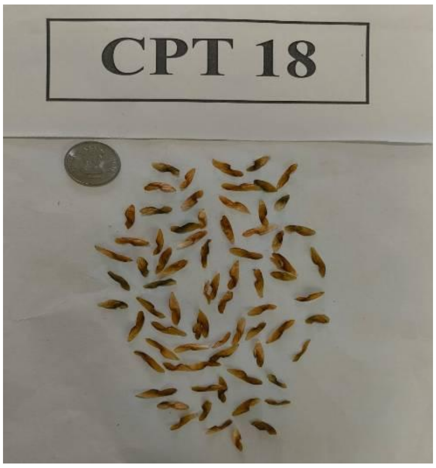
CPT 13

CPT 14

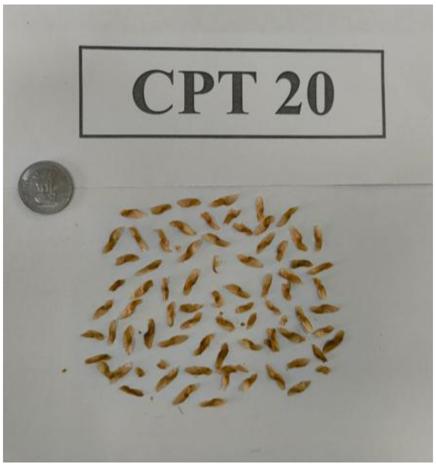
CPT 15

CPT 16

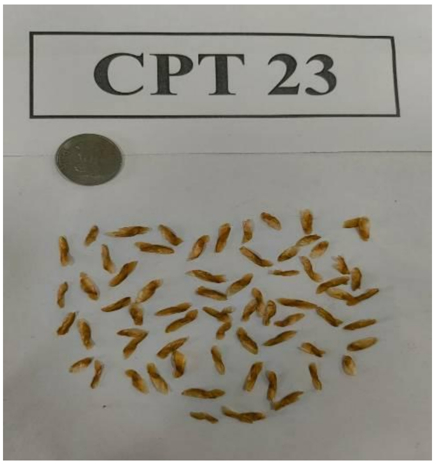

CPT 17

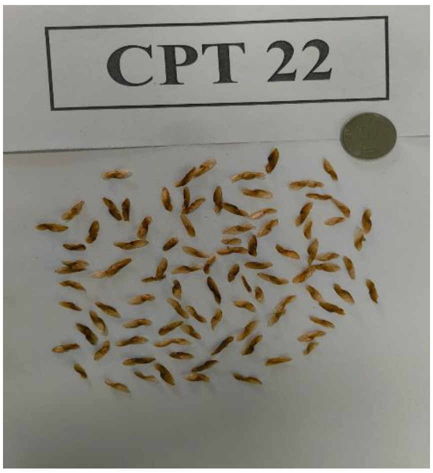

CPT 18


CPT 19

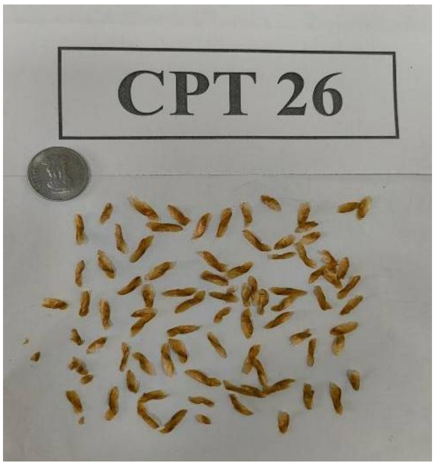
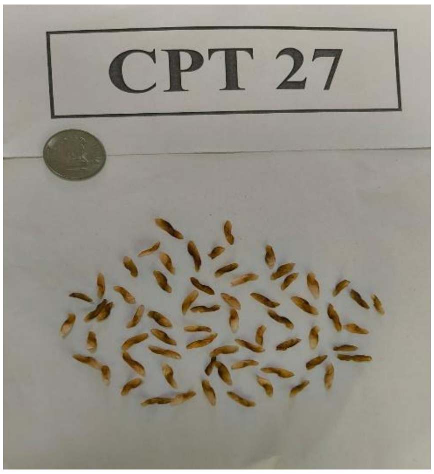

CPT 20


CPT 21


CPT 23


CPT 22


CPT 24


CPT 25

CPT 26

CPT 27

CPT 28

CPT 29

CPT 30

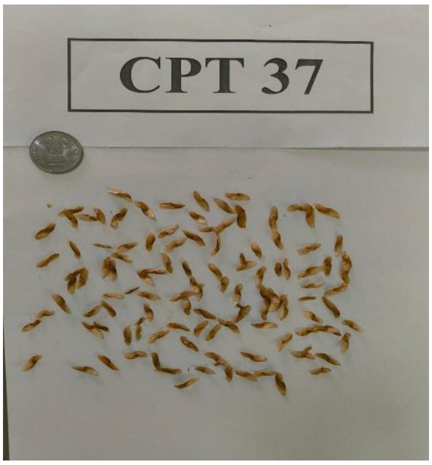
CPT 31

CPT 32


CPT 33

CPT 34

CPT 35

CPT 36

CPT 37

CPT 38

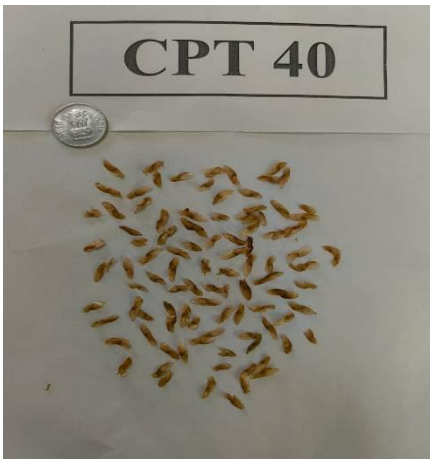
CPT 39

CPT 40

Table 3: Variation studies in seed parameters among different Candidate Plus Trees (CPTs).

CPTs	Seed length (with wing) (mm)	Seed length (without wing) (mm)	Seed width (mm)	Seed thickness (mm)	100 Seed weight (g)	Seed germination (%)
CPT 1	18.14	5.72	4.04	1.32	0.28	74.44
CPT 2	19.74	5.67	4.17	1.30	0.23	77.78
CPT 3	17.58	5.33	3.74	1.28	0.27	65.56
CPT 4	17.16	5.67	3.10	1.35	0.26	78.89
CPT 5	18.14	5.17	4.03	1.40	0.31	64.44
CPT 6	18.18	6.31	4.37	1.38	0.24	68.89
CPT 7	18.00	6.05	3.97	1.42	0.28	71.11
CPT 8	13.85	5.04	3.45	1.45	0.24	57.78
CPT 9	15.76	5.52	3.14	1.50	0.25	71.11
CPT 10	16.27	5.31	3.84	1.48	0.26	77.78
CPT 11	16.37	5.64	3.71	1.52	0.25	73.33
CPT 12	15.17	5.37	4.04	1.55	0.23	70.00
CPT 13	14.16	5.18	3.75	1.53	0.27	78.89
CPT 14	13.17	6.24	3.01	1.57	0.25	70.00
CPT 15	16.85	5.17	3.74	1.60	0.26	71.11
CPT 16	16.07	5.45	4.00	1.62	0.23	65.56
CPT 17	14.27	5.28	3.25	1.75	0.24	70.00
CPT 18	15.19	6.00	3.64	1.65	0.24	78.89
CPT 19	16.68	5.72	3.85	1.68	0.29	72.22
CPT 20	13.79	5.37	3.15	1.70	0.27	71.11
CPT 21	15.90	5.46	3.54	1.25	0.27	57.78
CPT 22	15.60	5.17	3.45	1.30	0.26	67.78
CPT 23	14.38	5.16	3.39	1.35	0.24	62.22
CPT 24	16.07	5.37	3.67	1.40	0.27	67.78
CPT 25	18.57	5.19	4.27	1.45	0.26	65.56

CPT 26	16.36	5.17	4.71	1.50	0.25	70.00
CPT 27	15.60	5.13	4.34	1.55	0.26	71.11
CPT 28	17.59	5.64	3.75	1.60	0.24	73.33
CPT 29	14.51	5.37	3.67	1.65	0.25	68.89
CPT 30	17.52	5.66	4.07	1.70	0.27	62.22
CPT 31	14.28	5.13	3.64	1.28	0.26	64.44
CPT 32	16.18	5.46	3.75	1.25	0.26	67.78
CPT 33	12.17	5.17	3.18	1.37	0.24	67.78
CPT 34	13.35	5.44	4.12	1.42	0.21	50.00
CPT 35	15.65	5.74	4.01	1.47	0.23	70.00
CPT 36	14.82	5.34	3.56	1.52	0.27	63.33
CPT 37	14.24	5.11	3.71	1.57	0.24	50.00
CPT 38	13.84	5.60	3.18	1.63	0.28	68.89
CPT 39	14.67	5.34	3.67	1.68	0.26	62.22
CPT 40	13.48	5.81	3.12	1.58	0.21	68.89
$CD_{0.05}$	**0.621**	**0.22**	**0.156**	**0.54**	**0.012**	**2.921**

The data presented in table 3 demonstrate significant variability among the Candidate Plus Trees (CPTs) in terms of seed characteristics. Seed length with wings ranged from 12.17mm to 19.74mm, while seed length without wings varied between 5.04mm and 6.24mm. Seed width and seed thickness ranged from 3.10mm to 4.71mm and 1.25mm to 1.75mm, respectively. The 100 seed weight showed notable differences across CPTs, ranging from 0.21g to 0.31g and germination percentage varied widely, from 50% to 78.89%. These results align well with findings reported by Javaid (2023), who documented *Toona ciliate* seed width with wings between 3.41mm and 5.29mm, seed width without wings from 2.15mm to 3.21mm and seed weight in the range of 0.15g to 0.36g. Similarly, Singh and Gupta (2017) observed 100-seed weight of *Toona ciliata* ranging from 0.18g to 0.31g. Significant variation in germination percentage among progenies, as observed in the current study, is also supported by Javaid (2023), who reported a range from 25.54% to 96.67%.

4.2.3 Variation studies in seed germination parameters among different Candidate Plus Trees (CPTs).

4.2.3.1 Germination Time (G.T.)

Germination time for forty Candidate Plus Trees (CPTs) showed minimal variation, ranging from 14.97 to 15.81 days. CPT-7 had the fastest germination (14.97 days), while CPT-32 was the slowest (15.81 days). Since the critical difference was not applicable, these observed differences in germination time among the CPTs were not statistically significant (Table 4).

4.2.3.2 Germination Index (G.I.)

Germination Index ranged from 21.94 to 38.79, indicating a moderate level of variation in seed germination performance. The highest germination index was recorded for CPT-2 (38.79) statistically at par with CPT-10 (38.63) and CPT-7 (38.32).

The lowest Germination Index was observed for CPT-33 (21.94) (Table 4).

4.2.3.3 Time Spread of Germination (T.S.G.)

Time spread of germination ranged from 12.33 to 20.33. The maximum TSG was observed in CPT-4 and CPT-18 both recording a value of 20.33.

The lowest TSG was recorded for CPT-34 with a value of 12.33 (Table 4).

4.2.3.4 Germination energy (G.E.)

Germination energy ranged from 32.22% to 58.89%. The top performers achieving 58.89% were CPT-1, CPT-7 and CPT-15. The values of germination energy for CPT-2, CPT-4, CPT-5, CPT-10, CPT-11, CPT-12, CPT-13 and CPT-14 were found to be statistically at par with each other ranging from 51.11% to 55.56%.

CPT-37 had the lowest germination energy at 32.22% (Table 4).

4.2.3.5 Vigour Index (V.I.)

The Vigour Index across the 40 CPTs ranged from 2180.50 to 4231.89. The highest vigour index was recorded for CPT-2 (4231.89) statistically at par with CPT-1 (4019.26) and CPT-3 (3460.68).

The lowest vigour index was observed in CPT-31 (2180.50) (Table 4).

4.2.3.6 First Day of Germination (F.D.G.)

First day of germination (F.D.G.) across the CPTs ranged from 2.33 to 5.67. The earliest germination (lowest F.D.G. value) was recorded for CPT-37(2.33).

The slowest germination (highest F.D.G.) was observed in CPT-2, CPT-7 and CPT-10 with mean value of 5.67 (Table 4).

4.2.3.7 Last Day of Germination (L.D.G.)

Last day of germination (L.D.G.) in 40 CPTs ranged from 15.00 to 23.67. Slowest germination (highest L.D.G.) was observed for CPT-4, CPT-13 and CPT-18 with mean value of 23.67.

The earliest completion of germination (lowest L.D.G.) was recorded for CPT-34 and CPT-37 with mean value of 15.00 (Table 4).

Table 4: Variation studies in seed germination parameters.

CPTs	Germination Time	Germination Index	Time Spread of Germination	Germination Energy	Vigour Index	Mean FDC	Mean LDG
CPT-1	15.23	36.32	17.33	58.89	4019.26	5.00	22.33
CPT-2	15.13	38.79	17.67	53.33	4231.89	5.67	23.33
CPT-3	15.02	34.26	14.33	46.67	3460.68	5.33	19.67
CPT-4	15.75	33.08	20.33	55.56	3927.88	3.33	23.67
CPT-5	15.28	31.08	15.67	53.33	3222.22	3.67	19.33
CPT-6	15.21	34.50	16.00	51.11	3475.44	4.67	20.67
CPT-7	14.97	38.32	15.67	58.89	3459.56	5.67	21.33
CPT-8	15.07	29.06	13.67	36.67	2876.18	3.67	17.33
CPT-9	15.42	32.37	16.67	48.89	3606.76	4.67	21.33
CPT-10	15.19	38.63	17.67	52.22	3818.11	5.67	23.33
CPT-11	15.24	34.69	17.33	51.11	3850.00	4.67	22.00
CPT-12	15.39	33.08	16.33	54.44	3490.20	4.67	21.00
CPT-13	15.66	33.47	19.67	51.11	3968.90	4.00	23.67
CPT-14	15.30	33.56	16.33	52.22	3176.60	4.67	21.00
CPT-15	15.00	37.37	16.33	58.89	3692.80	5.00	21.33

CPT-16	15.08	32.75	15.00	46.67	3376.11	4.67	19.67
CPT-17	15.45	30.64	17.67	50.00	3278.10	3.33	21.00
CPT-18	15.79	32.23	20.33	52.22	3703.04	3.33	23.67
CPT-19	15.40	32.01	17.33	46.67	3481.83	4.33	21.67
CPT-20	15.27	33.61	16.67	51.11	3346.49	4.67	21.33
CPT-21	15.08	28.38	13.67	37.78	2899.87	3.67	17.33
CPT-22	15.25	32.48	16.00	47.78	3739.98	4.33	20.33
CPT-23	15.30	28.35	15.33	42.22	3398.58	3.33	18.67
CPT-24	15.32	30.82	16.67	50.00	3315.69	3.67	20.33
CPT-25	15.29	28.41	16.33	38.89	3381.36	3.33	19.67
CPT-26	15.40	30.75	17.00	46.67	3658.90	4.00	21.00
CPT-27	15.48	31.68	17.33	50.00	3235.51	4.00	21.33
CPT-28	15.50	31.63	18.33	47.78	3668.70	3.67	22.00
CPT-29	15.48	30.22	17.00	45.56	3745.55	3.67	20.67
CPT-30	15.44	26.12	15.33	36.67	3206.93	3.33	18.67
CPT-31	15.67	26.12	16.33	41.11	3338.22	3.00	19.33
CPT-32	15.81	25.77	17.67	42.22	3226.33	2.67	20.33
CPT-33	15.74	26.12	17.67	41.11	3426.96	2.67	20.33
CPT-34	15.43	21.94	12.33	34.44	2180.50	2.67	15.00
CPT-35	15.37	31.84	17.00	48.89	3637.20	4.00	21.00
CPT-36	15.60	26.48	15.67	42.22	2986.01	3.33	19.00
CPT-37	15.35	22.14	12.67	32.22	2184.00	2.33	15.00
CPT-38	15.64	28.19	17.33	43.33	3089.72	3.33	20.67
CPT-39	15.59	26.40	15.33	38.89	2876.43	3.33	18.67
CPT-40	15.47	30.06	16.67	42.22	3300.52	4.00	20.67
$CD_{0.05}$	**N/A**	**1.38**	**0.61**	**2.03**	**145.813**	**0.14**	**0.85**

Among Candidate Plus Trees (CPTs), germination time displayed minimal, non-significant variation (14.97 to 15.81 days), with CPT-7 being the fastest and CPT-32 the slowest. In contrast, germination energy showed considerable variability (32.22% to 58.89%), with CPT-1, CPT-7 and CPT-15 achieving the highest (58.89%), while CPT-37 recorded the lowest (32.22%). Germination Index varied moderately (21.94 to 38.79), with CPT-2 having the highest and CPT-33 the lowest. Time spread of germination ranged from 12.33 to 20.33, with CPT-4 and CPT-18 showing the maximum spread and CPT-34, the minimum. Vigor Index spanned from 2180.50 to 4231.89, with CPT-2 exhibiting the highest vigor and CPT-31 the lowest. First day of germination ranged from 2.33 to 5.67 days (CPT-37 earliest, CPT-2, CPT-7, CPT-10 slowest) and last day of germination varied from 15.00 to 23.67 days (CPT-34 and CPT-37 earliest completion, CPT-4, CPT-13, CPT-18 slowest completion).

4.2.4 Mean performance of different Candidate Plus Trees (CPTs) for growth and biomass parameters

The growth and biomass parameters have been categorized into two main groups: seedling characteristics and biomass characteristics. Seedling characteristics include seedling height, shoot length, root length and collar diameter, while biomass characteristics encompass shoot fresh weight, shoot dry weight, root fresh weight, root dry weight and both fresh and dry root-to-shoot weight ratios. These categories are discussed under the following subheadings.

4.2.4.1 Growth parameters after 2 months

Evaluation of seedling growth measures after two months offers important information about the species initial growth, vigour and growth potential.

4.2.4.1.1 Shoot length (cm)

The maximum shoot height among genotypes was exhibited by CPT-2 (19.74cm).

Similarly, the values exhibited by CPT-16(18.64cm), CPT-17(18.74cm), CPT-18(18.37cm), CPT-19(18.71cm) and CPT-21 (18.34cm) were statistically at par with each other.

Minimum shoot height of 13.45cm was observed in CPT-40 (Table 5) (Plate 2).

4.2.4.1.2 Number of leaves per plant

The data revealed that the average number of leaves per plant varied from 17.32 to 26.56 with significant differences among the seedlings. The maximum value 26.56 was found in CPT-6.

Minimum average no of leaves per plant 17.32 were registered in CPT- 28. (Table 5) (Plate 2).

4.2.4.1.3 Seedling collar diameter (mm)

The seedlings obtained from CPT-21 recorded the maximum seedling collar diameter with mean value of 2.74mm. Whereas, minimum collar diameter was recorded seedlings of CPT-39 with mean value of 0.91mm (Table 5).

Table: 5 Variation in growth parameters among different Candidate Plus Trees (CPTs) of *Toona ciliata* after 2 months

CPT	Shoot height(cm)	Number of leaves per plant	Seedling collar diameter(mm)
CPT-1	17.14	21.23	2.14
CPT-2	19.74	22.97	2.64
CPT-3	17.12	17.8	2.01
CPT-4	16.17	22.53	1.34
CPT-5	17.84	23.98	2.07
CPT-6	17.18	26.56	2.04
CPT-7	16.74	18.74	1.68
CPT-8	17.18	17.12	1.85
CPT-9	17.94	17.56	1.82
CPT-10	16.74	18.72	1.24
CPT-11	18.07	24.62	1.97
CPT-12	17.37	23.13	1.64
CPT-13	17.94	22.69	1.67
CPT-14	16.71	19.42	1.32
CPT-15	16.74	19.87	1.38
CPT-16	18.64	20.43	2.32
CPT-17	18.74	25.12	2.14
CPT-18	18.37	24.72	2.08
CPT-19	18.71	23.64	2.34
CPT-20	17.37	23.51	2.04
CPT-21	18.34	23.01	2.74
CPT-22	17.64	21.75	1.97
CPT-23	17.04	22.57	1.85
CPT-24	17.37	22.43	1.75
CPT-25	17.34	23.86	1.28
CPT-26	16.84	19.88	1.34
CPT-27	16.71	19.32	1.15
CPT-28	17.94	17.32	1.84

CPT-29	18.00	18.9	1.94
CPT-30	17.94	18.62	1.84
CPT-31	14.00	20.55	0.98
CPT-32	14.74	20.36	1.04
CPT-33	14.37	22.17	1.09
CPT-34	13.74	21.52	1.54
CPT-35	14.07	23.02	1.34
CPT-36	14.97	23.67	1.54
CPT-37	14.84	22.51	1.74
CPT-38	14.00	19.82	0.99
CPT-39	13.94	18.39	0.91
CPT-40	13.45	20.45	0.98
$CD_{0.05}$	**0.746**	**0.869**	**0.87**

The data presented in Table 4 reveals that after 2 months of germination the shoot height ranged from 19.74cm to 13.45cm, average number of leaves per plant ranged from 26.56 to 17.32 and plant collar diameter ranged 2.74mm to 0.91mm.

4.2.4.2 Growth parameters after 4 months

Evaluation of seedling growth measures after four months offers important information about the species initial growth, vigour and growth potential.

4.2.4.2.1 Shoot height (cm)

The highest value for shoot height was recorded for seedlings obtained from CPT-2 (30.4cm) found to be statistically at par with CPT-16 (29.74cm).

Similarly, the value exhibited by CPT-1 (28.4cm), CPT-5 (28.17cm),CPT-6 (28.7cm), CPT-11 (28.13cm), CPT-17 (28.7cm), CPT-22 (28.34cm), CPT-24 (28.07cm), CPT-29 (28.07cm) and CPT-30 (28.97cm) were statistically at par. Minimum shoot height of 24.4cm was observed for by CPT-38. (Table 6) (Plate 2).

4.2.4.2.2 Number of leaves per plant

The data revealed that the average number of leaves per plant varied from 53.98 to 35.89 having significant differences among the CPTs. The maximum value 53.98 was found in CPT-6.

Minimum average number of leaves per plant 35.89 was registered in cCPT-31. (Table 6) (Plate 2).

4.2.4.2.3 Seedling collar diameter (mm)

The seedlings obtained from the seeds of CPT-21 recorded the maximum seedling collar diameter with mean value of 4.24mm. Whereas, minimum collar diameter was noticed in seedlings of CPT-15 with mean value of 2.97mm (Table 6).

Table: 6 Variation in growth parameters among different Candidate Plus Trees (CPTs) after 4 months

CPT	shoot height(cm)	number of leaves per plant	seedling collar diameter(mm)
CPT-1	28.40	44.67	3.98
CPT-2	30.40	45.73	4.14
CPT-3	27.38	37.32	3.84
CPT-4	27.32	45.18	3.14
CPT-5	28.17	48.46	2.98
CPT-6	28.70	53.98	3.01
CPT-7	27.18	38.11	3.05
CPT-8	25.00	41.38	3.15
CPT-9	25.30	41.07	3.45
CPT-10	26.40	38.33	3.01
CPT-11	28.13	50.32	3.54
CPT-12	26.74	48.53	3.64
CPT-13	26.70	44.13	3.34
CPT-14	25.67	39.56	2.98
CPT-15	25.74	40.28	2.97
CPT-16	29.74	41.57	3.98

CPT-17	28.70	51.34	3.84
CPT-18	27.67	50.06	4.12
CPT-19	27.347	49.67	3.97
CPT-20	26.74	49.30	3.75
CPT-21	27.74	48.63	4.24
CPT-22	28.34	42.77	4.14
CPT-23	27.97	43.94	3.85
CPT-24	28.07	42.93	3.65
CPT-25	27.46	47.31	3.75
CPT-26	26.74	38.75	3.14
CPT-27	26.94	38.12	3.34
CPT-28	27.09	36.54	3.67
CPT-29	28.07	37.38	3.85
CPT-30	28.97	37.05	3.73
CPT-31	25.74	35.89	3.17
CPT-32	25.94	35.95	3.54
CPT-33	24.67	45.78	3.41
CPT-34	25.18	44.58	3.35
CPT-35	25.34	45.67	3.51
CPT-36	24.65	46.03	3.42
CPT-37	25.34	43.95	3.05
CPT-38	24.40	39.42	2.98
CPT-39	25.43	37.11	2.85
CPT-40	25.17	41.32	3.00
$CD_{0.05}$	**1.199**	**1.839**	**0.139**

The data presented in Table 6 reveals that after 4 months of germination the shoot height ranged from 30.4cm to 24.4cm, average no of leaves per plant ranged from 35.89 to 53.98 and plant collar diameter ranged 4.24mm to 2.97mm.

4.2.4.3 Growth and biomass parameter after 6 months

The growth and biomass parameters have been divided into two categories i.e. seedling characters (shoot length, root length, seedling collar diameter and number of leaves per plant) and biomass characters (shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, root: shoot fresh weight ratio and root: shoot dry weight ratio), which are covered under the following headings:

4.2.4.3.1 Shoot length (cm)

The maximum seedling height among genotypes was exhibited by CPT-1 and CPT-29 (39.74cm) found to be statistically at par with CPT-2(38.17cm), CPT-7 (38.74cm), CPT-16 (38.94cm), CPT-24 (39.4cm), CPT-25 (38.67cm) and CPT-26 (38.74cm).

Whereas, the minimum seedling height of 33.54cm was observed in CPT-36. (Table 7) (Plate 2).

4.2.4.3.2 Root length (cm)

The seedlings obtained from the seeds of CPT-22 revealed the maximum root length with mean value of 17.24cm which was statistically at par with CPT-35 (16.84cm), whereas CPT-14 showed minimum root length having mean value of 8.41cm (Table 7).

4.2.4.3.3 Seedling length (cm)

The maximum seedling height among genotypes was exhibited by CPT-22 (55.18cm) statistically at par with CPT-2 (54.41cm), CPT-29 (54.37cm).

Whereas, the minimum seedling height of 43.61cm was exhibited by CPT-34 (Table 7).

4.2.4.3.4 Number of leaves per plant

The data revealed that the average number of leaves per plant varied from significantly from 50.41 to 75.81. The maximum value was found in CPT-6 (75.81) which was statistically at par with CPT-17 (73.98).

Minimum average number of leaves per plant (50.41) were found in CPT-39. (Table 7) (Plate 2).

4.2.4.3.5 Seedling collar diameter (mm)

It is evident from the data presented in Table 6 that the collar diameter of the seedlings ranged from 4.68mm to 6.11mm. The highest collar diameter was observed in CPT-21 (6.11mm), statistically at par with CPT-2 (5.98mm), CPT-18 (5.99mm) and CPT-22 (5.99mm).

The minimum value for this trait was recorded in CPT-40 (4.68mm) (Table7).

Table 7: Variation in growth parameters among different Candidate Plus Trees (CPTs) of *Toona ciliata* after 6 months

CPT	Shoot length (cm)	Root length (cm)	Seedling length (cm)	No of leaves per plant	Seedling collar diameter (mm)
CPT-1	39.74	14.25	53.99	61.74	5.59
CPT-2	38.17	16.24	54.41	67.38	5.98
CPT-3	37.37	15.42	52.79	58.53	5.28
CPT-4	37.34	12.45	49.79	65.34	5.19
CPT-5	38.14	11.86	50.00	71.39	5.12
CPT-6	37.97	12.48	50.45	75.81	5.19
CPT-7	38.74	9.91	48.65	59.22	5.28
CPT-8	36.47	13.31	49.78	55.32	5.38
CPT-9	37.14	13.58	50.72	55.87	5.39
CPT-10	36.74	12.35	49.09	60.52	5.28
CPT-11	37.19	15.31	52.50	72.64	5.61
CPT-12	37.46	12.4	49.86	70.48	5.48
CPT-13	36.47	13.84	50.31	63.71	5.39
CPT-14	36.97	8.41	45.38	57.54	5.15
CPT-15	36.14	15.79	51.93	59.41	5.22
CPT-16	38.94	12.56	51.5	60.86	5.89
CPT-17	38.14	8.69	46.83	73.98	5.82
CPT-18	37.15	9.79	46.94	71.05	5.99
CPT-19	37.67	10.54	48.21	69.88	5.88
CPT-20	35.14	11.92	47.06	68.95	5.79
CPT-21	36.74	13.45	50.19	66.93	6.11
CPT-22	37.94	17.24	55.18	62.73	5.99
CPT-23	38.15	16.47	54.62	63.95	5.88

CPT-24	39.40	9.52	48.92	62.18	5.81
CPT-25	38.67	12.91	51.58	65.43	5.79
CPT-26	38.74	13.53	52.27	55.9	5.18
CPT-27	34.54	10.96	45.5	55.06	5.22
CPT-28	35.67	14.36	50.03	53.45	5.31
CPT-29	39.74	14.63	54.37	54.86	5.38
CPT-30	38.14	13.4	51.54	54.33	5.81
CPT-31	35.44	16.36	51.8	61.57	5.28
CPT-32	34.15	13.45	47.6	60.95	5.28
CPT-33	35.67	14.89	50.56	65.87	5.19
CPT-34	34.15	9.46	43.61	63.96	5.16
CPT-35	35.12	16.84	51.96	66.12	5.48
CPT-36	33.54	13.61	47.15	67.95	5.15
CPT-37	33.94	9.74	43.68	61.57	5.14
CPT-38	34.01	10.84	44.85	53.46	4.99
CPT-39	34.64	11.59	46.23	50.41	4.79
CPT-40	34.94	12.97	47.91	59.56	4.68
$CD_{0.05}$	**1.598**	**0.548**	**2.07**	**2.828**	**0.192**

The data mentioned in table 7 reveals that shoot length varied from 33.54cm (CPT-36) to 39.74cm (CPT-1 and CPT-29). Root length ranged from 8.41cm (CPT-14) to 17.24cm (CPT-22). Seedling length (shoot length+ root length) varied from 43.61cm (CPT-34) to 55.18cm (CPT-22). The Number of Leaves per plant ranged from 50.41 (CPT-39) to 75.81 (CPT-6). Collar diameter showed was found in between 4.68mm (CPT-40) and 6.11mm (CPT-21).

4.2.4.3.6 Shoot fresh weight (g)

Data pertaining to fresh shoot weight depicted maximum average fresh shoot weight of 9.14 g in CPT-2, statistically at par with CPT-29 (8.97g) and CPT-27 (8.91g).

On the other hand, CPT-5 registered the minimum value of 6.54g. (Table 8).

4.2.4.3.7 Root fresh weight (g)

The data presented in table 7 depicted significant differences among Candidate Plus Trees for root fresh weight. For this parameter the variation ranged between 4.01g -7.17g. The analysis exhibited maximum fresh root weight in CPT-2 with a value of 7.17g.

The data also revealed that the values exhibited for this parameter by CPT-10 (6.84g), CPT-16 (6.84g), CPT-26 (6.71g) were also statistically at par with each other.

Whereas the minimum fresh root weight of 4.01 g was recorded in CPT-5 (Table 8).

4.2.4.3.8 Dry shoot weight (g)

Variation was found to be significant for dry shoot weight among the Candidate Plus Trees. CPT-2 registered maximum value of 3.89g for dry shoot weight which was found to be statistically at par with CPT-16 (3.84 g).

The least value for dry shoot weight (2.14g) was observed in CPT-11 and CPT-15 (Table 8).

4.2.4.3.9 Dry root weight (g)

It is apparent from the Table 7 that the values differed significantly among the Candidate Plus Trees and varied from 1.04g-2.74g. CPT-2 registered the highest value for dry root weight (2.74g).

Whereas, the minimum value was found in CPT-8 (1.04g) (Table 8).

4.2.4.3.10 Fresh Root/Shoot Ratio

A critical exegesis of data in Table 8 indicated the highest ratio of root-shoot fresh weight for CPT-1 and CPT-35 with mean value of 0.86 which was found statistically at par withCPT-16 (0.84g) and CPT 39 (0.85g).

CPT-5 and CPT-34 attained lowest mean value of 0.61g (Table 8).

4.2.4.3.11 Dry Root/Shoot Ratio

Data from table 7 revealed that the highest average dry root-shoot ratio was observed in CPT-31 with mean value of 0.76g.

Whereas, CPT-9 and CPT-18 attained lowest mean value of 0.34g. (Table 8).

Plate 2: Overview of seedlings in the field after 2,4 and 6 months

Table 8: Variation in biomass parameters among different Candidate Plus Trees (CPTs)

CPTs	Fresh weight (gm)		Dry weight (gm)		Root/Shoot ratio	
	Shoot	Root	Shoot	Root	Fresh	Dry
CPT-1	7.12	6.1	2.71	1.74	0.86	0.64
CPT-2	9.14	7.17	3.89	2.74	0.78	0.70
CPT-3	8.33	5.14	3.07	1.84	0.62	0.60
CPT-4	7.19	4.98	2.94	1.64	0.69	0.56
CPT-5	6.54	4.01	2.17	1.05	0.61	0.48
CPT-6	7.23	5.75	2.74	1.64	0.80	0.60
CPT-7	8.34	6.47	3.17	1.84	0.78	0.58
CPT-8	6.75	5.03	2.84	1.04	0.75	0.37
CPT-9	7.75	5.74	3.64	1.24	0.74	0.34
CPT-10	8.67	6.84	2.84	2.01	0.79	0.71
CPT-11	6.71	4.78	2.14	1.06	0.71	0.50
CPT-12	7.07	5.14	2.94	1.41	0.73	0.48
CPT-13	7.13	5.37	2.84	1.24	0.75	0.44
CPT-14	7.85	5.61	3.05	1.64	0.71	0.54
CPT-15	6.77	5.01	2.14	1.08	0.74	0.50
CPT-16	8.19	6.84	3.84	2.14	0.84	0.56
CPT-17	8.06	6.31	3.45	2.31	0.78	0.67
CPT-18	7.91	4.91	3.14	1.07	0.62	0.34
CPT-19	8.37	5.82	3.05	1.45	0.70	0.48
CPT-20	7.18	5.14	2.88	1.05	0.72	0.36
CPT-21	7.17	5.17	2.94	1.61	0.72	0.55
CPT-22	7.34	5.37	2.74	1.04	0.73	0.38
CPT-23	8.19	5.91	3.64	1.74	0.72	0.48
CPT-24	8.74	6.17	3.71	1.84	0.71	0.50
CPT-25	8.37	6.34	3.64	1.74	0.76	0.48
CPT-26	8.67	6.71	3.24	1.84	0.77	0.57

CPT-27	8.91	6.19	3.15	1.34	0.69	0.43
CPT-28	7.87	5.37	3.00	1.14	0.68	0.38
CPT-29	8.97	6.17	3.14	1.84	0.69	0.59
CPT-30	7.94	6.09	2.84	1.74	0.77	0.61
CPT-31	7.11	5.37	2.17	1.64	0.76	0.76
CPT-32	6.78	4.19	2.19	1.14	0.62	0.52
CPT-33	6.85	4.37	2.67	1.17	0.64	0.44
CPT-34	6.91	4.19	2.48	1.32	0.61	0.53
CPT-35	7.05	6.04	2.37	1.51	0.86	0.64
CPT-36	7.91	5.91	2.40	1.74	0.75	0.73
CPT-37	7.14	5.84	2.37	1.67	0.82	0.70
CPT-38	7.37	5.37	2.84	1.57	0.73	0.55
CPT-39	7.24	6.14	2.54	1.64	0.85	0.65
CPT-40	6.84	4.71	2.83	1.45	0.69	0.51
$CD_{0.05}$	**0.323**	**0.268**	**0.129**	**0.062**	**0.02**	**0.02**

The present study revealed significant variation among Candidate Plus Trees (CPTs) of *Toona ciliata* in various biomass-related parameters, including shoot and root weights and their respective ratios. The highest shoot fresh weight was recorded in CPT-2 (9.14g), statistically comparable to CPT-29 (8.97g) and CPT-27 (8.91g), while the minimum was noted in CPT-5 (6.54g). Similarly, CPT-2 also exhibited the maximum root fresh weight (7.17g), followed closely by CPT-10 and CPT-16 (6.84g) and CPT-26 (6.71g), all statistically at par with CPT-5 showing the lowest value (4.01g). Dry shoot weight was having maximum value in CPT-2 (3.89g), followed by CPT-16 (3.84g), whereas CPT-11 and CPT-15 exhibited the lowest values (2.14g). CPT-2 again led in dry root weight (2.74g), while CPT-8 (1.04g) recorded the lowest. The highest fresh root-to-shoot ratio was observed in CPT-1 and CPT-35 (0.86), statistically at par to CPT-16 and CPT-39, while CPT-5 and CPT-34 had the lowest (0.61). For dry root-to-shoot ratio, CPT-31 had the highest mean value (0.76), with CPT-9 and CPT-18 showing the lowest (0.34). These findings align with earlier studies indicating genetic variability in *T. ciliata* by Singh (2021) who reported significant variation in seedling traits such as height, collar diameter and number of leaves among different *Toona ciliata* provenances. Kaushik (1993) also recorded similar variations for collar diameter, seedling height in *Toona Ciliata.* Rana *et al.* (2009) identified considerable variation in seedling height, collar diameter and leaf number among 25 seed sources after 120 days of sowing, supporting the feasibility of early-stage selection under nursery conditions. Similarly Uppal and Singh (2010) reported significant variation in seed and seedling traits, particularly shoot and root lengths, traits such as seedling height, collar diameter and root-shoot biomass development were found to be genetically controlled and stable across environment in *Toona ciliata*.

4.2.5 Genetic parameters of variability

4.2.5.1 Estimates of phenotypic and genotypic coefficient of variability.

Understanding the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) is crucial for assessing the genetic diversity within a population. This assessment helps in developing effective breeding and selection strategies. In this study the PCV values were slightly higher than the GCV values, suggesting that both genetic makeup (genotype) and environmental factors contribute to the observed variation (Table 9 and 10).

Because environmental influences are unpredictable, relying solely on observable traits (phenotype) for selection requires caution. As per Sivasubramanian and Madhavamenon (1973), GCV and PCV values are categorized as:

* Low: Less than 10%

* Moderate: 10% to 20%

* High: Above 20%

The highest heritability was observed for 100 seed weight (99.99%), seed length with wing (95.34%), seed width (94.52%), seed thickness (95.08%) and germination percentage (93.17%), indicating strong genetic control and minimal environmental influence on these traits. The PCV and GCV values for these traits were also very close, suggesting that the phenotypic expression is largely governed by genetic factors. These traits also showed high genetic gain, particularly seed length with wing (22.1%), seed width (21.22%), seed thickness

(18.75%) and germination percentage (19.31%), making them suitable candidates for effective improvement through direct selection.

Seed length without wing exhibited moderate heritability (82.88%) and low genetic gain (10.4%), implying that while selection may be effective, progress would be slower (Table 9)

Table 9: Estimates of different parameters of variability for pod and seeds parameters of different Candidate Plus Trees (CPTs) of *Toona ciliata*.

Traits	GCV	PCV	Heritability(%) (Broad sense heritability)	Genetic advance (%)	Genetic gain (%)
seed length (with wing) (mm)	10.98	11.25	95.34	3.47	22.10
seed length (without wing)(mm)	5.54	6.09	82.88	0.56	10.40
seed width (mm)	10.59	10.89	94.52	0.78	21.22
seed thickness (mm)	8.91	9.57	95.08	0.27	18.75
100 seed weight (g)	7.15	7.17	99.99	0.03	14.77
germination (%)	9.71	10.06	93.17	13.17	19.31

GCV and PCV represents phenotypic and genotypic coefficient of variability, respectively.

4.2.5.2 Heritability

Heritability is a useful indicator for evaluating how much of genetic variance to overall phenotypic variance. Planning breeding programs with the required level of projected genetic advancement and researching the inheritance of quantitative traits are both aided by the information on heritability estimates. According to Robinson *et al.* (1949), heritability of 0-30% is low, 30-60% moderate and 60% and above high.

Table 10: Estimates of different parameters of variability for growth and biomass parameters of different Candidate Plus Trees (CPTs)

	Traits	GCV	PCV	Heritability(%) (Broad sense heritability)	Genetic advance (%)	Genetic gain (%)
Shoot height(cm)	after two months	9.70	10.08	92.63	3.22	19.23
	after four months	5.27	5.94	78.80	2.59	9.64
	after six months	4.47	5.20	73.77	2.91	7.91
Collar diameter (mm)	after two months	27.42	27.61	98.62	0.94	56.10
	after four months	11.51	11.76	95.84	0.81	23.22
	after six months	6.32	6.68	89.42	0.67	12.32
Number of leaves	after two months	11.18	11.45	95.24	4.8	22.47
	after four months	11.25	11.55	94.84	9.75	22.57
	after six months	9.94	10.32	92.78	12.36	19.73
	Shoot fresh weight (g)	9.52	9.86	93.13	1.44	18.92
	Root fresh weight (g)	13.62	13.93	95.55	1.53	27.43
	Shoot dry weight (g)	16.36	16.57	97.42	0.96	33.27
	root dry weight (g)	24.75	24.83	99.32	0.78	50.82
	fresh Root/Shoot Ratio	8.75	9.00	99.87	0.13	18.54
	dry Root/Shoot Ratio	19.89	20.74	99.76	0.22	42.72

GCV and PCV represents genotypic and phenotypic coefficient of variability, respectively.

4.2.5.3 Genetic advance

For a successful selection program knowing heritability alone is not enough. It's much more helpful to consider genetic advance alongside heritability. This is because high heritability and high genetic variability are both crucial for achieving greater genetic gain and genetic advance doesn't always directly correlate with either.Only the number of leaves at six months falls into the moderate GA category (12.36%), which indicates a mix of additive and non-additive genetic control and suggests a reasonable chance of improvement through selection, according to the classification by Johnson *et al.* (1955), where genetic advance as a percentage of mean is considered low (<10%), moderate (10–20%)

and high (>20%). Shoot height, collar diameter, biomass attributes are among the other variables that show minimal genetic advance (<10%), suggesting that they are probably controlled by non-additive gene action and may not react well to traditional phenotypic selection.(Table 9).

4.2.5.4 Genetic gain

Johnson *et al.* (1955) defined the range of genetic advancement as a percentage of the mean (genetic gain) as low (less than 10%), moderate (10-20%) and high (more than 20%).In root dry weight parameters(50.82%) exhibited high genetic gain.The moderate genetic gain was observed in shoot length(2 months) (19.23%) followed by shoot fresh weight (18.92%).whereas low genetic gain was observed in shoot height after four and six months (9.62 and 7.91%) (Table 9).

The present studies are supported by the findings of Dhiman (2018) also reported similar findings. He found coefficient of phenotypic and genotypic variability and broad sense heritability values 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. These results are in line 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.

Parthiban (2019) reported higher phenotypic coefficient of variance (PCV) values than their corresponding genotypic coefficient of variance (GCV) values. The heritability values were low ranging between 0.11 (clear bole height and number of branches) to 0.30 (plant height).

Uppal *et al.* (2010) examined that seedlings of all the sources were grown at the same place, variations occurring in seedling characters might be attributed to genetic differences. Results indicate that the root and shoot lengths come under genetic control, whereas germination percentage falls under environmental influence. Besides this, heritability (h^2), genetic advance and genetic gain were again higher for root and shoot lengths.

4.3 CORRELATION COEFFICIENT ANALYSIS

In addition to learning about the type and extent of variation it's critical to understand how characters relate to one another and how traits are determined to improve the effectiveness of direct and indirect selection and ultimately define the ideal plant type. Choudhary *et al.* (2017) claimed that as the development of one character will result in the concurrent modification of other related characteristics, knowledge of correlation is crucial to any improvement program.Correlation analysis was conducted to determine the extent and direction of relationships among various seed and seedling parameters in different Candidate Plus Trees (CPTs)

Seed length (with wing) exhibited significant positive correlations with several traits, including seed width (r = 0.584, p < 0.01), shoot length (r = 0.507, p < 0.01), seedling length (r = 0.452, p < 0.01), root fresh weight (r = 0.328, $p < 0.05$) and 100 seed weight (r = 0.335, $p < 0.05$).

Seed width was also positively correlated with root fresh weight (r = 0.359, $p < 0.05$) and shoot fresh weight (r = 0.295).

Shoot length showed a highly significant positive correlation with seedling length (r = 0.635, p < 0.01), shoot dry weight (r = 0.557, p < 0.01), shoot fresh weight (r = 0.439, p < 0.01) and seedling collar diameter (r = 0.518, p < 0.01). Seedling length was significantly correlated with root length (r = 0.818, p < 0.01) and collar diameter (r = 0.408, p < 0.01).

Strong positive correlations were observed among biomass traits. Shoot fresh weight showed a highly significant correlation with root fresh weight (r = 0.768, p < 0.01) and shoot dry weight (r = 0.739, p < 0.01), whereas root fresh weight correlated strongly with root dry weight (r = 0.770, p < 0.01). Additionally, dry root/shoot ratio was significantly correlated with root dry weight (r = 0.716, p < 0.01) and fresh root/shoot ratio (r = 0.494, p < 0.01).

On the other hand, many traits such as seed length without wing seed thickness and root length showed non-significant correlations with most other traits.

Table 11: Estimate of correlation coefficient for seed and seedling parameters among different Candidate Plus Trees (CPTs).

Parameters	Seed length (wing) (mm)	Seed length (without wing) (mm)	Seed width (mm)	Seed thickness (mm)	100 seed weight (g)	Shoot length (cm)	Root length (cm)	Seedling length (cm)	Seedling collar diameter (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Fresh root/shoot ratio	Dry root/shoot ratio
Seed length (wing) (mm)	1														
Seed length (without wing) (mm)	0.243^{NS}	1													
Seed width (mm)	0.584^{**}	-0.028^{NS}	1												
Seed thickness (mm)	-0.288^{NS}	0.087^{NS}	-0.121^{NS}	1											
100 seed weight (g)	0.335^{*}	-0.103^{NS}	0.026^{NS}	-0.078^{NS}	1										
Shoot length (cm)	0.507^{**}	0.151^{NS}	0.266^{NS}	-0.110^{NS}	0.178^{NS}	1									
Root length (cm)	0.206^{NS}	-0.273^{NS}	0.071^{NS}	-0.441^{**}	-0.078^{NS}	0.075^{NS}	1								
Seedling length (cm)	0.452^{**}	-0.125^{NS}	0.209^{NS}	-0.405^{**}	0.042^{NS}	0.635^{**}	0.818^{**}	1							
Seedling collar diameter (cm)	0.271^{NS}	-0.011^{NS}	0.084^{NS}	-0.068^{NS}	0.062^{NS}	0.518^{**}	0.141^{NS}	0.408^{**}	1						
Shoot fresh weight (g)	0.306^{NS}	0.040^{NS}	0.295^{NS}	0.138^{NS}	0.050^{NS}	0.439^{**}	-0.128^{NS}	0.154^{NS}	0.317^{*}	1					
Root fresh weight (g)	0.328^{*}	0.058^{NS}	0.359^{*}	0.193^{NS}	-0.010^{NS}	0.411^{**}	-0.024^{NS}	0.218^{NS}	0.274^{NS}	0.768^{**}	1				
Shoot dry weight (g)	0.192^{NS}	0.087^{NS}	0.031^{NS}	0.088^{NS}	-0.169^{NS}	0.557^{**}	-0.163^{NS}	0.195^{NS}	0.478^{**}	0.739^{**}	0.599^{**}	1			
Root dry weight (g)	0.296^{NS}	0.115^{NS}	0.225^{NS}	-0.042^{NS}	-0.111^{NS}	0.379^{*}	-0.081^{NS}	0.156^{NS}	0.183^{NS}	0.649^{**}	0.770^{**}	0.547^{**}	1		
Fresh root/shoot ratio	0.162^{NS}	0.056^{NS}	0.226^{NS}	0.162^{NS}	-0.062^{NS}	0.155^{NS}	0.105^{NS}	0.170^{NS}	0.081^{NS}	0.106^{NS}	0.715^{**}	0.116^{NS}	0.471^{**}	1	
Dry root/shoot ratio	0.152^{NS}	0.048^{NS}	0.222^{NS}	-0.120^{NS}	0.014^{NS}	-0.041^{NS}	0.033^{NS}	0.002^{NS}	-0.197^{NS}	0.171^{NS}	0.441^{**}	-0.174^{NS}	0.716^{**}	0.494^{**}	1

****Significant at P=0.01 *Significant at P=0.05**

Current study found a significant negative correlation between the weight of 100 seeds and seed germination, aligning with previous findings by Luna *et al.* (2006) in *Acacia catechu* and Gargi *et al.* (2011) for *Terminalia tomentosa*. Furthermore, the 100-seed weight showed a highly significant correlation with collar diameter across all measured levels and a significant correlation at the environmental level, consistent with Bhat and Chauhan's (2002) research on *Albizia lebbeck*.

In the present study seedling height exhibited a highly significant positive correlation with both collar diameter and the number of branches. Similar findings were reported by Dhiman (2018), who analyzed the correlation between seed characteristics, germination and nursery growth in 36 plus trees of *Toona ciliata* from Punjab and Himachal Pradesh. His study revealed that 100-seed weight was positively and significantly associated with seed germination (r = 0.54), survival rate (r = 0.34), seedling height (r = 0.51), collar diameter (r = 0.29) and number of leaves per seedling (r = 0.43). Additionally, seed germination showed a strong positive correlation with survival percentage (r = 0.82), seedling height (r = 0.48), collar diameter (r = 0.31) and number of leaves per seedling (r = 0.31).

4.4 GENETIC DIVERGENCE

Assessing the level of variability within a population is essential for the genetic improvement of any tree species. In breeding programs estimating genetic distance is crucial for identifying parent combinations that possess adequate genetic diversity and for grouping germplasm into well-defined heterotic groups. Evaluating genetic diversity among genotypes helps in the selection of superior parents for hybridization, as this diversity significantly contributes to the expression of heterosis in hybrid offspring. Multivariate techniques, particularly Mahalanobis' D^2 statistics, have proven to be effective biometric tools for measuring genetic divergence within plant germplasm collections (Rao, 1952). This method allows breeders to identify suitable parental combinations for crossing even before initiating the hybridization program.

Table 12: Clustering pattern of different candidate plus tress (CPTs) based on high heritability.

Cluster No	Number of CPTs	CPTs
1	9	CPT-3, 5, 16, 23, 25, 30, 31, 36, 39
2	21	CPT-6, 7, 9, 11, 12, 14, 15, 17, 19, 20, 22, 24, 26, 27, 28, 29, 32, 33, 35, 38, 40
3	4	CPT-8, 21, 34, 37
4	6	CPT-1, 2, 4, 10, 13, 18

Based on D^2 analysis 40 Candidate Plus Trees were grouped into 4 clusters using Tocher's method (Table 12). Cluster 2 includes maximum number of Candidate Plus Trees i.e. CPT-6, CPT-7, CPT-9, CPT-11, CPT-12, CPT-14, CPT-15, CPT-17, CPT-19, CPT-20, CPT-22, CPT-24, CPT-26, CPT-27, CPT-28, CPT-29, CPT-32, CPT-33, CPT-35, CPT-38, CPT-40. Cluster 3 include minimum numbers of clusters i.e. CPT-8, CPT-21, CPT-34, CPT-37.

In the current investigation a high quantum of genetic divergence was found among forty possibilities. All the CPTs were divided into four groups, with cluster II having the highest number of CPTs, followed by clusters I, IV and III. The present finding are supported by the results of Parthiban *et al.* (2019) who conducted a progeny evaluation of 23 *Toona ciliata* genotypes from the Western Ghats. D^2 analysis grouped the progenies into seven clusters, with Cluster V showing maximum intra-cluster distance. Mohanraj *et al.* (2022) studied genetic diversity in sixteen *Toona ciliata* progenies using D^2 clustering and grouped them into five clusters. The highest intra-cluster and inter-cluster distances were found in Cluster II and between Clusters III and IV. The results stand similar with the findings of Kanna *et al.* (2019) who classified thirty *Ailanthus excelsa* progenies into nine clusters. Cluster IV had most progenies (10 progenies) of the nine clusters.

Chapter-5

SUMMARY AND CONCLUSION

In 2023-2024, the Department of Tree Improvement and Genetic Resources, Dr. Y.S. Parmar UHF, College of Horticulture and Forestry, Neri Hamirpur (H.P.) conducted the current study, "Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *Toona ciliata* M. Roem." For the current study, forty Candidate Plus Trees (CPTs) of the species were chosen from four districts three in Himachal Pradesh i.e. Kangra, Hamirpur and Mandi and one in Punjab Ludhiana, with ten CPTs from each district. These CPTs seedlings were cultivated in the experimental field at the College of Horticulture and Forestry Neri, Hamirpur, in order to determine the best CPT, assess genetic divergence among them and determine the degree of variation among CPTs. The following is a summary of the findings:

5.1 STUDIES ON PHENOTYPIC VARIATION

Selected Candidate Plus Trees (CPTs) showed notable phenotypic variation in characteristics such as tree height, clear bole height and diameter at breast height (DBH). The clear bole height ranged from 2.12 to 2.91m, the tree height 20.45 to 29.01m and the DBH 28.12 to 33.14cm.

5.2 GENETIC VARIABILITY STUDIES

The study revealed a wide range of variation among CPTs for both seed and seedling traits. Seed parameters like length, width, thickness, weight and germination showed statistically significant differences as did seedling growth and biomass traits evaluated at multiple stages (2, 4 and 6 months).

5.2.1 Seed parameters

CPTs showed considerable variation in their seed characteristics. For instance, seed length with wings varied significantly, from 12.17mm (CPT-33) to 19.74mm (CPT-2). Without wings, seed length ranged from 5.04mm (CPT-8) to 6.31mm (CPT-6). The widest seeds were 4.71mm (CPT-26), while the narrowest were 3.10mm (CPT-4). Seed thickness also varied, falling between 1.25mm and 1.75mm. In terms of weight, the highest 100-seed weight was 0.31g (CPT-5) and the lowest was 0.21g (CPT-34, CPT-40). Germination percentages spanned from 50% (CPT-34, CPT-37) to an impressive 78.89% (CPT-4, CPT-13, CPT-18).

5.2.2 Seed germination parameters

Among forty Candidate Plus Trees (CPTs), germination time displayed minimal, non-significant variation (14.97 to 15.81 days), with CPT-7 being the fastest and CPT-32 the slowest. In contrast germination energy showed considerable variability (32.22% to 58.89%), with CPT-1, CPT-7 and CPT-15 achieving the highest (58.89%) while CPT-37 recorded the lowest (32.22%). Germination Index varied moderately (21.94 to 38.79), with CPT-2 having the highest and CPT-33 the lowest. Time spread of germination ranged from 12.33 to 20.33, with CPT-4 and CPT-18 showing the maximum spread and CPT-34 the minimum. Vigor index spanned from 2180.50 to 4231.89, with CPT-2 exhibiting the highest vigor and CPT-31 the lowest. Lastly, first day of germination ranged from 2.33 to 5.67 days (CPT-37 earliest, CPT-2, CPT-7, CPT-10 latest) and last day of germination varied from 15.00 to 23.67 days (CPT-34 and CPT-37 earliest completion, CPT-4, CPT-13, CPT-18 latest completion).

5.2.3 Growth and biomass parameters.

After 2 months shoot height ranged from 13.45cm (CPT-40) to 19.74cm (CPT-2); number of leaves per plant from 17.32 (CPT-28) to 26.56 (CPT-6), collar diameter from 0.91mm (CPT-39) to 2.74mm (CPT-21).

After 4 months shoot height ranged from 24.4cm (CPT-38) to 30.4cm (CPT-2), number of leaves from 35.89 (CPT-31) to 53.98 (CPT-6); collar diameter from 2.97mm (CPT-15) to 4.24m (CPT-21).

After 6 months maximum seedling length was 55.18cm (CPT-22), root length ranged from 8.41cm to 17.24cm and collar diameter varied from 4.68mm to 6.11mm. The highest fresh shoot weight was 9.14g (CPT-2) and root fresh weight 7.17g (CPT-2). Dry weights and root/shoot ratios also exhibited significant variability.

5.2.4 Genetic parameters

Genetic analysis revealed that PCV values were slightly higher than GCV values, indicating environmental influence along with genetic factors. High heritability was observed in traits such as 100 seed weight (99.99%), seed length with wing (95.34%), seed width (94.52%), seed thickness (95.08%) and germination percentage (93.17%), suggesting strong genetic control. These traits also showed high genetic gain, making them ideal for selection. In contrast traits like number of leaves at six months had moderate heritability and gain, while most growth and biomass traits showed low genetic advance, indicating non-additive gene action. Root dry weight showed the highest genetic gain (50.82%), followed by shoot fresh weight (18.92%) and shoot length (19.23%).

5.3 Correlation coefficient

Traits such as seed length (with wing), seed width, shoot length, seedling length and collar diameter demonstrated strong positive correlations with various growth and biomass trait. The seedling length and biomass traits were especially well-correlated. However, several seed traits like seed length without wing and seed thickness showed weak or no association with seedling parameters.

5.4 Genetic divergence

The clustering of 40 candidate plus trees into four genetically distinct groups using Mahalanobis D^2 statistics demonstrated the presence of substantial genetic divergence among the genotypes. Cluster II contained the maximum number of CPTs, indicating a high degree of similarity among them while other clusters represented more distinct and potentially valuable genetic diversity.

CONCLUSION

- Tree growth parameters such as tree height, clear bole height and DBH showed wide variation among CPTs with CPT-22, CPT-28 and CPT-19 demonstrating superior growth traits.
- Seed traits including seed length (with and without wings), width, thickness, 100 seed weight and germination percentage exhibited significant variation. CPT-2 (Halehr, Kangra) consistently performed better across most seed traits.
- Seedling traits after 2, 4 and 6 months (shoot height, collar diameter, number of leaves, root length) revealed significant variability, highlighting differential early growth vigour among genotypes.

- CPT-2 (Halehr, Kangra), CPT-6 (Dhaneri, Kangra), CPT-21 (Sandhol, Mandi) and CPT-22 (Ghanala, Mandi) emerged as top performers across seedling growth and biomass traits.
- Biomass traits such as shoot/root fresh and dry weights and root/shoot ratios also showed wide differences, indicating the presence of CPTs with superior resource allocation and growth strategies.
- Genetic variability estimates showed higher phenotypic coefficients of variation (PCV) than genotypic coefficients of variation (GCV) for most traits.
- Heritability estimates were highest for seed traits like 100 seed weight, seed length (with wings), seed width, thickness and germination percentage (>90%), suggesting that these traits are primarily under genetic control and suitable for selection.
- Genetic advance and genetic gain values identified seed traits as ideal for selection due to their high heritability coupled with high genetic gain. For example, seed length with wings had genetic gain >22% and root dry weight had gain >50%.
- In Correlation analysis seed length (with wing) showed significant positive correlations with seed width, shoot length, seedling length, root fresh weight and 100-seed weight. Shoot length and seedling length were strongly correlated with biomass traits (shoot/root weights), shoot dry weight and collar diameter. Biomass traits (fresh and dry weights of shoot and root) showed strong internal associations, indicating balanced seedling growth. Weak or non-significant correlations were observed for seed length (without wing), seed thickness and root length.
- In clustering analysis, cluster II had the highest number of CPTs (21), indicating genetic similarity while cluster III had the least number (4), suggesting distinct or unique genotypes.
- Overall, CPTs from Kangra, Hamirpur and Mandi zones (notably CPT-2, CPT-6, CPT-21, CPT-22) were found to be superior in most traits and can be recommended for further genetic improvement programs and plantation initiatives.

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APPENIX –I

Analysis of Variance for seed length with wings (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	355.313	9.111	62.583	1.58
Error	80	11.646	0.146		
Total	119	366.959			

Analysis of Variance for seed length without wings (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	11.518	0.295	15.951	1.58
Error	80	1.481	0.019		
Total	119	12.999			

Analysis of Variance for seed length width (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	18.527	0.475	51.709	1.58
Error	80	0.735	0.009		
Total	119	19.262			

Analysis of Variance for seed thickness (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	2.318	0.059	54.478	1.58
Error	80	0.087	0.001		
Total	119	2.405			

Analysis of Variance for 100 seed weight (g)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	0.049	0.001	22.366	1.58
Error	80	0.004	0		
Total	119	0.053			

Analysis of variance for seed germination percent (%)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	5,265.15	135.004	41.932	1.58
Error	80	257.565	3.22		
Total	119	5,522.72			

Analysis of variance for Germination Time

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	5.868	0.15	0.783	1.58
Error	80	15.366	0.192		
Total	119	21.234			

Analysis of variance for Germination Index

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	1,955.31	50.136	69.774	1.58
Error	80	57.484	0.719		
Total	119	2,012.79			

Analysis of variance for Time Spread of Germination

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	347.473	8.91	63.536	1.58
Error	80	11.218	0.14		
Total	119	358.691			

Analysis of variance for Germination Energy

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	5,401.72	138.506	89.02	1.58
Error	80	124.472	1.556		
Total	119	5,526.19			

Analysis of variance for Vigour Index

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	2,09,46,638.22	5,37,093.29	66.949	1.58
Error	80	6,41,796.07	8,022.45		
Total	119	2,15,88,434.29			

Analysis of variance for First Day of Germination

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	87.545	2.245	326.161	1.58
Error	80	0.551	0.007		
Total	119	88.096			

Analysis of variance for Last Day of Germination

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	473.744	12.147	44.197	1.58
Error	80	21.988	0.275		
Total	119	495.731			

Analysis of variance for shoot height after 2 months (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	317.03	8.129	38.68	1.58
Error	80	16.813	0.21		
Total	119	333.843			

Analysis of variance for number of leaves after 2 months.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	678.648	17.401	61.011	1.58
Error	80	22.817	0.285		
Total	119	701.465			

Analysis of variance for seedling collar diameter after 2 months (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	25.216	0.647	226.008	1.58
Error	80	0.229	0.003		
Total	119	25.445			

Analysis of variance for shoot height after 4 months (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	256.929	6.588	12.148	1.58
Error	80	43.384	0.542		
Total	119	300.313			

Analysis of variance for number of leaves after 4 months.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	2,814.75	72.173	56.572	1.58
Error	80	102.062	1.276		
Total	119	2,916.81			

Analysis of variance for seedling collar diameter after 4 months (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	19.134	0.491	67.68	1.58
Error	80	0.58	0.007		
Total	119	19.714			

Analysis of variance for shoot height after 6 months (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	354.526	9.09	9.439	1.58
Error	80	77.043	0.963		
Total	119	431.569			

Analysis of variance for root length after 6 months (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	639.087	16.387	144.534	1.58
Error	80	9.07	0.113		
Total	119	648.157			

Analysis of variance for seedling length after 6 months (cm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	1,064.32	27.29	16.885	1.58
Error	80	129.301	1.616		
Total	119	1,193.62			

Analysis of variance for number of leaves after 6 months.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	4,658.02	119.436	39.575	1.58
Error	80	241.438	3.018		
Total	119	4,899.46			

Analysis of variance for seedling collar diameter after 6 months (mm)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	14.399	0.369	26.67	1.58
Error	80	1.107	0.014		
Total	119	15.507			

Analysis of variance for shoot fresh weight (g)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	63.439	1.627	41.337	1.58
Error	80	3.148	0.039		
Total	119	66.587			

Analysis of variance for root fresh weight (g)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	69.018	1.77	65.436	1.58
Error	80	2.164	0.027		
Total	119	71.182			

Analysis of variance for shoot dry weight (g)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	26.737	0.686	109.805	1.58
Error	80	0.499	0.006		
Total	119	27.236			

Analysis of variance for root dry weight (g)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	17.222	0.442	303.328	1.58
Error	80	0.116	0.001		
Total	119	17.338			

Analysis of variance for fresh root/shoot ratio

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	0.513	0.013	59.367	1.58
Error	80	0.018	0		
Total	119	0.531			

Analysis of variance for dry root/shoot ratio

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	F-Tabulated
Treatment	39	1.438	0.037	200.166	1.58
Error	80	0.015	0		
Total	119	1.452			

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ABSTRACT

The present investigation entitled "Genetic Variability and Divergence Studies for Seed and Seedling Traits among Candidate Plus Trees (CPTs) of *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, College of Horticulture and Forestry, Neri, Hamirpur, Himachal Pradesh during 2024-2025. The experiment was conducted to evaluate phenotypic variation, genetic parameters, germination behaviour, seedling vigour and genetic divergence among 40 Candidate Plus Trees (CPTs) selected from diverse regions of Himachal Pradesh and Punjab. Significant phenotypic variation was recorded in tree height (20.45 m to 29.01 m), clear bole height (2.12 m to 2.91 m) and diameter at breast height (28.12 cm to 33.14 cm) indicating a broad genetic base. Seed traits showed high variability in seed length (with wing) ranging from 12.17 mm to 19.74 mm, seed width 3.10 mm to 4.71 mm and 100-seed weight 0.21 g to 0.31 g. These traits also exhibited high heritability and genetic gain. Germination behaviour revealed variability in germination percentage (50.00%–78.89%), germination energy (32.22%–58.89%) and vigor index (2180.50–4231.89), suggesting differences in seed viability and early growth potential. Seedling traits at different growth stages also varied significantly. Among all the CPTs, CPT-2 consistently performed best, with the highest shoot fresh weight (9.14 g), root fresh weight (7.17 g), dry shoot weight (3.89 g) and dry root weight (2.74 g). The root: shoot fresh and dry weight ratios varied from 0.61 to 0.86 and 0.34 to 0.76, respectively. These results highlight strong genetic influence on biomass accumulation and allocation. Genetic parameters indicated high heritability (>90%) in seed traits and moderate to high heritability in seedling traits. Genetic gain was high for root dry weight (50.82%), moderate for shoot fresh weight (18.92%) and shoot length (19.23%) during first two months of seedling growth. Traits with low genetic advance, such as shoot height after six months (7.91%), likely involve non-additive gene action. Correlation analysis revealed strong positive associations between seed size traits and seedling vigour indicators such as shoot length and collar diameter. Biomass traits namely shoot and root weights were also found having positive correlation. Conversely, 100-seed weight showed a negative correlation with germination percentage. Genetic divergence analysis using Mahalanobis D^2 statistics grouped the CPTs into four distinct clusters, with Cluster II containing the largest number of genotypes (21 CPTs). This clustering highlights substantial inter and intra-cluster variability, indicating scope for exploiting genetic diversity in breeding programs. The study confirms considerable genetic variability among CPTs. Traits such as seedling height, collar diameter, seed size and root–shoot biomass ratios were found to be genetically controlled and can serve as effective selection criteria. The superior CPTs identified in this study offer significant role in enhancing productivity, adaptability and genetic improvement of this valuable multipurpose species.

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