ASSESSMENT OF GENOTYPIC VARIATION FOR MORPHO-PHYSIOLOGICAL CHARACTERISTICS OF *Toona ciliata* M. Roem

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Plant Breeding and Genetics)

By

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2021

CERTIFICATE – I

This is to certify that the thesis entitled **"Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem"** submitted for the degree of **Master of Science** in the subject of **Forestry** (Minor subject: **Plant Breeding and Genetics**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ranjeet Singh** (**L-2018-A-86-M**) under my supervision and that no part of this thesis has been submitted for any other degree.

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

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ACKNOWLEDGEMENTS

Pride, praise and perfection belong to almighty God alone. Every creation is motivated by purpose and all purposes have a destiny predestined by the creator. I thank Almighty for bestowing me with the fruitful purpose to enlighten the obscure spheres of my life.

Every effort is motivated by an ambition and all ambitions have inspirations behind. I owe this pride place to my ever-loving parents: ***Sh. Gurmit Singh*** *and* ***Smt. Tripta Devi*** *for their oceans of love and moral support bestowed upon me which steered the life of this cipher to the present shape. Any and every good quality which seems to be of myself is actually theirs. I thank the supernatural for giving me such caring and sacrificial parents to whom I owe all that is mine. I thank them from the depths of my existence for all that which helped me achieve this goal.*

I also acknowledge my lovable Sister ***Jaspreet Kaur*** *whose love and affection, everlasting blessings and sacrifices has always stood by me and enabled me to achieve this arduous destiny cheerfully.*

I express my profound sense of gratitude to the chairperson of my Advisory committee ***Dr. Sapna Thakur,*** *Assistant Professor (Forestry) for her illuminating guidance, unfailing encouragement, scholarly suggestions, unique supervision, constructive criticism, sympathetic attitude and keen interest during the course of the investigations and preparation of this manuscript.*

I am thankful to members of my Advisory Committee, ***Dr. Harmeet Singh Saralach,*** *Professor (Forestry),* ***Dr. Neha Gupta*** *(Botanist) and* ***Dr. Rakesh Kumar Garg,*** *Professor (Forestry) for their timely help, valuable suggestions, persistent encouragement, constructive criticism and support.*

My sincere thanks to my friends and lab partner ***Gaurav Palial, Arshdeep Kaur, Taruna Suthar, Navjeet Singh, Manpreet Sran, Lakhwinder Singh*** *and* ***Rajdeep Singh*** *for their kind co-operation and their constant suggestions during my research work.*

I place on record my heartiest gratitude towards my friends ***Parwinder Perry, Gurwinder Guri, Aman Dhnulla, Gurjeet Sarsa, Varinder, Kanwar, Amrit, Jaskaran Jassa, Manpreet Manna, Jagnandan Jagga, Gurpreet Gopi, Mandeep Mandy, Arsh Abohar, Aalm Birring, Joban Hanzra, Bikram Vicky, Harry, Shakti, Kinda, Robin, Yogesh Sharma, Avneet Doad, Davinder Deep, Harsimran Honey, Babbla, Prince, Paras cream, Harsimran***

Simmu, Dilpreet Dabangi, Maninder Mani, Navneet Kaur and Harpreet Kaur *for their help and inspiration.*

I would like to extend my thanks to ***Dr. Sanjeev Kumar Chauhan,*** *Professor & Head Department of Forestry and Natural Resources for providing the necessary facilities.*

I cordially acknowledge the time to time help & support extended by the office (especially ***Kuldeep Mam****) and field staff of Department of Forestry and Natural Resources for timely and sincere help during the course of my degree.*

Lastly thanks to all beloved and respected people around me who directly and indirectly helped me during my degree programme and could not find separate mention.

Being a social animal, nobody is perfect, so all error and omission are mine.

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Title of the Thesis	**:**	Assessment of genotypic variation for morpho-physiological characteristics of *Toona cillata* M. Roem
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Major Subject	**:**	Forestry
Minor Subject	**:**	Plant Breeding and Genetics
Name and designation of Major Advisor	**:**	Dr. Sapna Thakur Assistant Professor
Degree to be Awarded	**:**	M.Sc.
Year of award of degree	**:**	2021
Total pages in thesis	**:**	62 + VITA
Name of the University	**:**	Punjab Agricultural University, Ludhiana – 141 004, Punjab, India

ABSTRACT

The present investigation entitled "Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem" was carried out in the Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana, during 2019-20. Superior two year old half sib progenies of twenty four genotypes from eight seed source viz., Talwara, Kamahi Devi, Ludhiana, Sujanpur, Salouni, Chabutra, Shah Talai and Suhari Takoli were evaluated for growth and physiological traits. On the basis of mean performance, seed source S_5 (Salouni), S_6 (Chabutra) and S_2 (Kamahi Devi) exhibited outstanding performance for growth and physiological traits whereas among genotypes, progenies of S_6G_{16} (Chabutra), S_5G_{15} (Salouni), S_6G_{17} (Chabutra), S_2G_4 (Kamahi Devi) and S_5G_{13} (Salouni) were found superior for morphological and physiological characters. Highest index score of 15 was recorded for morphological traits (plant height, clear bole height, collar diameter and stem straightness) in genotypes S_2G_4 (Kamahi Devi), S_5G_{13} (Salouni) and S_5G_{15} (Salouni). Highest genotypic coefficient of variation was observed for leaf area and clear bole height whereas highest phenotypic coefficient of variation was found in starch content, total soluble sugar and chlorophyll index. Moderate to high heritability and genetic gain were observed for leaf area, petiole length, clear bole height and carotenoid content. Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height; chlorophyll a with chlorophyll b, total chlorophyll and carotenoids; chlorophyll b with total chlorophyll and carotenoids and total chlorophyll with carotenoids. On the basis of principal component analysis, total chlorophyll should be given due weightage while selection, since it is the largest contributor towards the total genetic diversity in the genotypes.

Keywords: *Toona ciliata*, seed source, genotype, progenies, index score, heritability, genetic gain, correlation, principal component.

Signature of Major Advisor **Signature of the Student**

ਖੋਜ ਦਾ ਸਿਰਲੇਖ	:	ਤੂਨਾ ਸਿਲੇਟਾ ਐਮ ਰੋਇਮ ਦੀਆਂ ਮੋਰਫੋ-ਫਿਜ਼ੀਓਲੈਜੀਕਲ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ ਲਈ ਜੀਨੋਟਾਈਪਿਕ ਪਰਿਵਰਤਨ ਦਾ ਮੁਲਾਂਕਣ
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ਅਤੇ ਦਾਖਲਾ ਨੰਬਰ		ਐਲ-2018-ਏ-86-ਐਮ
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	:	ਜੰਗਲਾਤ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	:	ਪਲਾਂਟਬ੍ਰੀਡਿੰਗ ਅਤੇ ਜੈਨੇਟਿਕਸ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ	:	ਡਾ. ਸਪਨਾ ਠਾਕੁਰ
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ਡਿਗਰੀ	:	ਐਮ.ਐੱਸ.ਸੀ.
ਡਿਗਰੀ ਦੇ ਪੁਰਸਕਾਰ ਦਾ ਸਾਲ	:	2021
ਖੋਜ ਪੱਤਰ ਵਿਚ ਕੁੱਲ ਪੇਜ	:	62 + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ - 141 004, ਪੰਜਾਬ, ਭਾਰਤ

ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ, "ਤੂਨਾ ਸਿਲੇਟਾ ਐਮ ਰੋਇਮ ਦੀਆਂ ਮੋਰਫੋ-ਫਿਜ਼ੀਓਲੈਜੀਕਲ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ ਲਈ ਜੀਨੋਟਾਈਪਿਕ ਪਰਿਵਰਤਨ ਦਾ ਮੁਲਾਂਕਣ", ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਵਿਖੇ, ਸਾਲ 2019-20 ਦੌਰਾਨ ਜੰਗਲਾਤ ਅਤੇ ਕੁਦਰਤੀ ਸਰੋਤ ਵਿਭਾਗ ਵਿੱਚ ਕੀਤੀ ਗਿਆ ਸੀ। ਅੱਠ ਬੀਜ ਸਰੋਤਾਂ, ਤਲਵਾੜਾ, ਕਮਾਹੀ ਦੇਵੀ, ਲੁਧਿਆਣਾ, ਸੁਜਾਨਪੁਰ, ਸਲੋਨੀ, ਚਬੂਤਰਾ, ਸ਼ਾਹ ਤਲਾਈ ਅਤੇ ਸੁਹਾਰੀ ਟਕੋਲੀ ਤੋਂ ਚੌਵੀ ਜੀਨੇ ਟਾਈਪਾਂ ਦੀਆਂ ਦੋ ਸਾਲਾਂ ਹਾਲਫ ਸਿਬ ਉੱਤਮ ਬੂਟਿਆਂ ਦਾ ਸੰਭਾਵਨਾ ਦਾ ਵਿਕਾਸ ਅਤੇ ਫਿਜ਼ੀਓਲੈਜੀਕਲ ਗੁਣਾਂ ਲਈ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ। ਸਧਾਰਣ ਪ੍ਰਦਰਸ਼ਨ ਦੇ ਅਧਾਰ ਤੇ, ਬੀਜ ਸਰੋਤ S_5 (ਸਲੋਨੀ), S_6 (ਚਬੂਤਰਾ) ਅਤੇ S_2 (ਕਮਾਹੀ ਦੇਵੀ) ਨੇ ਵਿਕਾਸ ਅਤੇ ਫਿਜ਼ੀਓਲੈਜੀਕਲ ਗੁਣਾਂ ਲਈ ਸ਼ਾਨਦਾਰ ਪ੍ਰਦਰਸ਼ਨ ਕੀਤਾ ਜਦੋਂ ਕਿ ਜੀਨੋਟਾਈਪਜ਼ ਵਿੱਚ, S_6G_{16} (ਚਬੂਤਰਾ), S_5G_{15} (ਸਲੋਨੀ), S_6G_{17} (ਚਬੂਤਰਾ), S_2G_4 (ਕਮਾਹੀ ਦੇਵੀ) ਅਤੇ S_5G_{13} (ਸਲੋਨੀ) ਵਿਕਾਸ ਅਤੇ ਫਿਜ਼ੀਓਲੈਜੀਕਲ ਗੁਣਾਂ ਲਈ ਉੱਤਮ ਪਾਏ ਗਏ । ਜੀਨੋਟਾਈਪਸ S_2G_4 (ਕਮਾਹੀ ਦੇਵੀ), S_5G_{13} (ਸਲੋਨੀ) ਅਤੇ S_5G_{15} (ਸਲੋਨੀ) ਵਿੱਚ ਰੂਪ ਵਿਗਿਆਨਕ ਗੁਣਾਂ (ਪੌਦਿਆਂ ਦੀ ਉਚਾਈ, ਸਪਸ਼ਟ ਬੋਲਦੀ ਉਚਾਈ, ਕਾਲਰ ਵਿਆਸ ਅਤੇ ਸਟੈਮ ਸਿੱਧਾ) ਲਈ 15 ਦਾ ਉੱਚਤਮ ਸੂਚਕਾਂਕ ਅੰਕ ਦਰਜ ਕੀਤਾ ਗਿਆ । ਪੱਤੇ ਦੇ ਖੇਤਰਫਲ ਅਤੇ ਸਪਸ਼ਟ ਬੋਲ ਦੀ ਉਚਾਈ ਲਈ ਪਰਿਵਰਤਨ ਦਾ ਉੱਚ ਜੀਨੋਟਾਈਪਿਕ ਗੁਣਾਂਕ ਦੇਖਿਆ ਗਿਆ ਹੈ ਜਿੱਥੇ ਸਟਾਰਚ ਦੀ ਸਮਗਰੀ, ਕੁੱਲ ਘੁਲਣਸ਼ੀਲ ਚੀਨੀ ਅਤੇ ਕਲੋਰੋਫਿਲ ਇੰਡੈਕਸ ਵਿੱਚ ਪਰਿਵਰਤਨ ਦੇ ਉੱਚ ਫੀਨੋਟਾਈਪਿਕ ਗੁਣਾਂਕ ਪਾਇਆ ਗਿਆ ਸੀ । ਪੱਤੇ ਦੇ ਖੇਤਰਫਲ, ਪੇਟੀਓਲ ਦੀ ਲੰਬਾਈ, ਸਪਸ਼ਟ ਬੋਲ ਦੀ ਉਚਾਈ ਅਤੇ ਸਟਾਰਚ ਦੀ ਸਮਗਰੀ ਲਈ ਦਰਮਿਆਨੀ ਤੋਂ ਉੱਚਵਿਰਾਸਤ ਅਤੇ ਜੈਨੇਟਿਕ ਲਾਭ ਦਰਜ ਕੀਤਾ ਗਿਆ । ਸਪਸ਼ਟ ਬੋਲ ਦੀ ਉਚਾਈ ਦੇ ਨਾਲ ਪੌਦੇ ਦੀ ਉਚਾਈ; ਕਲੋਰੋਫਿਲ ਏ ਦਾ ਕਲੋਰੋਫਿਲ ਬੀ, ਕੁੱਲ ਕਲੋਰੋਫਿਲ ਅਤੇ ਕੈਰੋਟਿਨੋਇਡਜ਼ ਨਾਲ; ਕਲੋਰੀਫਿਲ ਬੀ ਦਾ ਕੁੱਲ ਕਲੋਰੋਫਿਲ ਅਤੇ ਕੈਰੋਟਿਨੋਇਡਜ਼ ਨਾਲ ਅਤੇ ਕੁੱਲ ਕਲੋਰੋਫਿਲ ਦਾ ਕੈਰੋਟਿਨੋਇਡਜ਼ ਨਾਲ ਬਹੁਤ ਮਹੱਤਵਪੂਰਨ ਅਤੇ ਸਕਾਰਾਤਮਕ ਜੀਨੋਟਾਈਪਿਕ ਅਤੇ ਫੀਨੋਟਾਈਪਿਕ ਸਬੰਧ ਦਰਜ ਕੀਤਾ ਗਿਆ । ਪ੍ਰਮੁੱਖ ਹਿੱਸੇ ਦੇ ਵਿਸ਼ਲੇਸ਼ਣ ਦੇ ਅਧਾਰ ਤੇ, ਕੁੱਲ ਕਲੋਰੋਫਿਲ ਨੂੰ ਚੋਣ ਕਰਨ ਵੇਲੇ ਭਾਰ ਦਿੱਤਾ ਜਾਣਾ ਚਾਹੀਦਾ ਹੈ, ਕਿਉਂਕਿ ਉਹ ਜੀਨੋਟਾਈਪਾਂ ਵਿਚ ਕੁੱਲ ਜੈਨੇਟਿਕ ਵਿਭਿੰਨਤਾ ਵਿਚ ਸਭ ਤੋਂ ਵੱਡਾ ਯੋਗਦਾਨ ਪਾਉਂਦੇ ਹਨ ।

ਮੁੱਖ ਸ਼ਬਦ: ਤੂਨਾ ਸਿਲੇਟਾ, ਬੀਜ ਸਰੋਤ, ਜੀਨੋਟਾਈਪ, ਪ੍ਰੋਜਨੀਜ, ਇੰਡੈਕਸ ਸਕੋਰ, ਵਿਰਾਸਤ, ਜੈਨੇਟਿਕ ਲਾਭ, ਸੰਬੰਧ, ਪ੍ਰਮੁੱਖ ਭਾਗ।

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ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation		Meaning
%	:	Percent
/	:	Per
0	:	Degree
“	:	Minute
‘	:	Second
b.s.	:	Broad sense
CBH	:	Clear bole height
Chl	:	Chlorophyll
DMSO	:	Dimethylsulphoxide
TSS	:	Total soluble sugar
ha	:	Hectare
m	:	Metre
cm	:	Centimetre
cm^2	:	Square centimetre
mg	:	Milligram
g	:	Gram
FW	:	Fresh weight
etc.	:	etcetera (and so on)
Fig.	:	Figure
GCV	:	Genotypic coefficient of variability
NS	:	Non-Significant
i.e.	:	That is
PCV	:	Phenotypic coefficient of variability
H^2	:	Heritability
T.	:	*Toona*
viz.,	:	Videlicet (Namely)
PCA	:	Principal component analysis
FSI	:	Forest survey of India
P	:	Phosphorus
K	:	Potassium
Ca	:	Cadmium
Mg	:	Magnesium
DBH	:	Diameter at breast height
MPTs	:	Multipurpose tree species
WUE	:	Water use efficiency
LAI	:	Leaf area index

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CHAPTER-I

INTRODUCTION

Forests acts as a stabilizing force for maintaining the global climatic system, playing a twofold role by acting as a source and a sink for carbon emissions. As per the Global Forest Resources Assessment (Anon 2015), the world's forest area has shown a decline from 31.60 per cent to 30.60 per cent from 1990-2015. Moreover, increasing population has widened the gap between demand and supply of forest products which in turn is affecting and exhausting our natural forest resources. As per the National Forest Policy of 1988, in order to maintain the ecological balance, at least one-third area of the country should be under forest cover. The prelude and foremost recourse to reduce the increasing pressure on natural forest resources, is to encourage tree-based land use systems, such as agroforestry, short rotation forestry, urban forestry, etc. In this direction, National Agroforestry policy (2014) encourages expanding the tree plantations outside the forests and in integration with crops and livestock, so as to meet the domestic wood demand of farmers, increasing their source of income generation and in turn reducing the pressure on natural forests.

Punjab is an agrarian state having 85 per cent of total land area under intensive agriculture and has given significant contribution towards the national food grain production. The geographical area of Punjab is 5.0362 million hectares and area under forest cover and tree cover is 3441 km^2 which is only 6.83% of total area of Punjab (Anon 2019). To meet the twin objectives of increasing the area under tree cover in Punjab as well as to meet the ever-increasing demand for wood products, plantations of short rotation tree species are much required. In Punjab, commercial plantations of exotic species like *Populus*, *Eucalyptus* are highly preferred by farmers owing to their fast growth, high productivity and demand of wood-based industries. However, in the absence of any research conducted to harness the potential native species, species like toon still remains unexplored and demands a well-planned tree improvement programme.

The genus *Toona* belongs to family Meliaceae and consists of four species, namely *Toona sinensis*, *T. fargesii*, *T. sureni* and *T. ciliata* (Edmonds 1995). *Toona ciliata* commonly known as toon or red cedar is highly valued for its quality wood and ease of cultivation in plantations (Uppal and Singh 2010). It is a large fast growing deciduous or semi-deciduous tree with a well spread crown, commonly attaining a height of upto 20-30 m and a girth of 1.83 m (Orwa *et al* 2009; Hua and Edmonds 2008). It is native to Australia and has been distributed naturally in India, Burma, Laos, Pakistan, Thailand, Malaysia, Indonesia, and China. In India, the species is distributed throughout the sub-Himalayan tract and the valleys of outer-Himalayas, plains of Assam, Madhya Pradesh, Tamil Nadu, Karnataka,

Eastern and Western Ghats up to an elevation of 1200 m in the Western peninsular region. It is the tree of eastern alluvial secondary semi evergreen forests in Assam. In Punjab, *T. ciliata* comes under dry deciduous scrub forest mostly found in Kandi tracts of the state.

T. ciliata is light-demanding in nature and an early pioneer species in forest succession that spreads rapidly in cleared areas or in disturbed forests (Weber 2003). It has been proven invasive outside its native range (Anon 2012). It is a frost hardy and drought sensitive species and strongly associated with *Tetrameles, Stereospermum spp., Albizzia procera* and *Artocarpus chaplasha*. Toon is largely susceptible to shoot borer (*Hypsiphyla robusta*), which attacks in first summer after planting and generally reappears every summer at juvenile stage (Erskine *et al* 2005). It favors moist localities with an average rainfall range of 1100-4000 mm per year and temperature ranging between 5- 47.5°C. However, if proper tending operations are performed on plants in the early stages, it can be cultivated under dry localities receiving as low as 750 mm rainfall with 2-6 dry months with a maximum temperature as high as 49°C (Troup 1921). Toon is one of the prominent species dominating the agricultural landscapes of the subtropical and sub-temperate northwest Himalayas (Yogeshwari 2013) and is generally planted as border tree on agriculture fields and along roadside plantations in Himachal Pradesh, Uttarakhand and in some part of Punjab. Toon gives remarkable growth performance on well-drained, deep, fertile soils (Orwa *et al* 2009) and does not come up well on poor sandy soil and compact soil. The species has great potential to attain an average annual increase in height of upto 30 m^3 ha^{-1} yr^{-1} under the good cultivation conditions which consist of soil, climate, precipitation, and management practices (Vilela and Stehling 2012). *T. ciliata* exhibits adaptability to stress conditions caused by air pollution. Higher tolerance and anticipated performance index reported in *T. ciliata,* suggests its suitability for roadside plantations so as to intercept the air pollutants (Haseena and Bhardwaj 2018).

Toon is one of the most valuable and appreciated timber species of tropics and serving the same purpose as the pines serves in north temperate zones (Bahadur 1988; Zhan *et al* 2019). The species has stood up recently owing to important economic characteristics including rapid growth, a relatively short growth cycle (15 years); straight clean bole, good yields, and high value in both domestic and international markets (Murakami 2008; Dordel *et al* 2010; Andrade *et al* 2020). Owing to attractive good textured, pinkish to reddish brown heartwood with moderate weight, quality and hardness, it is widely used for making Grade I commercial plywood as well Grade I moisture proof plywood. The wood finds its applicability in various wood-based industries for making plywood, furniture, matchbox, house construction, floors, boarding, panels of doors and windows, musical instruments, etc.

(Ares *et al* 2000; Haines *et al* 2016; Thakur 2014 and Xia *et al* 2018).

T. ciliata is enriched with many biological compounds with medicinal properties. Cedrelone and dysobinin extracted from *T. ciliata* have exhibited significant cytotoxicity to cancer cells (Jiang *et al* 2012; Liu *et al* 2012 and Liu *et al* 2011). Similarly, ethyl acetate extracts have anti-cancer effects on human breast cancer cell lines (Liu *et al* 2011). In traditional medicine system, decoction of bark is used to cure dysentery, ulcer, leprosy, fever, headache and rheumatism etc.

In addition, toon is looped for fodder and fuel wood purpose; the leaves are excellent source of fodder during the lean period (Thakur 2014). The flowers contain red coloured matter called as "gunar" which is used for preparing dye whereas tannin content in the bark is used in leather industry (Divakar and Rattan 2017). Thus, short rotation plantations of *Toona ciliata* has immense potential to make a paradigm shift of wood supply from natural forests to commercial plantations and thus reducing the pressure on existing forest resources.

Keeping in view the diverse uses and economic potential as a timber species, the tree improvement programme on *T. ciliata* was started at Punjab Agricultural University Ludhiana in 2017 and the selected half sib progenies were established under field conditions in 2018. In the present study, these genotypes were assessed for genetic variation in morphological and physiological traits with the following objectives:

i. Evaluation of genotypes on the basis of morphological and physiological characters in the field.
ii. Selection of superior genotypes of *T. ciliata* from existing field trial.

CHAPTER-II

REVIEW OF LITERATURE

The selection and solution of any research problem is always based on collecting available literature on that problem. It is an established fact that the review of related literature provides a good framework for developing a sound research problem and to get acquainted with the explored and unexplored aspects of the problem as well as to gather information given by different investigators in their researches in related fields. In the present investigation entitled "Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem" the relevant literature has been reviewed under the following heads:

2.1 Genetic variability for morphological traits
2.2 Genetic variability for physiological traits
2.3 Correlation studies and principal component analysis

2.1 Genetic variability for morphological traits

Navarro *et al* (2002) examined morphological variation among 63 families of 10 populations of *Cedrela odorata* from two habitant types i.e., dry and mesic to quantify the relationship between morphometric traits and site of population origin. The results revealed that with climatic grouping of provenances, the seedlings from dry habitat were found significantly different from those of mesic habitat, explaining 52.00% of the total variance and 80.00% of the genetic variance. Cluster analysis for seedling traits showed two natural groupings of families into mesic (Atlantic and South Pacific) and dry (North Pacific) groups. Further, seeds from dry habitat populations were heavier (43.00%), while the seedlings were taller (61.00%) with a greater collar diameter (117.00%), and the leaflets were longer and wider (39%; 81.00%) than mesic habitat, inferring these differences to fast growth in the dry zone for taking advantage of moisture availability during early stages of life cycle.

Cunningham *et al* (2004) quantified leaf tissue compositional variation in 153 *Toona ciliata* trees using near infrared spectroscopy (NIRS) to determine its relation with damage caused by *Hypsiphyla robusta*. Discriminant analysis based on NIRS data, classified the leaflets into high and low damage classes while regression model revealed variation in tree height. Further, they concluded that taller trees of *T. ciliata* were more frequently susceptible to damage by *H. robusta* suggesting a link between leaf (nitrogen) composition and *H. robusta* behaviour.

Heinrich and Banks (2006) while analyzing variation in phenology, growth and anatomy of *Toona sinensis* and *T. ciliata* in relation to different environmental conditions

reported that restricted growth conditions led to longer leafless periods, shorter flushes of leaves, and decreased height and diameter growth increments, along with more but smaller vessels. However, under optimum conditions, *T. ciliata* did not become leafless.

Santos *et al* (2006) examined the effect of light on morphological characteristics of *Cedrela fissilis* by planting seeds under two different conditions *i.e.* at east border of a forest having red: far-red ratio of 1.15 and under canopy with full radiation having photosynthetic photon flux density of 0.22-7.00% and far-red ratio of 0.21 - 0.36. Seedling growth in terms of plant height and stem diameter was faster under sun as compared to shade condition, similarly roots showed continuous growth and number of leaves was almost twice than shade condition. The old leaves of shade plants under sun condition (15 days), did not showed any change while the new leaves adapted to increased light radiation, whereas sun plants placed under shade conditions did not performed with same photosynthetic rate as shade plants had but they also did not lose leaves.

Dhillon *et al* (2009) studied the genetic variation among open pollinated progenies of *M. azedarach* under nursery and field conditions in Punjab. Significant differences were recorded for collar diameter and plant height at nursery stage. Moderate estimates of heritability were recorded for diameter (40.76 to 85.08 %) and plant height (52.07 to 76.25 %). Genetic gain (as % of mean) was recorded higher for collar diameter (24.51 %) under field conditions and for plant height (35.34 %) under nursery conditions. Similarly, PCV and GCV were recorded higher for plant height (22.50 %, 19.65 %) under nursery conditions and for diameter (17.88 %, 14.59 %) under field conditions.

Rana *et al* (2009) evaluated the progeny performance of twenty-five plus trees of *T. ciliata* collected from different seed zones of Himachal Pradesh under nursery and field conditions and reported significant variation for seedling height, collar diameter and number of leaves under nursery conditions. High heritability (broad sense) and genetic advance was exhibited by seedling height and collar diameter. Further, under field conditions seed sources viz. S_1, S_2, S_5 and S_6 exhibited outstanding performance for growth traits.

Dordel *et al* (2010) conducted an experiment to estimate establishment success, stem morphology and productivity of *T. ciliata* in Argentina, under planted condition and also checked the effects of nurse species and thinning density. The results showed that growth, stem morphology and survival rate of under planted *T. ciliata* was influenced by over storey nurse plant. Stand density of nurse plant initially consisted of *Pinus taeda* (625 stems/hac), *P. elliotti* × *P. caribaea* (625 stems/ ha) and *Grevillea robusta* (833 stems/ ha) and were thinned by 0%, 25%, 50% and 75%. Initial mortality rate, availability of light and growth traits of *T.*

ciliata along with nurse tree species was recorded before and two years of thinning. In third year, stem morphology (straightness and height to diameter ration) including destructive sampling of *T. ciliata* was performed to examine the thinning density and light availability and over storey nurse species. The mortality rate of *T. ciliata* was lower while the productivity was higher under *G. robusta* as compared to pines. The productivity of *T. ciliata* was higher where thinning practices of 75% were performed irrespective of nurse tree. The stem form was best under 50% thinning operation under the plantation of *P. taeda*. However, growth rate and stem morphology were not correlated with light availability.

Hidayat (2010) examined the morphological diversity of candidate plus trees (CPTs) of *Toona sinensis* collected from community forest populations at 16 districts of West Java and Central Java using the comparison tree method. Out of the ninety-six CPTs, morphological and seed characters were examined on twenty-four selected CPTs. The analysis of variance and dendrogram tree analysis revealed non-significant differences for morphological and seed characters reflecting low morphological diversity in CPTs from West Java and Central Java provinces. Significant positive correlation was found for stem height; clear bole height and crown length with diameter as well as rainfall.

Uppal and Singh (2010) conducted an experiment to study the effect of seed source on growth performance of *T. ciliata* seedlings and revealed that high heritability (h^2), genetic advance and genetic gain was found for root and shoot length respectively, indicating that these traits are under strong genetic control which may be attained, on account of seedlings emergence from heavy seeds containing stored food reserves responsible for more pre-photosynthetic growth at early stages. Further, they suggested that these traits could be useful for screening of seed sources for improvement programme of *T. ciliata*.

Ferreira *et al* (2012) revealed that application of individual best linear unbiased prediction (BLUP) procedure with repeated measures was found to be useful for estimation of genetic parameters and predict genotypic values for *T. ciliata* under the situations of unbalanced data and information for breeding programs of *T. ciliata*. Out of the 90 genotypes evaluated, 38 expressed genotypic values predicted for the diameter at breast height higher than the general average of this character, 33 for the cylindrical volume and 49 for height, allowing gains of up to 24.90 per cent in average for cylindrical volume.

Early selection and evaluation of two-year-old 14 half-sib families of *T. ciliata* var. *pubescens* was conducted by Huang *et al* (2012) in four provenances of Jiangxi province, China. Significant variation among families as well as provenances were recorded for collar diameter, plant height, height to diameter ratio, crown width, crown diameter ratio, under

crown height, number of branches, pest resistance and cold resistance index. The coefficient of variation for different traits ranged between 1.75% - 52.73% and provenances and family heritability between 0.21 to 0.86 per cent and 0.29 to 0.75per cent, respectively. Four superior families viz., 1, 2, 5, 9 were selected on the basis of morphometric traits viz., collar diameter, crown width, under crown height, number of branches and resistance, belonging to Guanshan mountain natural reserve provenance.

Wu *et al* (2015) evaluated genetic diversity for growth performance of 173 *T. ciliata* families at the age of eighteen months at two locations i.e., Xinhui and Lianping in Guangdong province of China. The results reported highly significant differences for plant height and diameter at breast height among provenances and replicates. The coefficient of genetic variation for plant height and dbh were 42.19% and 44.89% at Xinhui while 42.10% and 44.23% at Liangping. High heritability (bs) for plant height and dbh (0.88; 0.90) were obtained for Xinhui whereas high heritability for plant height (0.97) and moderate heritability (0.37) was recorded for Lianping. Family No. 169, 143, 154, 149 and 153 showed slowest growth whereas family No. 8, 1, 4, 116 and 39 exhibited fastest growth at Xinhui provenance. Family No. 134, 11, 86, 121 and 43 had significantly slowest growth whereas family No. 123, 24, 89, 105 and 51 were the fastest growing families for plant height at Liangping provenance.

Batista *et al* (2016) conducted studies on root morphology and nutrient uptake kinetics in four Australian cedar clones (HE, XF, XD, and XE) and reported significant variability for root morphological characteristics viz., length, volume, surface area, average diameter, and root length per diameter class. Clone XD exhibited the largest root system development. However, the uptake efficiency of P, K, Ca, and Mg also varied between different Australian cedar clones. When availability differed, clones XE and XF exhibited greater plasticity in the uptake of P and K respectively, and similar results were found for clone HE in the uptake of Ca and Mg.

Patil *et al* (2017) conducted an experiment on *Melia Dubia* to evaluate its growth and productivity under different planting density. The growth traits were recorded at different intervals of time viz., 42, 45, 48 and 51 months after planting. Significant variation was found for growth performance at different planting densities and maximum girth (cm)and plant height (m) was observed in planting density of 714 trees/ha (46.85 cm, 10.59 m; 50.14 cm, 10.99 m; 52.99 cm,11.22 m and 55.76 cm,11.43 m) with respect to all the time intervals. Though, the total stand volume (m^3 /ha) was expressively higher in case of planting density of 2500 trees/ha (125.00 m^3 /ha, 148.33 m^3 /ha, 165.83 m^3 / ha and 189.25 m^3 /ha) in the entire time intervals. The research concluded that, the planting density of 2500 trees/ha showed

significantly higher stand volume as compared to other planting density.

Sharma *et al* (2017) conducted an experiment to study the effect of tree spacing on growth performance of *Melia composita* at two experimental sites in Punjab viz., Handesra, Mohali and Bhera Village, Hoshiarpur at a spacing of 2×2m, 3×3m and 4×4m in the year of 2014, 2015 and 2016. The growth parameters; both plant height and collar diameter were measured for three consecutive years which depicted a maximum increase in height at Site-2 with a spacing of 3×3m in 2016 and minimum was recorded at a spacing of 4×4 in 2014. Similarly, in case of diameter the maximum diameter was recorded at site-2 with a spacing of 3×3m in year 2016. The results showed significant increment in growth parameters of tree species at both the sites. However, best growth performance was obtained in 3×3m spacing after several years of plantation. The study revealed that appropriate spacing plays a crucial role in determining bole height increment and wood production for the industries.

Genetic diversity and growth dynamics studies of fifty-three half-sib families of *Melia azedarach* was conducted by Chauhan *et al* (2018) at mid rotation (fourth year) and end rotation (eighth year). Significant variation was observed among and within seed provenances for all the growth traits at both the rotations. Maximum (broad sense) heritability was found at mid-rotation which depicted that the growth is genetically controlled but with the time environmental factors influenced the growth pattern. Further, they concluded that early stage selection is quite effective than later stage selection for all the growth traits except clear bole height which can be manipulated and is highly influenced by tree management practices and other environment factors.

Morphological characterization of fifteen *T. sinensis* populations were conducted by Jayusman and Fiani (2019). The selected population consisted of 8 populations from Central Java, 5 from West Java and 2 from East Java and were planted 12 year ago in a (*ex situ*) conservation area. Observations were recorded on quantitative growth parameters like total plant height, stem diameter, leaf edge, leaf surface, free height of branches and branching and qualitative traits like shape, colour surface of bark, canopy shape and leaf aroma. The cluster analysis revealed cross-population grouping with high morphological similarity (78 to 99%) while analysis of qualitative traits and 27 qualitative sub-traits of various geographic source of population of provinces showed cross- population grouping with morphological similarity of 80 to 99%. High morphological diversity was exhibited by three quantitative traits i.e., plant height, free height of branches and surface or stem diameter and two qualitative characters i.e., stem shape and canopy shape.

Parthiban *et al* (2019) examined 23 progenies of *T. ciliata* selected from its natural ranges distributed in Western Ghats, India. Significant variation was revealed by progenies for height, diameter at breast height (DBH) and volume during three growth periods. The progeny viz., TC02 was found to be superior with plant height (4.95 m), DBH (6.45 cm) and volume (0.010 m^3). The growth traits showed higher phenotypic coefficient of variance (PCV) values than their equivalent 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), which may be attributed to early evaluation at juvenile stage.

Zhan *et al* (2019) studied genetic diversity and population structure of *T. ciliata* using simple sequence repeat markers (SSRs). The study comprised of 29 populations having 551 individuals and the results revealed 0.723 polymorphic content and 146 alleles from all the populations using 12 microsatellite markers. Structure analysis divided the population into two major genetic linkages with a 28.00% genetic differentiation among the two lineages. Higher level of genetic diversity was found in western lineage in comparison to eastern lineage. Further, it was concluded that the two genetic lineages should be treated independently while making conservation strategy of *T. ciliata* resources.

2.2 Genetic variability for physiological traits

Ares and Fownes (2000) studied productivity, nutrient and water-use efficiency of *Eucalyptus saligna* and *Toona ciliata* in Hawaii islands. They observed that with increase in elevation there is an increase in leaf carbon isotope composition and specific leaf weight whereas decrease in the leaf area index of *E. saligna* which may be attributed to adjustment in structural (changes in stand leaf area, physiological (increased water use efficiency throughout stomatal closure) and leaf morphology so as to reduce the water availability. High net primary above ground productivity of *E. saligna* on young organic soil explained higher nitrogen productivity (NP=467kg ha^{-1} per year). While in *T. ciliata* leaf characteristics did not displayed any change along with the elevation gradient. Average N content per unit leaf area was similar but N content per unit leaf weight of *T. ciliata* was higher than *E. saligna.* The productivity and nitrogen productivity of *T. ciliata* was about half of *E. saligna,* although the productivity of *T. ciliata* was higher on volcanic ash soils in comparison to organic soils. Further, they concluded that different species exhibits different growth and physiological responses to environmental changes.

Thakur and Kaur (2001) compared physiological and growth traits of 12, ten-year-old multipurpose trees. Among all, *Grewia optiva, Bauhinia variegata, Robinia pseudoacacia, Melia azedarach, Dalbergia sissoo, Gmelina arborea and Albizia stipulata* exhibited outstanding performance for growth traits. Photosynthetic rate was found significantly higher

from July to November in most of the tree species whereas a declining trend was reported for transpiration rate from August onwards. However, water use efficiency was found to be low for all the MPTs with values ranging between 0.0031 and 0.0870 with the maximum WUE in *Albizia* and minimum in *Morus*. Further, Leaf area index (LAI) ranged between 0.47 and 3.23 from June to November. Monthly variations for LAI was observed, with an increasing trend from June to November for *Grewia optiva, Bauhinia variegata, Robinia pseudoacacia, Melia azedarach, Dalbergia sissoo, Albizia stipulata and Punica granatum* in contrast to decreasing trend for *Morus, Toona ciliata, Sapindus mukorossi and Gmelina arborea.*

Xiao *et al* (2008) studied two *Populus cathayana* populations to check its adaptive responses against progressive drought stress, where they exposed, young vegetatively propagated cuttings of *P. cathayana* to a drought stress for 12 weeks in a greenhouse situation to characterize the physiological and biochemical base of drought adaptation in woody plants. They found that the adaptive responses of *P. cathayana* to drought stress were affected by drought intensity and poplar genotype (population). The progressive drought stress significantly reserved plant growth, enlarged carotenoid contents and at the same time, accumulated soluble sugars and free proline in the plants of both populations tested. On the other side, the slowly increased drought also persuaded antioxidative systems containing the increase of the actions of superoxide dismutase (SOD) and glycol peroxidase (POD). Later they suggested that this difference in drought tolerance to efficient photo protective system, accumulation of the osmo protectant proline in addition to the increased capability of the antioxidative system to scavenge reactive oxygen species and the resultant suppressed level of lipid peroxidation under drought conditions.

Aasamaa *et al* (2010) identified that leaf morpho-physiological characteristics such as high chlorophyll content, maximum rate of photosynthetic electron transport, and flat vertical gradient (through foliage) could serve as the strongest indicators of high biomass production in *Salix* clones grown as vegetation filter for waste water purification system.

Zhen *et al* (2011) conducted a pot experiment to study the effect of drought stress on photosynthetic characteristics of seedling of *T. sinensis* from six different provenances viz., Nanjing, Guangyuan, Dongkou, Suizhou, Xixia and Ankang cities. The result showed a decreasing trend in photosynthetic rate and stomatal conductance in leaves of all the provenances under drought condition while intercellular carbon dioxide (CO_2) concentration displayed different trend. Highest decrease in photosynthetic rate was found in Dongkou provenance which showed less recovery after watering and very much less tolerant to drought stress. With prolonged stress,CO_2concentration and stomatal conductance decreased under two stress levels in seedlings of Nanjing, Guangyuan, Xixia and Ankang provenances in

which stomatal factors act as barrier for photosynthetic abilities while in seedling of Dongkou and Suizhou provenances, stomatal conductance decreased and CO_2 concentration increased at the end period of treatment and photosynthetic abilities were controlled by both stomatal and non-stomatal factors and plants from these provenances recovered slowly after watering.

Bouman and Sylliboy (2012) while testing growth parameters of different willow varieties reported significant differences for leaf area, leaf chlorophyll concentration, biomass and leaf allocation of biomass. Willow growth was functionally balanced as root biomass scaled positively with leaf area whereas the relationship between leaf chlorophyll concentration and leaf area remained non-significant.

Huiwu *et al* (2012) compared the photosynthetic characteristics of two-year-old *T. ciliata* var. pubescens from three different provenances (Guans Han Nature Reserve, Matoushan Nature Reserve and Jijulianshan Nature Reserve). Results indicated that under high temperature *T. ciliata* var. pubescens from Guanshan Nature Reserve has higher photosynthetic rate than the other two provenances. The diurnal variation of net photosynthetic rate (Pn curve) was "twin peaked" and the value of peak was between 10:00 to 14:00. They observed a midday depression phenomenon during sunny time and the growth of *T. ciliata* var. pubescens was at peak during the month of September.

Murphy *et al* (2012) compared the function and anatomy of leaf hydraulic systems in the leaves of *T. ciliata* grown under high and low irradiance under controlled conditions. The results indicated that in toon, differential leaf expansion regulates the density of veins and stomata such that leaf hydraulic conductance and stomatal conductance remained proportional. Further, leaf size plasticity can provide an efficient way for plants to acclimate hydraulic and stomatal conductance to the contrasting evaporative conditions of sun and shade.

Jun *et al* (2014) evaluated the performance of *T. sinensis* under different forest gap size (50 m^2,100 m^2 and 200 m^2 and open field conditions) at central Sichuan, China to examine the response of varying light intensity on photosynthetic characteristics, growth and physiology of *T. sinensis*. The results revealed that plant height, diameter and crown area was significantly affected by increase in forest gap. With increase in forest gap size, the rate of net photosynthesis (at noon), maximum net photosynthetic rate, photosynthetic nitrogen utilization efficiency, light use efficiency, chlorophyll a/b, leaf thickness, leaf fresh mass, leaf dry mass, malondialdehyde, superoxide dismutase and soluble protein increased. On other hand, net photosynthetic rate (day), chlorophyll a, chlorophyll b, carotenoids decreased with increase in forest gap size. It was concluded that with increase in forest gap size,

photosynthetic capacity of *T. sinensis* decreased and showed positive effect on differences of photosynthetic capacity and growth. The non-stomatal limitation was the main factor that inhibited net photosynthetic rate and during initial stages of gap formation, gap II had high photosynthetic capacity and productivity.

Liu *et al* (2019) examined the potential of foliar exogenous application of polyamines (PAs) to improve drought- induced oxidative damage and physiological inhibition in two-year-old *T. ciliata* seedlings. The seedlings were given foliar spray of three PAs i.e., putrescine (Put), spermidine (Spd) and spermine (Spm)) in 1 mM solutions three times at intervals of one day and then they were exposed to drought stress by withholding of irrigation over a period of 21 days. The pre-treatments of PA considerably reduced water loss and improved membrane integrity, photosynthetic capacity, antioxidant systems and up regulation of the expression of S-adenosylmethionine decarboylase (SAMDC) gene of trees under drought stress. Pre-treatments of Spd or Spm were found superior to Put. The improved drought tolerance of young seedlings of *T. ciliata* induced by PA pre-treatments was associated with enhanced photosynthetic capacity whereas reduction in the loss of water with altered anatomy of leaves.

Andrade *et al* (2020) studied morphological and physiological variation in *T. ciliata* under water and salinity stress using seven treatments including control, the complete suspension of irrigation, the permanent saturation of the pot and four doses of NaCl (50, 100, 200, 400 μmol). Reduction in morphological and physiological growth traits was recorded in all the treatments. However, later in the end of the experiment all individuals under stress recovered slightly and adapted to all the conditions and started sprouting.

2.3 Correlation studies and principal component analysis

Kundu (2000) evaluated provenance variation on early growth and survival of *Azadirachta indica* at three sites of International provenance trial in India and Bangladesh and reported significant positive correlation between plant height and collar diameter with survival rate at all sites. Two principal components with total variation of 99% for site-I, 98% for site-II and 100% at site-III were obtained. The first principal component contributed 83% at site-I, 86% at site-II and 72% for site-III whereas second principal component accounted 16% at site-I, 12% at site-II and 28% at site-III. The PCA revealed that at all the three sites, distinct population variation was observed for plant height and survival in *A. indica*.

Isik and Toplu (2004) investigated *Populus nigra* clones for survival, growth and quality traits in southeast region of Turkey using principal component analysis which revealed that the first three components contributed ninety per cent towards the total variation. First

principal component had maximum loadings of 52% for plant height, diameter and apical dominance; the second component had 25% loading with maximum value for branchiness and straightness whereas third principal component had 12 % loading, with maximum values for bole straightness and branching index. Moderate correlation was exhibited between diameter and bole straightness (0.34).

Jun *et al* (2008) evaluated genetic variation for growth and biomass traits among plus trees seedlings of *T. ciliata* var. Pubescens. The results showed significant variation for growth traits among families and found positive significant correlation for seedling height with collar diameter and shoot dry weight; collar diameter with root dry weight, shoot dry weight and root volume. Among root traits significant positive correlation was found between root length, surface area of roots and root volume. They concluded that, seedling height and collar diameter as the important traits for selection.

Danquah *et al* (2011) examined morphological variation in leaves traits of two species of African Mahoganies i.e., *Khaya ivorensis* and *Khaya anthotheca*. Thirteen leaf morphometric traits were scored in 50 leaflets randomly sampled from 195 individual's of11 provenances representing natural distribution of African mahoganies in Ghana. The Principal component analysis revealed four principal components which explained 97.50% and 98.50% of total variation in *K. ivorensis* and *K. anthotheca* respectively. Significant differences were found for leaf morphology in *Khaya ivorensis* at both, populations ($P<0.001$) and ecological zones level ($P<0.001$), whereas in case of *K. anthotheca* significant difference was observed at population level ($P<0.001$) only. The UPGMA and PCA suggested that two clusters of populations of *K. anthotheca* and one cluster of *K. ivorensis* were morphologically similar. Moreover, the results of discriminant function analysis indicated that the two species of *Khaya* might have existed as separate species, although their distributions overlap in some ecological zones.

Wani *et al* (2012) studied association analysis for morphological and biomass traits in *Albizzia lebbeck* seedlings under green house and field conditions. Seeds were collected from twenty different seed sources of Uttar Pradesh and examined for morphological and biomass traits viz., seeding height, collar diameter, internodal length, branches/seedlings, leaf area, shoot and root fresh and dry weight, shot/root ratio and seedling biomass. Out of 55 correlation combination within both the environments, 26 and 10 were positive and highly significant, 10 and 9 were positive and significant correlation. Positive and significant correlation was discovered between the seedling height and collar diameter, leaf area, shoot fresh weight and root dry weight. Root dry weight and shoot dry weight showed significant and positive correlation with seedling biomass under both the environment. The result

revealed a strong inherent association between these characters.

Sangram and Keerthika (2013) studied genetic variability for morphological characteristics of *Leucaena leucocephala* germplasm collected from three states i.e., Tamil Nadu, Andhra Pradesh and Maharashtra. Positive significant phenotypic and genotypic correlation was found for volume index with plant height (0.76) and basal diameter (0.97); basal area with plant height (0.61 and 0.77) while plant height shows positive but non-significant phenotypic (.02) and genotypic (.16) inter-correlation with number of branches. They suggested that basal area and plant height had direct effect on volume index.

Singh *et al* (2014) analyzed genetic variability among the sixty-nine *P. deltoides* clones and reported significant differences for various growth attributes. Low to moderate heritability was recorded for stem diameter, trunk volume and plant height whereas maximum value for genetic advance was recorded in sylleptic branch number. Strong positive and significant genotypic correlation was observed between stem diameter and sylleptic branch number (0.97). Principal component analysis revealed that the first principal component explained the maximum 58% contribution in the total variation followed by principal component two and third. 25 top clones were identified on the basis of loadings pertaining to PC I.

Li *et al* (2015) investigate genetic diversity among 30 population of *T. ciliata* by using 24 selected sequence-related amplified polymorphism (SRAP) markers. Total 656 SRAP bands ranging from 100 to 1500 bp were obtained, out of which 505 bands (77%) were found to be polymorphic. The polymorphism information content (PIC) values ranged from 0.32 to 0.45, with an average of 0.41. The results obtained from analysis of molecular variance (AMOVA) indicated that maximum significant variation was attributed to differences among populations and minimum within the population. The unweighted pair group method of arithmetic averages (UPGMA) clustering and principal coordinate's analysis (PCoA) showed that the 30 populations of *T. ciliata* were divided into four types indicating a clear geographical trend for *T. ciliata* in China which could be used as a theoretical basis for future breeding and conservation strategy of *T. ciliata.*

Thakur and Thakur (2015) studied correlation in growth characteristics of progenies of *Melia azedarach* and reported that plant height had significant positive genotypic and phenotypic correlation with number of branches (0.85 and 0.82) and collar diameter (0.84 and 0.81), similarly collar diameter showed positive phenotypic and genotypic correlation with number of branches (0.83 and 0.74) and number of leave (0.70 and 0.65).

Deepanjli (2018) conducted variation studies on *T. ciliata* under nursery conditions and reported highly significant positive correlation between seed weight and germination percent, germination percent and survival percent, seedling height and collar diameter, seedling height and dry shoot weight. The genotype G1 and G7 were found outstanding for most of the growth and biomass traits.

Lastin *et al* (2019) conducted experiment to estimate and correlation between *T. sinensis* leaves weight with different growth parameters. Total 110 trees were selected from private forest in Sumedang district, West java province, Indonesia and observations were recorded for diameter at breast height, total height, timber height, crown height, crown diameter and leaf weight. Significant positive correlation was found between leaf weight and diameter at breast height, total height, crown height and crown diameter. The highest correlation (0.75) was found between leaf weight and diameter at breast height. Approximate weight of leaves of tree having DBH 10-19 cm was 8 to11 kg/tree and for DBH- 20cm or above was between 18 to 23 kg/tree.

Kundal *et al* (2020) evaluated growth performance of half sib progenies of *T. ciliata* M. Roem under field conditions and found that seed source S_3(Ludhiana) showed outstanding performance while among genotypes S_3G_7 (Ludhiana), S_3G_8 (Ludhiana), S_1G_1 (Talwara) and S_2G_4 (Kamahi Devi) were observed to be outstanding for growth traits. Phenotypic coefficient of variation was higher than genetic coefficient of variation and moderate heritability and genetic gain was registered for branch angle and pant height. Plant height showed highly positive significant phenotypic and genotypic correlation with collar diameter and stem straightness and collar diameter with number of branches per plant. The genotypes were clustered into three groups and maximum diversity (30.568) was observed between cluster I and II.

CHAPTER-III

MATERIAL AND METHODS

The present investigation entitled, "Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem" was carried out with the objective of evaluation of genotypes on the basis of morphological and physiological characters in the field and selection of superior genotypes of *T. ciliata* from existing field trial. Detailed information of the experiment related to seed sources, experimental site, field evaluation of half sib progenies of genotypes and methodology adopted for the research are explained here under following headers: -

3.1 Studies on growth and physiological traits in *Toona ciliata*
3.2 Statistical analysis
3.3 Index score analysis
3.4 Correlation studies
3.5 Principal component analysis

3.1 Experiment: Studies on growth and physiological traits in *Toona ciliata*

3.1.1 Location

The experiment was laid out in Teaching area, Department of Forestry & Natural Resources, Punjab Agricultural University, Ludhiana. The area is situated at 30° 54' 26 " N latitude and 75° 47' 38" E longitude at an elevation of 247 m above mean sea level, representing the central zone of Punjab.

3.1.2 Climate

Climate is subtropical to tropical, semi-arid having three distinct seasons i.e. hot and dry summer (April to June), hot and humid monsoon (July to September) and cold winters (December to February). Occurrence of frost is not common. Site receives an average annual rainfall of 700-750 mm, mostly received during the months of July and September.

3.1.3 Methodology

Assessment of morpho-physiological traits was performed on progeny trial of *T. ciliata* established in the year 2018, using randomized complete block design (RCBD) with 4 replications at a distance of 4 x 3 m in east-west (row distance) direction. The detailed list of *T. ciliata* seed sources and genotypes established in the progeny trial are presented in Table 1. The soil texture of the experimental site was clayey loam. The trial was irrigated at fortnight intervals in summers and at monthly intervals in winters. Weeding was performed at monthly intervals. Observation on growth parameters (plant height, clear bole height, collar diameter, straightness scores and petiole length) were recorded at an interval of six month and

observation on leaf area was recorded once in the month of August. The pigment concentration (chlorophyll a, chlorophyll b, chlorophyll index (a/b), total chlorophyll and carotenoids) and sugar accumulation content (total soluble sugar, sucrose and starch) was analyzed in the laboratory of Department of Plant Breeding and Genetics.

Table 1: Details of *T. ciliata* seed sources and genotypes used in the study:

Code Name	Seed sources (Districts)	Genotypes	Latitude (°)	Longitude (°)	Altitude (above msl)
S1	Talwara (Hoshiarpur, Punjab)	G1	31° 55' 52"	75° 53' 38"	380
		G2	31° 56' 20"	75°52'30"	367
		G3	31°56'55"	75°48'28"	350
S2	Kamahi Devi (Hoshiarpur, Punjab)	G4	31° 64' 23"	75° 53' 29"	368
		G5	31°54'24"	75°49'24"	330
		G6	31°59'35"	75°58'47"	394
S3	Ludhiana (Punjab)	G7	30° 50' 43"	75° 53' 12"	255
		G8	30°46'04"	75°51'27"	250
		G9	30°47'32"	75°51'11"	250
S4	Sujanpur (Hamirpur, HP)	G10	31°48'59"	76°31'3"	726
		G11	31°48'05"	76°28'06"	610
		G12	31°47'57"	76°27'58"	601
S5	Salouni (Hamirpur, HP)	G13	31° 31' 42"	76° 27' 49"	805
		G14	31°33'46"	76°28'45"	807
		G15	31°63'26"	76°28'43"	808
S6	Chabutra (Hamirpur, HP)	G16	31° 44' 27"	76° 28' 24"	750
		G17	31°44'28"	76°28'30"	749
		G18	31°44'20"	76°28"36"	740
S7	Shah Talai (Bilaspur, HP)	G19	31° 26' 09"	76° 32' 28"	610
		G20	31°27'09"	76°32"28"	613
		G21	31°26'03"	76°32'38"	618
S8	Suhari Takoli (Una, HP)	G22	31° 40' 23"	76° 14' 50"	630
		G23	31°40'12"	76°14'58"	625
		G24	31°40'23"	76°14'50"	626

3.1.4 Experimental procedure:

The observations on growth characters were taken at an interval of six months for one year.

Growth traits

i. **Plant height (cm):**

Plant height was measured from basal area to the tip of leading shoot by using measuring tape.

ii. **Collar diameter (cm):**

Collar diameter of the plant was measured at 2-5 cm above ground level (collar region) by using digital vernier caliper.

iii. **Petiole length (mm):**

Petiole is the stalk that attaches the leaf blade to the stem. Petiole length was measured from the stalk to leaf blade which is attached to stem by using measuring scale.

iv. **Clear bole height (m):**

Clear bole height represents the tree height from the base of tree to first crown forming branch and was measured by using tape.

v. **Stem straightness (1-5):**

Stem straightness was visually scored from 1 (least straight) to 5 (most straight) keeping in view the stem crookedness, crown spread and forking.

vi. Leaf area (cm^2):

For the measurement of leaf area, five fully expanded leaves per plant were randomly selected and detached from each plant. The detached leaves were collected in paper bags. The leaf area was calculated using leaf area meter. Each leaf was placed under arm of the leaf area meter and was digitally scanned to determine the leaf area. The leaf area was determined in cm^2.

Physiological traits

I. Pigment concentration (mg/g FW):

A 50mg (0.05g) of fresh leaf tissues of *T. ciliata* were placed in test tube and dipped in 5ml Dimethyl sulphoxide (DMSO). The test tubes were kept in an oven at 65^{o} C for 3 to 5 hours so that leaves facilitate complete extraction of pigments and then allowed to cool at room temperature. The absorbed color was recorded at 645 nm and 663 nm for chlorophyll a, chlorophyll b and total chlorophyll at 480 nm, 645 nm; and 663 nm for the carotenoid by

using spectrophotometer. The recorded data was used for measuring pigment concentration by using following equations:

$$\text{Chl a} = [12.19 \times A663 - 3.43 \times A645] \times \frac{V}{1000 \times W}$$

$$\text{Chl b} = [12.99 \times A645 - 5.32 \times A663] \times \frac{V}{1000 \times W}$$

$$\text{Total chlorophyll} = [20.2 \times A645 - 8.02 \times A663] \times \frac{V}{1000 \times W}$$

$$\text{Carotenoid content} = [A480 + .114 \times A663 - .638 \times A645] \times \frac{V}{1000 \times W}$$

Where A480, A645 and A663 refers to absorbance of colour at 480 nm, 645 nm and 663 nm respectively on spectrophotometer, V refers to total volume of the extract (ml) and W is fresh weight of leaf tissue (g).

II. Sugar accumulation content (g sugar/g FW):

Sugar accumulation consists of total soluble sugar, sucrose and starch content. For extraction of sugar 100mg (.1g) sample of fresh leaves was taken in mortar and pestle and crushed in 2 ml of 80% of alcohol and then rinsed with another 2 ml of 80% alcohol and collected in test tubes. The test tubes were centrifuged at 500 rpm for 10 minutes and the supernatant liquid and residue was collected separately. The supernatant liquid was pooled up to 15 ml and used for extraction of total soluble sugar and sucrose content while the residue was used to extract the starch content.

a. Total soluble sugar (g glucose/g FW)

0.2 ml of the supernatant and 3.8 ml of distilled water was taken in a test tube to make 4 ml volume and then 1 ml 5% phenol was added in the test tube. The test tubes were spinned in a vortex and placed for 10 min at room temperature. After that 5ml of ice cold concentrated H_2SO_4 was added in the test tubes and kept for 20 min at room temperature. After cooling of the test tube, the absorbance of orange colour solution was measured using spectrophotometer at 490 nm against the reagent blank. The calculation of total sugar concentration was done by taking glucose standard curve (10-100µg/ml).

b. Sucrose (g sucrose/g FW)

1 ml of sugar extract was taken and 1 ml of 6% KOH was added in the test tube and placed in an oven for 20 minutes at 100^{o}C, followed by cooling at room temperature. Then, 1 ml of resorcinol solution and 3 ml of 30% HCl was added in the test tubes and incubated at 80^{o}C for 10 minutes. After that, the absorbance of pink color was measured at 490 nm against blank. The sucrose content was calculated from glucose standard curve (300-400µg/ml).

c. Starch (g starch/g FW)

0.2 ml of residual extract was taken and 3.8 ml of distilled water was added in the test tube to make 4 ml volume. After that, 1 ml of 5% phenol was added and the test tubes were kept for 10 minutes and then 5 ml of concentrate H_2SO_4 was added in the test tubes and placed at room temperature for 30 minutes for cooling. The absorbance of orange yellow chromophore was measured at 490 nm against the blank. The total starch concentration was calculated from glucose standard curve (10-100µg/ml). Starch content was measured by multiplying sugar content with 0.9 factor.

3.2 Statistical analysis

The data recorded for each trait was subjected to statistical analysis as per the procedure laid down for Randomized complete block design (RCBD Factorial). Analysis of variance, critical difference (CD) and variance components were calculated as suggested by Panse and Sukhatme (1989).

3.2.1 ANOVA

Source of variation	Degree of freedom	Mean of squares	Fcal
Replication	(r-1)	Mr	
Treatments	(ab-1)	Mt	Mt/Me
Seed source (A)	(a-1)	MS_a	MS_a/Me
Genotype (B)	(b-1)	MS_b	MS_b/Me
Interaction (A × B)	(a-1) × (b-1)	MS_{ab}	MS_{ab}/Me
Error	(r-1) × (ab-1)	Me	
Total	(rab-1)		

Where,

r = Number of replications

t = Number of treatments

Mr = Mean sum of squares due to replications

Mt = Mean sum of squares due to treatments

MS_a = Mean sum of squares due to seed source

MS_b = Mean sum of squares due to genotypes

MS_{ab} = Mean sum of squares due to (seed source × genotype) interaction

Me = Mean sum of squares due to error

3.2.2 Critical difference (CD)

The critical difference (CD) was calculated as under:

CD = $SE_d \times t_{0.05}$ error degree of freedom

Where;

SE_d = Standard error of difference calculated as:

$$SE_d = \frac{\sqrt{2\,Me}}{r}$$

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

3.2.3 Variability parameters

Phenotypic, genotypic, and environmental variances were calculated as follows:

(Phenotypic variance) Vp = Vg + Me

(Environmental variance) Me = Mean sum of square due to error

$$\text{(Genotypic variance) Vg} = Mt - \left[\frac{Me}{r}\right]$$

Coefficient of variability was calculated as under:

$$CV\ (\%) = \left[\frac{\sqrt{SD}}{\overline{X}}\right] x100$$

Coefficient of phenotypic, genotypic and environmental variability was worked out as under:

$$PCV\ (\%) = \left[\frac{\sqrt{Vp}}{\overline{X}}\right] x100$$

$$GCV\ (\%) = \left[\frac{\sqrt{Vg}}{\overline{X}}\right] x100$$

$$ECV\ (\%) = \left[\frac{\sqrt{Ve}}{\overline{X}}\right] x100$$

Where,

SD = Standard deviation

$\overline{X}$ = Population mean

Vp = Phenotypic variance

Vg = Genotypic variance

Ve = Environmental variance

PCV = Phenotypic coefficient of variability

GCV = Genotypic coefficient of variability

3.2.4 Heritability (Broad sense)

Heritability in broad sense was calculated as suggested by Burton and Devane (1953) and Johnson *et al* (1955).

$$h^2_{b.s.} = \left[\frac{Vg}{Vp}\right] x\,100$$

Where,

$H^2_{b.s}$ = Heritability (broad sense)

3.2.5 Genetic advance

The genetic advance was calculated by the formula as suggested by Johnson *et al* (1955).

$$\text{Genetic advance (GA)} = \left[\frac{Vg}{Vp}\right] x \left(\sqrt{Vp}\right) x\, K$$

Where,

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

3.2.6 Genetic gain

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

$$\text{Genetic gain (\%)} = \left[\frac{GA}{\overline{X}}\right] x\,100$$

3.3 Index score analysis

Index score analysis was performed on mean data of morphological traits viz., plant height, clear bole height, collar diameter and stem straightness (Anderson 1957). The class intervals used for different parameters are presented in Table 2. Scores were given to the genotypes between 1 to 4 on the basis of the mean values for these parameters with respect to the class intervals.

Table 2: Class intervals for index scoring for morphological traits of 24 genotypes of *T. ciliata*

Scores / Characters	1	2	3	4
Plant height (m)	≤ 3.00	3.01-3.50	3.51-4.00	> 4.01
Clear bole height (m)	≤ 1.00	1.01-1.40	1.41-1.80	> 1.81
Collar diameter (cm)	≤ 6.00	6.01-7.00	7.01-8.00	> 8.01
Stem straightness (1-5)	≤ 3.00	3.01-3.50	3.51-4.00	>4.01

3.4 Correlation coefficients

The genotypic and phenotypic correlation coefficients were worked out using OPSTAT software.

3.5 Principal component analysis

Principal component analysis (PCA) was performed on data recorded for morphological and physiological traits using SPSS software, version 10.0. The latent root criterion (Eigen values greater than unity) was applied for extracting the number of principal components.

CHAPTER-IV

RESULTS AND DISCUSSION

The present investigation entitled "Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem" was performed during 2019-20 on progeny trial of *T. ciliata* established in year 2018 at Teaching area, Department of Forestry & N.R., Punjab Agricultural University, Ludhiana with the objective of evaluation of genotype on the basis of morphological and physiological characters and selection of superior genotypes of *T. ciliata* from the existing field trial. The result observed on different morphological and physiological parameters has been discussed separately under the following headings.

4.1 Morphological characteristics

4.2 Index scores analysis

4.3 Physiological characteristics

4.4 Variability estimates and genetic parameters

4.5 Correlation studies

4.6 Principal component analysis

4.1 Morphological characteristics

The observations on growth characteristics i.e., plant height, clear bole height, collar diameter, petiole length and stem straightness were recorded at interval of six months. However, leaf area was recorded once at stage II only.

4.1.1 Plant height (m)

The analysis of variance depicted significant differences for plant height among different seed source as well as genotypes within seed sources at both the stages.

Stage-I

Data pertaining to Table 3 revealed that in stage – I, mean maximum plant height (2.32 m) among seed sources was achieved by S_2 followed by S_6, S_3, S_5 and S_1 with plant height of 2.23 m, 2.18 m, 2.12 m and 2.10 m respectively. While minimum plant height was registered in S_7 (1.84 m).

Maximum plant height among genotypes within seed sources was 2.99 m for S_2G_4 proceeded by 2.58 m for S_6G_{16}. The minimum value for the trait (1.69 m) was recorded in S_7G_{21}.

Stage-II

At stage-II seed source S_5 attained mean maximum plant height of 3.98 m whereas S_7

was found to have minimum value (3.33 m) for the trait.

Table 3: Effect of seed source and genotypes within seed sources on plant height (m) of *T. ciliata* progeny

Seed source	Genotypes	Plant height (m)	
		Stage-I	Stage-II
S1 (Talwara)	G1	2.07	3.52
	G2	2.17	3.56
	G3	2.05	3.30
	Mean	2.10	3.46
S2 (Kamahi Devi)	G4	2.99	4.01
	G5	2.03	3.35
	G6	1.93	3.32
	Mean	2.32	3.56
S3 (Ludhiana)	G7	2.03	3.64
	G8	2.31	3.73
	G9	2.21	3.58
	Mean	2.18	3.65
S4 (Sujanpur)	G10	1.88	3.43
	G11	2.13	3.49
	G12	1.87	3.25
	Mean	1.96	3.39
S5 (Salouni)	G13	2.29	4.30
	G14	1.84	3.51
	G15	2.22	4.12
	Mean	2.12	3.98
S6 (Chabutra)	G16	2.58	3.64
	G17	2.14	3.73
	G18	1.99	3.08
	Mean	2.23	3.48
S7 (Shah Talai)	G19	1.76	3.39
	G20	2.06	3.36
	G21	1.69	3.24
	Mean	1.84	3.33
S8 (Suhari Takoli)	G22	1.87	3.40
	G23	2.25	3.63
	G24	1.92	3.30
	Mean	2.01	3.44
Mean		2.09	3.54
Range		1.69-2.99	3.08-4.30
CD (p=0.05)			
Seed source		0.27	0.27
Interaction (Seed source × Genotype)		0.47	0.47

While among genotypes within seed sources, S_5G_{13} had maximum plant height (4.30 m) which was statistically at par with S_5G_{15}, S_2G_4 with plant height of 4.12m, 4.01m respectively, whereas mean minimum value for plant height (3.08 m) was recorded in genotype S_6G_{18}.

4.1.2 Clear bole height (m)

Table 4: Effect of seed source and genotypes within seed sources on clear bole height (m) of *T. ciliata* progeny

Seed source	Genotypes	Clear bole height (m)	
		Stage-I	Stage-II
S1 (Talwara)	G1	0.94	1.21
	G2	0.98	1.36
	G3	0.93	1.10
	Mean	0.95	1.22
S2 (Kamahi Devi)	G4	2.46	1.99
	G5	0.96	1.33
	G6	0.86	1.47
	Mean	1.43	1.60
S3 (Ludhiana)	G7	0.95	1.11
	G8	0.93	1.11
	G9	0.98	1.26
	Mean	0.95	1.16
S4 (Sujanpur)	G10	1.01	1.57
	G11	1.04	1.43
	G12	0.97	1.29
	Mean	1.01	1.43
S5 (Salouni)	G13	1.03	1.96
	G14	0.89	1.35
	G15	1.50	1.87
	Mean	1.14	1.73
S6 (Chabutra)	G16	1.57	1.34
	G17	1.05	1.32
	G18	0.81	1.19
	Mean	1.14	1.28
S7 (Shah Talai)	G19	0.78	1.56
	G20	1.02	1.42
	G21	0.69	1.41
	Mean	0.83	1.46
S8 (Suhari Takoli)	G22	0.76	1.05
	G23	1.06	1.46
	G24	1.09	1.15
	Mean	0.97	1.22
Mean		1.05	1.39
Range		0.69-2.46	1.05-1.99
CD (p=0.05)			
Seed source		0.21	0.20
Interaction (Seed source × Genotype)		0.36	0.34

The analysis of variance depicted significant differences for clear bole height among seed sources as well as genotypes within seed sources at both the stages.

Stage-I

Perusal of Table 4 depicted that in stage – I, maximum clear bole height (1.43 m) was observed in seed source S_2 whereas the mean minimum value was showed by seed source S_7 (0.83 m).

Maximum clear bole height among genotypes within seed sources (2.46 m) was registered in genotype S_2G_4 while minimum value for the trait (0.69 m) in genotype S_7G_{21}.

Stage-II

An appraisal of Table 4 elucidated that at stage II, seed source S_5 had maximum clear bole height of 1.73 m followed by S_2 (1.60 m). The mean minimum value for the trait was found in seed source S_3 which was 1.16 m.

Among genotypes within seed sources, the mean maximum value for clear bole height was (1.99 m) was observed in genotype S_2G_4 followed by S_5G_{13} and S_5G_{15} having clear bole height of 1.96 m and 1.87 m, respectively. However, the mean minimum value for clear bole height was observed in genotype S_8G_{22} (1.05 m).

4.1.3 Collar diameter (cm)

The analysis of variance depicted significant differences for collar diameter among the different seed sources as well as genotypes within seed sources at both the stages.

Stage-I

A critical rummage of Table 5 explicated that for collar diameter, at stage - I seed source S_3 attained mean maximum value of 4.06 cm followed by seed source S_1, S_2, S_5 and S_8 having collar diameter of 3.97 cm, 3.86 cm, 3.80 cm and 3.68 cm, respectively. The minimum value for collar diameter (3.34 cm) was recorded for seed source S_4.

Maximum collar diameter among genotypes within seed sources was registered in S_5G_{13} (4.66 cm), followed by S_2G_4, S_3G_8, S_3G_9, S_1G_3 and S_1G_1 having corresponding collar diameter of 4.42 cm, 4.40 cm, 4.07 cm, 4.03 cm and 3.99 cm whereas the mean minimum value for the trait (2.98 cm) was observed for S_5G_{14}.

Stage-II

At stage -II maximum collar diameter among seed sources was observed in S_3 (7.98 cm) followed by 7.66 cm, 7.55 cm, 7.43 cm and 7.22 cm for S_5, S_1, S_6 and S_8 respectively, while minimum value (6.37 cm) for the trait in seed source S_4.

Table 5: Effect of seed source and genotypes within seed sources on collar diameter (cm) of *T. ciliata* progeny

Seed source	Genotypes	Collar diameter (cm)	
		Stage-I	Stage-II
S1 (Talwara)	G1	3.99	7.55
	G2	3.89	7.28
	G3	4.03	7.83
	Mean	3.97	7.55
S2 (Kamahi Devi)	G4	4.42	7.19
	G5	3.77	7.25
	G6	3.40	6.68
	Mean	3.86	7.04
S3 (Ludhiana)	G7	3.69	7.15
	G8	4.40	8.88
	G9	4.07	7.93
	Mean	4.06	7.98
S4 (Sujanpur)	G10	3.15	6.28
	G11	3.55	6.73
	G12	3.30	6.10
	Mean	3.34	6.37
S5 (Salouni)	G13	4.66	9.18
	G14	2.98	6.55
	G15	3.76	7.24
	Mean	3.80	7.66
S6 (Chabutra)	G16	3.77	9.01
	G17	3.44	7.18
	G18	3.29	6.10
	Mean	3.50	7.43
S7 (Shah Talai)	G19	3.40	6.53
	G20	3.68	6.78
	G21	3.24	6.16
	Mean	3.44	6.49
S8 (Suhari Takoli)	G22	3.60	6.73
	G23	3.62	7.38
	G24	3.82	7.56
	Mean	3.68	7.22
Mean		3.71	7.22
Range		2.98-4.66	6.10-9.18
CD (p=0.05)			
Seed source		0.44	0.84
Interaction (Seed source × Genotype)		0.76	1.46

While examining the table 5, the mean maximum collar diameter among genotypes within seed sources was 9.18 cm registered for genotype S_5G_{13} followed by S_6G_{16}, S_3G_8, S_3G_9 and S_1G_3 with collar diameter of 9.01 cm, 8.88 cm, 7.93 cm and 7.83 cm, respectively. The mean minimum value for collar diameter (6.10 cm) was observed in genotype S_4G_{12} and S_6G_{18}. While examining the table 5, the mean maximum collar diameter among genotypes within seed sources was 9.18 cm registered for genotype S_5G_{13} followed by S_6G_{16}, S_3G_8, S_3G_9 and S_1G_3 with collar diameter of 9.01 cm, 8.88 cm, 7.93 cm and 7.83 cm, respectively. The

Plate 1: Overview of progeny trial of *Toona ciliata* under field conditions

Plate 2: Morphological view of genotype S_5G_{15}

mean minimum value for collar diameter (6.10 cm) was observed in genotype S_4G_{12} and S_6G_{18}.

4.1.4 Stem straightness (1-5)

Table 6: Effect of seed source and genotypes within seeds sources on stem straightness of *T. ciliata* progeny

Seed source	Genotypes	Straightness score (1-5)	
		Stage-I	Stage-II
S1 (Talwara)	G1	4.21	4.13
	G2	4.31	4.38
	G3	4.17	4.21
	Mean	4.23	4.24
S2 (Kamahi Devi)	G4	4.81	4.88
	G5	4.08	4.15
	G6	4.25	4.31
	Mean	4.38	4.44
S3 (Ludhiana)	G7	4.13	4.19
	G8	4.25	4.31
	G9	4.31	4.38
	Mean	4.23	4.29
S4 (Sujanpur)	G10	3.98	4.00
	G11	3.60	3.94
	G12	4.29	4.31
	Mean	3.96	4.08
S5 (Salouni)	G13	3.94	4.00
	G14	4.69	4.56
	G15	4.19	4.25
	Mean	4.27	4.27
S6 (Chabutra)	G16	4.19	4.31
	G17	4.17	4.19
	G18	3.81	3.88
	Mean	4.06	4.13
S7 (Shah Talai)	G19	4.08	4.13
	G20	4.08	4.31
	G21	4.02	4.13
	Mean	4.06	4.19
S8 (Suhari Takoli)	G22	4.00	4.25
	G23	4.02	3.88
	G24	4.02	4.13
	Mean	4.01	4.08
Mean		4.15	4.22
Range		3.81-4.81	3.88-4.88
CD (p=0.05)			
Seed source		0.29	NS
Interaction (Seed source × Genotype)		0.50	0.44

Significant differences for stem straightness were observed among genotypes within seed sources at both the stages, whereas among seeds sources significant differences were recorded at stage - I whereas non-significant differences were observed at stage –II.

Stage-I

The data presented in Table 6 revealed that maximum mean value (4.38) for stem straightness was observed in seed source S_2 which was found to be statistically at par with seed source S_1 (4.23), S_3 (4.23) and S_5 (4.27) whereas, minimum value for stem straightness was showed by S_4 (3.96).

While among genotypes within seed sources, maximum stem straightness was recorded for genotype S_2G_4 (4.81) followed by S_5G_{14} (4.69), S_1G_2 and S_3G_9 (4.31). The minimum vale for the trait was observed in S_4G_{11} (3.60).

Stage-II

At stage- II, stem straightness among genotypes within seed sources was registered in genotype S_2G_4 having highest value for stem straightness (4.88) followed by S_5G_{14} (4.56), while S_6G_{18} and S_8G_{23} showed lowest value (3.88).

4.1.5 Petiole length (cm)

The analysis of variance depicted significant differences for petiole length among the different seed source as well as genotypes within seed sources at both the stages.

Stage-I

The scrutiny of Table 7 depicted that seed source S_8 had maximum petiole length of 11.56 cm followed by seed source S_2 (10.80 cm) whereas minimum value for petiole length (9.17 cm) was recorded in seed source S_1.

Maximum petiole length among genotypes within seed sources (14.31 cm) was recorded for S_8G_{22} which was statistically equivalent to S_2G_4 (13.00 cm). While, mean minimum value for petiole length (7.56 cm) was observed in genotype S_4G_{12}.

Stage-II

An assessment of Table 7 clarified that at stage- II, maximum petiole length was attained by seed source S_8 (11.71cm) followed by S_2 (11.59 cm) whereas, the minimum value for petiole length (9.25 cm) was observed in S_1.

Among genotypes within seed sources, the mean maximum petiole length of 15.24 cm was recorded for S_2G_4 which was statistically at par with S_8G_{22} (14.50 cm). The minimum value for the trait was found in S_7G_{19} (7.95 cm).

Table 7: Effect of seed source and genotypes within seeds sources on petiole length (cm) of *T. ciliata* progeny

Seed source	Genotypes	Petiole length (cm)	
		Stage-I	Stage-II
S1 (Talwara)	G1	8.19	8.38
	G2	9.06	9.09
	G3	10.26	10.30
	Mean	9.17	9.25
S2 (Kamahi Devi)	G4	13.00	15.24
	G5	10.00	10.08
	G6	9.41	9.46
	Mean	10.80	11.59
S3 (Ludhiana)	G7	9.32	9.30
	G8	10.84	10.98
	G9	9.60	9.63
	Mean	9.92	9.97
S4 (Sujanpur)	G10	10.00	10.04
	G11	10.38	10.53
	G12	7.56	8.48
	Mean	9.31	9.68
S5 (Salouni)	G13	10.08	10.25
	G14	9.73	9.50
	G15	10.96	11.25
	Mean	10.26	10.33
S6 (Chabutra)	G16	9.86	9.48
	G17	10.64	10.93
	G18	9.64	9.90
	Mean	10.04	10.10
S7 (Shah Talai)	G19	8.83	7.95
	G20	10.25	10.26
	G21	10.41	10.30
	Mean	9.83	9.50
S8 (Suhari Takoli)	G22	14.31	14.50
	G23	10.09	10.38
	G24	10.28	10.25
	Mean	11.56	11.71
Mean		10.11	10.27
Range		7.56-14.31	7.95-15.24
CD (p=0.05)			
Seed source		1.29	1.25
Interaction (Seed source × Genotype)		2.24	2.16

4.1.6 Leaf area (cm^2)

Significant differences were recorded for leaf area among different seed sources as well as genotypes within seed sources.

Stage-II

Scrutiny of Table 8 indicated that mean maximum leaf area among seed sources was recorded in S_5 (51.67 cm^2) which was found to be statistically at par with S_3 (48.00 cm^2). The

minimum value for leaf area (36.67 cm^2) was observed in S_8.

While studying genotypes within seed sources, maximum value for leaf area (59.00 cm^2) was recorded in genotype S_2G_4 followed by genotypes S_3G_8, S_5G_{15}, S_5G_{14} and S_3G_9 with leaf area of 55.00 cm^2, 55.00 cm^2, 54.00 cm^2 and 53.00 cm^2 whereas, minimum value (30.00 cm^2) for genotype S_6G_{17}.

Table 8: Effect of seed source and genotypes within seeds sources on leaf area (cm^2) of *T. ciliata* progeny

Seed source	Genotypes	Leaf area (cm^2)
		Stage-II
S1 (Talwara)	G1	47.00
	G2	43.00
	G3	50.00
	Mean	46.67
S2 (Kamahi Devi)	G4	59.00
	G5	40.00
	G6	37.00
	Mean	45.33
S3 (Ludhiana)	G7	36.00
	G8	55.00
	G9	53.00
	Mean	48.00
S4 (Sujanpur)	G10	50.00
	G11	35.00
	G12	34.00
	Mean	39.67
S5 (Salouni)	G13	46.00
	G14	54.00
	G15	55.00
	Mean	51.67
S6 (Chabutra)	G16	51.00
	G17	30.00
	G18	31.00
	Mean	37.33
S7 (Shah Talai)	G19	44.00
	G20	49.00
	G21	33.00
	Mean	42.00
S8 (Suhari Takoli)	G22	36.00
	G23	39.00
	G24	35.00
	Mean	36.67
Mean		43.42
Range		30-59
CD (p=0.05)		
Seed source		3.82
Interaction (Seed source × Genotype)		6.61

4.2 Index scores analysis

Index score analysis was carried out in twenty-four genotypes of *T. ciliata*. Data displayed in Table 9 represents the classification of genotype on the basis of important morphological traits for wood production. By using index score analysis, it was deciphered that which genotype is superior for the concerned end use.

Index score with respect to wood production ranged from 9 to 15 among all the genotypes. Highest score of 15 was recorded for genotype S_2G_4, S_5G_{13} and S_5G_{15} which indicated their overall superiority for morphological characteristics (S_2G_4 and $S_5G_{15}$with maximum index score (4) for plant height, clear bole height and stem straightness; S_5G_{13} with maximum index score (4) for plant height, clear bole height and collar diameter) followed by genotypes S_3G_8 and S_6G_{16} with index score of 13. Minimum index score of 9 was registered in S_6G_{18} (with mean minimum values for plant height, clear bole height and collar diameter).

Table 9: Index scores for different morphological characters recorded in genotypes of *T. ciliata*

Genotypes	Plant height	Clear bole height	Collar diameter	Straightness score	Total score
S1G1	3	2	3	4	12
S1G2	3	2	3	4	12
S1G3	2	2	3	4	11
S2G4	4	4	3	4	15
S2G5	2	2	3	4	11
S2G6	2	3	2	4	11
S3G7	3	2	3	4	12
S3G8	3	2	4	4	13
S3G9	3	2	3	4	12
S4G10	2	3	2	3	10
S4G11	2	3	2	3	10
S4G12	2	2	2	4	10
S5G13	4	4	4	3	15
S5G14	3	2	2	4	11
S5G15	4	4	3	4	15
S6G16	3	2	4	4	13
S6G17	3	2	3	4	12
S6G18	2	2	2	3	9
S7G19	2	3	2	4	11
S7G20	2	3	2	4	11
S7G21	2	3	2	4	11
S8G22	2	2	2	4	10
S8G23	3	3	3	3	12
S8G24	2	2	3	4	11

4.3 Physiological characteristics

4.3.1 Pigment concentration (mg /g FW)

Chlorophyll is structurally same like porphyrins and is a chlorin pigment having magnesium ion in center. Chlorophyll has an important role in photosynthesis and act as protective factors against UV radiation (Yuan 2007). In the present study, the analysis of variance depicted significant differences for chlorophyll a, chlorophyll b, total chlorophyll, chlorophyll index (a/b) and carotenoid content in different seed source as well as genotypes within seed sources.

4.3.1.1 Chlorophyll a (mg /g FW)

A critical rummage of Table 10 revealed that maximum chlorophyll a (2.10 mg/g FW) among seed sources was recorded in seed source S_6 which was found to be statistically at par with S_5 (1.98 mg/g FW) and S_7 (1.97 mg/g FW) while minimum value for the parameter was found in seed source S_1 (1.74 mg/g FW).

Among genotypes within seed sources, maximum chlorophyll a (2.19 mg/g FW) was registered for genotype S_5G_{17} followed by S_7G_{20} (2.15 mg/g FW), S_4G_{11} (2.10 mg/g FW), S_6G_{18} (2.06 mg/g FW), S_4G_{12} (2.04 mg/g FW), S_5G_{13} (2.03 mg/g FW), S_6G_{16} (2.03 mg/g FW), S_5G_{15} (2.00 mg/g FW) and S_2G_4 (1.96 mg/g FW) whereas minimum chlorophyll a was recorded in genotype S_1G_3 (1.56 mg/g FW).

4.3.1.2 Chlorophyll b (mg /g FW)

An assessment of Table 10 explained that maximum pigment concentration of chlorophyll b (0.554 mg/g FW) was recorded in seed source S_7, proceeded by 0.501 mg/g FW for seed source S_8. The minimum chlorophyll b content as observed in seed source S_3 (0.379 mg/g FW).

While examining genotypes within seed sources, the results revealed that maximum chlorophyll b pigment was recorded for genotype S_7G_{20} (0.656 mg/g FW) which was statistically equivalent with genotype S_8G_{23} (0.601 mg/g FW). The minimum value for the trait was obtained for S_4G_{10} (0.332 mg/g FW).

4.3.1.3 Chlorophyll index (chlorophyll a/ chlorophyll b)

Examination of Table 10 revealed that maximum chlorophyll index was obtained for seed source S_5 (5.24) followed by seed source S_4 (5.01), S_6 (4.92) and S_3 (4.79), while minimum chlorophyll index was registered in seed source S_7 (3.68).

However, non-significant difference among genotypes within seed sources was

observed for genotypes within seed sources.

Table 10: Effect of seed source and genotypes within seed sources on pigment concentration (mg/g FW) of *T. ciliata* progeny

Seed source	Genotypes	Pigment concentration (mg/g FW)		
		Chlorophyll a	Chlorophyll b	Chl a / chl b
S1 (Talwara)	G1	1.84	0.471	3.94
	G2	1.83	0.483	3.85
	G3	1.56	0.427	3.70
	Mean	1.74	0.460	3.83
S2 (Kamahi Devi)	G4	1.96	0.489	4.02
	G5	1.68	0.396	4.25
	G6	1.87	0.481	3.90
	Mean	1.84	0.455	4.06
S3 (Ludhiana)	G7	1.75	0.381	4.62
	G8	1.77	0.360	4.96
	G9	1.86	0.397	4.78
	Mean	1.80	0.379	4.79
S4 (Sujanpur)	G10	1.69	0.332	5.35
	G11	2.10	0.475	4.76
	G12	2.04	0.418	4.92
	Mean	1.94	0.408	5.01
S5 (Salouni)	G13	2.03	0.404	5.76
	G14	1.91	0.378	5.34
	G15	2.00	0.469	4.62
	Mean	1.98	0.417	5.24
S6 (Chabutra)	G16	2.03	0.477	4.33
	G17	2.19	0.494	4.95
	G18	2.06	0.403	5.47
	Mean	2.10	0.458	4.92
S7 (Shah Talai)	G19	1.89	0.512	3.89
	G20	2.15	0.656	3.30
	G21	1.88	0.493	3.84
	Mean	1.97	0.554	3.68
S8 (Suhari Takoli)	G22	1.62	0.473	3.57
	G23	1.85	0.601	3.22
	G24	1.83	0.430	4.42
	Mean	1.77	0.501	3.74
Mean		1.89	0.454	4.41
Range		1.56-2.19	0.332-0.656	3.22-5.76
CD (p=0.05)				
Seed sources		0.14	0.07	0.82
Interaction (Seed source × Genotype)		0.24	0.12	NS

Table 11: Effect of seed source and genotypes within seed sources on pigment concentration (mg/g FW) of *T. ciliata* progeny

Seed source	Genotypes	Pigment concentration (mg/g FW)	
		Total Chlorophyll	Carotenoids
S1 (Talwara)	G1	2.61	0.105
	G2	2.61	0.108
	G3	2.48	0.104
	Mean	2.57	0.106
S2 (Kamahi Devi)	G4	2.77	0.114
	G5	2.13	0.104
	G6	2.66	0.115
	Mean	2.52	0.111
S3 (Ludhiana)	G7	2.41	0.109
	G8	2.40	0.111
	G9	2.55	0.111
	Mean	2.46	0.110
S4 (Sujanpur)	G10	2.29	0.106
	G11	2.91	0.129
	G12	2.77	0.119
	Mean	2.66	0.118
S5 (Salouni)	G13	2.75	0.122
	G14	2.59	0.120
	G15	2.79	0.121
	Mean	2.71	0.121
S6 (Chabutra)	G16	2.83	0.125
	G17	3.03	0.130
	G18	2.79	0.137
	Mean	2.88	0.130
S7 (Shah Talai)	G19	2.71	0.118
	G20	3.16	0.135
	G21	2.68	0.121
	Mean	2.85	0.125
S8 (Suhari Takoli)	G22	2.37	0.105
	G23	2.76	0.130
	G24	2.55	0.114
	Mean	2.56	0.117
Mean		2.65	0.117
Range		2.13-3.16	0.104-0.137
CD (p=0.05)			
Seed sources		0.19	0.0069
Interaction (Seed source × Genotype)		0.33	0.0121

4.3.1.4 Total chlorophyll (mg /g FW)

Total chlorophyll content of leaves of *T. ciliata*, depicted in Table 11, explained that highest total chlorophyll pigment concentration was found in S_6 (2.88 mg/g FW) followed by S_7 (2.85 mg/g FW) and S_5 (2.71 mg/g FW), while minimum value for total chlorophyll content was found in seed source S_3 (2.46 mg/g FW).

The results revealed that, among genotypes within seed sources maximum total chlorophyll pigment concentration (3.16 mg/g FW) was recorded in S_7G_{20}, which was statistically at par with genotype S_7G_{17} (3.03 mg/g FW), S_4G_{11} (2.91 mg/g FW) and S_6G_{16} (2.83 mg/g FW). The minimum value for total chlorophyll pigment was recorded in genotype S_2G_5 (2.13 mg/g FW).

4.3.1.5 Carotenoids (mg /g FW)

Scrutiny of Table 11 clearly indicated that maximum mean value for carotenoid content was recorded in seed source S_6 (0.130 mg/g FW) followed by seed source S_7, S_5, S_4, S_8, S_2 and S_3 with mean values of 0.125 mg/g FW, 0.121 mg/g FW, 0.118 mg/g FW, 0.117 mg/g FW, 0.11 mg/g FW and 0.110 mg/g FW, respectively, while minimum in seed source S_1 (0.106 mg/g FW).

Maximum carotenoid content among genotypes within seed sources was found in S_6G_{18} (0.137 mg/g FW) which was statistically equivalent to genotype S_7G_{20} (0.135 mg/g FW), S_6G_{17} (0.130 mg/g FW), S_8G_{23} (0.130 mg/g FW), S_4G_{11} (0.129 mg/g FW), S_6G_{16} (0.125 mg/g FW) whereas the minimum value for the parameter was found in genotypes S_1G_3 and S_2G_5 (0.104 mg/g FW).

4.3.2 Sugar accumulation content

Sugars are one of the major components contributing to the total carbohydrate of plant and provide carbon skeleton for biosynthesis of phenolics, terpenes, lectins, etc. The analysis of variance depicted significant differences for total soluble sugar, sucrose and starch content among the different seed source as well as genotypes within seed sources.

4.3.2.1 Total soluble sugar (g glucose/g FW)

Data presented in Table 12 showed that among seed sources, maximum total soluble sugar was present in seed source S_6 (0.147 g glucose/g FW) which was statistically equivalent with seed source S_4 (0.137 g glucose/g FW), S_5 (0.135 g glucose/g FW), S_7 (0.127 g glucose/g FW), S_1 (0.125 g glucose/g FW) and S_3 (0.124 g glucose/g FW). The minimum amount of total soluble sugar was obtained in seed source S_8 (0.101 g glucose/g FW).

Maximum total soluble sugar in genotypes within seed sources was observed in

S_6G_{17} (0.166 g glucose/g FW) followed by S_1G_2 (0.156 g glucose/g FW), S_5G_{14} (0.154 g glucose/g FW), S_3G_7 (0.152 g glucose/g FW), S_7G_{19} (0.148 g glucose/g FW), S_4G_{10} (0.146 g glucose/g FW), S_6G_{17} (0.143 g glucose/g FW), S_4G_{12} (0.134 g glucose/g FW), S_7G_{21} (0.134 g glucose/g FW) and S_6G_{18} (0.133 g glucose/g FW), S_4G_{11} (0.130 g glucose/ g FW) and S_5G_{15} (0.129 g glucose/ g FW). The minimum value for the trait was recorded in two genotypes S_2G_5 and S_8G_{23} (0.092 g glucose/g FW).

4.3.2.2 Sucrose (g sucrose/g FW)

Non-significant differences were observed for sucrose content among different seed sources.

While among genotypes within seed sources, maximum amount sucrose content was registered in S_4G_{10} (0.0153g sucrose/g FW), which was significantly at par with genotypes S_2G_5 (0.0129 g sucrose/g FW), S_3G_7 (0.0129 g sucrose/g FW), S_3G_9 (0.0128 g sucrose/g FW), S_6G_{17} (0.0131 g sucrose/g FW), S_2G_6 (0.0124 g sucrose/g FW), S_1G_2 (0.0121 g sucrose/g FW) and S_5G_{13} (0.0119 g sucrose/g FW). The minimum quantity for the parameter was recorded in genotype S_1G_3 (0.0091 g sucrose/g FW).

4.3.2.3 Starch (g starch/g FW)

Investigation of Table 12 indicated that maximum value for starch content was reported in seed source S_3 (0.111g starch/g FW), followed by S_2 (0.103 g starch/g FW), S_7 (0.0102g starch/g FW), S_4 (0.097g starch/g FW), S_5 (0.097g starch/g FW) and S_6 (0.096 g starch/g FW) whereas minimum in S_8 (0.078g starch/g FW).

While during examination of genotypes within seed sources, maximum amount of starch content was recorded in genotypes S_3G_8 (0.118g starch/g FW) and S_7G_{21} (0.118 g starch/g FW) followed by S_2G_5 (0.113g starch/g FW), S_6G_{16} (0.113g starch/g FW), S_4G_{10} (0.111g starch/g FW), S_3G_7 (0.108g starch/g FW), S_3G_9 (0.108g starch/g FW), S_7G_{19} (0.105g starch/g FW), S_2G_6 (0.102g starch/g FW), S_5G_{14} (0.102g starch/g FW), S_5G_{15} (0.101 g starch/g FW), S_6G_{18} (0.101g starch/g FW), S_4G_{11} (0.097 g starch/g FW), S_1G_1 (0.096 g starch/g FW), S_2G_4 (0.094 g starch/g FW), S_8G_{22} (0.092 g starch/g FW), S_5G_{13} (0.090 g starch/g FW), S_8G_{24} (0.087 g starch/g FW) and S_4G_{12} (0.085g starch/g FW). The minimum amount of starch content was recorded in genotype S_8G_{23} which was 0.055g starch/g FW.

Significant variation was recorded for morphological and physiological traits among different seed sources (except for stem straightness and sucrose content) and genotypes within seed sources. The mean values for morphological traits ranged between 3.08-4.30 m for plant height, 1.05-1.99 m for clean bole height, 6.10-9.18 cm for collar diameter, 7.95-15.24 cm for petiole length and 30.00-59.00 cm^2 for leaf area and 3.88-4.88 for stem straightness.

Table 12: Effect of seed source and genotypes within seed sources on sugar accumulation content (g sugar/g FW) of *T. ciliata* progeny

Seed source	Genotypes	Sugar accumulation content (g/g FW)		
		Total soluble sugar (g glucose/g FW)	Sucrose (g sucrose/g FW)	Starch (g starch/g FW)
S1 (Talwara)	G1	0.118	0.0103	0.096
	G2	0.156	0.0121	0.073
	G3	0.101	0.0091	0.082
	Mean	0.125	0.0105	0.084
S2 (Kamahi Devi)	G4	0.112	0.0117	0.094
	G5	0.092	0.0129	0.113
	G6	0.107	0.0124	0.102
	Mean	0.104	0.0123	0.103
S3 (Ludhiana)	G7	0.152	0.0129	0.108
	G8	0.115	0.0102	0.118
	G9	0.105	0.0128	0.108
	Mean	0.124	0.0120	0.111
S4 (Sujanpur)	G10	0.146	0.0153	0.111
	G11	0.130	0.0112	0.097
	G12	0.134	0.0101	0.085
	Mean	0.137	0.0122	0.097
S5 (Salouni)	G13	0.121	0.0119	0.090
	G14	0.154	0.0117	0.102
	G15	0.129	0.0111	0.101
	Mean	0.135	0.0116	0.097
S6 (Chabutra)	G16	0.166	0.0115	0.113
	G17	0.143	0.0131	0.074
	G18	0.133	0.0115	0.101
	Mean	0.147	0.0120	0.096
S7 (Shah Talai)	G19	0.148	0.0111	0.105
	G20	0.100	0.0109	0.082
	G21	0.134	0.0099	0.118
	Mean	0.127	0.0106	0.102
S8 (Suhari Takoli)	G22	0.097	0.0098	0.092
	G23	0.092	0.0107	0.055
	G24	0.113	0.0095	0.087
	Mean	0.101	0.0100	0.078
Mean		0.125	0.0114	0.096
Range		0.092-0.166	0.0091-0.0153	0.055-0.118
CD (p=0.05)				
Seed sources		0.0248	NS	0.021
Interaction (Seed source × Genotype)		0.0430	0.0033	0.035

For physiological traits, the mean values for pigment concentration and sugar accumulation content ranged from 1.56-2.19 mg/g FW for chlorophyll a, 0.332-0.656 mg/g FW for chlorophyll b, 2.13-3.16 mg/g FW for total chlorophyll, 3.22-5.76 for chlorophyll a/b, 0.104-0.137 mg/g FW for carotenoid content, 0.092-0.166 g glucose/g FW for total soluble sugar and 0.055-0.118 g starch/g FW for starch content and 0.0091-0.0153 g sucrose/g FW for sucrose content.

Since, these progenies belong to genotypes from different seed sources and had been planted under uniform experimental conditions; the variability in various morphological and physiological characters may be attributed to genetic variability existing in these genotypes.

The above findings revealed a particular growth trend for some of the morphological parameters. Clear bole height and stem straightness showed a similar trend for mean maximum value recorded for genotype S_2G_4 at both the stages. Similarly, for collar diameter, genotype S_5G_{13} registered mean maximum values recorded at both the stages, while for petiole length similar pattern for mean maximum value was found in genotype S_4G_{12}. However, there were no specific trend was found in plant height for mean minimum and mean maximum values at both the stages.

On the basis of overall mean performance for morphological and physiological characteristics, seed source S_5 was found outstanding for plant height, clear bole height, collar diameter, leaf area, chlorophyll a, total chlorophyll, total soluble sugar and starch followed by seed source S_2 with mean maximum or statistically equivalent values for clear bole height, collar diameter, stem straightness, chlorophyll b, sucrose and starch. Among genotypes within seed sources S_6G_{16} was found superior for plant height, collar diameter, stem straightness, leaf area, chlorophyll a, total chlorophyll, carotenoid content, total soluble sugar and starch followed by S_2G_4, S_5G_{13} and S_5G_{15} with mean maximum or statistically equivalent values for plant height, clear bole height, collar diameter, stem straightness, chlorophyll a, total soluble sugar, sucrose and starch content.

Similarly, Parthiban *et al* (2019); Honglan *et al* (2012); Hadiyat (2010) and Rana *et al* (2009) reported significant variation for morphological traits in *T. ciliata* progenies. Similarly, Jayusman and Fiani (2019) recorded significant variation for bark, shape and canopy characteristics in *T. sinensis* while Navarro *et al* (2002) observed significant variation for plant height and collar diameter in *Cedrela odorata.* However, Wu *et al* (2015) registered non-significant variation for collar diameter among families though significant variation for plant height and collar diameter was observed among different provenances in *T. ciliata*.

Variability with respect to physiological parameters has also been reported by Liu *et al* (2019), Murphy *et al* (2012), Huiwu *et al* (2012) in *T. ciliata* and Zhen *et al* (2011) in *T. sinensis.* On the similar lines, significant variation for morphological and physiological characters under salinity condition in *T. ciliata* had also been reported by Andrade *et al* (2020). Jun *et al* (2014) recorded significant variation for photosynthetic, chlorophyll a, chlorophyll b and carotenoids in *T. sinensis*; Bouman and Sylliboy (2010) reported significant differences for leaf area, leaf chlorophyll concentration, biomass and leaf allocation of biomass in willow; Aasamaa *et al* (2010) observed significant variation for chlorophyll content and photosynthesis electron transport and suggested that these traits could serve as strong indicator of high biomass production in *Salix* clones. While, Kundu *et al* (1998) observed significant variation for net photosynthesis (8.14 to 15.13 μ mol m^{-2} s^{-1}), stomatal conductance (0.37 to 0.59 mol m^{-2} s^{-1}) and total guard length (2681 to 3873 μ m) in *Azadirachta indica*.

4.4 Variability estimation and genetic parameters

Variations are paramount for adaptation and genetic improvement of a species. Knowledge of the extent of variability present in a population is decisive for selection of high yielding genotypes and their genetic improvement. Genetic variability is the sum total of additive and non-additive component of variation. The additive variance is heritable and can be transmitted through sexual propagation through seeds, whereas the non-additive variance (dominance + epistasis) is non-heritable and can be transmitted through vegetative propagation only. Heritability expresses the degree to which expression of a trait is controlled by heredity as compared to environment variance and is important for estimating the genetic gain that can be achieved from recurrent selection programmes.

Variability and genetic parameters were recorded for growth and physiological characters *viz*., plant height, clear bole height, collar diameter, stem straightness, petiole length, leaf area, chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, chlorophyll index (a/b), total soluble sugar, sucrose and starch content. On the basis of analysis of variance, the genetic components such that mean, range, genotypic and phenotypic coefficient of variation, heritability in broad sense, genetic advance and genetic gain as per cent of mean were estimated.

Data furnished in Table 13 depicted the mean values of 3.54 m, 1.39 m, 7.22 cm, 4.22, 10.27 cm, 43.42 cm^2 were recorded for plant height, clear bole height, collar diameter, straightness score, petiole length and leaf area respectively, among the genotypes. For physiological traits, mean values of 1.89 mg/g FW, 0.454 mg/g FW, 2.65 mg/g FW, 0.117 mg/g FW, 4.41, 0.125 g glucose/g FW, 0.0114 g sucrose/g FW, 0.096 g starch/g FW were

observed for chlorophyll a, chlorophyll b, total chlorophyll, chlorophyll index (a/b), carotenoid content, total soluble sugar, sucrose and starch, respectively.

Variation with respect to growth and physiological characters among the genotypes ranged between 3.08-4.30 m for plant height, 1.05-1.99 m for clear bole height, 6.10-9.18 cm for collar diameter, 3.88-4.88 for straightness score, 7.95-15.24 cm for petiole length, 30.00-59.00 cm^2 for leaf area, 1.56-2.19 mg/g FW for chlorophyll a, 0.332-0.656 mg/g FW for chlorophyll b, 2.13-3.16 mg/g FW for total chlorophyll, 0.104-0.137 mg/g FW for carotenoid content, 3.22-5.76 for chlorophyll index (a/b), 0.092-0.166 g glucose/g FW for total soluble sugar, 0.0091-0.0153 g sucrose/g FW for sucrose and 0.055-0.118 g starch/g FW for starch.

The perusal of Table 13 revealed that the magnitude of genotypic coefficient of variation (GCV) was registered low to moderate for all the growth and physiological traits. Moderate genotypic coefficient of variation was recorded for leaf area (19.44%) followed by clear bole height (16.34%), petiole length (14.07%), total soluble sugar (12.60%), chlorophyll b (12.09%) and chlorophyll index (chl a/b) (11.19%). However, low genotypic coefficient of variation was observed for Starch (9.83%), collar diameter (9.64%), chlorophyll a (7.61%), total chlorophyll (7.50%), carotenoid content (7.20%), sucrose (6.68%), plant height (6.63) and stem straightness (3.61%).

Highest value for phenotypic coefficient of variation (PCV) was observed for starch (27.65%) followed by total soluble sugar (27.55%), chlorophyll index (chl a/b) (25.25%) clear bole height (23.99%), chlorophyll b (22.42%), leaf area (22.25%), sucrose (22.02%) and petiole length (20.54%). Moderate phenotypic coefficient of variation was recorded for collar diameter (17.32%), chlorophyll a (12.23%), total chlorophyll (12.14%), plant height (11.57%) and carotenoid content (10.99%) whereas, lowest value for phenotypic coefficient of variation was observed for stem straightness (8.26%).

The magnitude of genotypic coefficient of variation was lower than the corresponding phenotypic coefficient of variation for all the traits which might be due to the genotype x environment interaction or environmental influences on the expression of these traits. Above findings are in line with Kundal *et al* (2020), who recorded higher values for phenotypic coefficient of variation than genotypic coefficient of variation in *T. ciliata*. Similar results were also obtained by Thakur *et al* (2015) in *Melia azedarach*; Sangram and Keerthika (2013) in *Leucaena leucocephala*; Dhillon *et al* (2009) in *Melia azedarach* and Wani *et al* (2012) in *Albizzia lebbeck.*

Table 13: Variability and genetic estimates for growth and physiological characters of *T. ciliata* genotypes

Parameter	Mean	Range	Coefficient of variation (%)		h^2_{bs} (%)	Genetic advance	Genetic gain (%)
			Genotypic	Phenotypic			
Plant height (m)	3.54	3.08-4.30	6.63	11.57	32.91	0.28	7.92
Clear bole height(m)	1.39	1.05-1.99	16.34	23.99	46.30	0.32	23.06
Collar diameter (cm)	7.22	6.10-9.18	9.64	17.32	30.98	0.80	11.08
Stem straightness (1-5)	4.22	3.88-4.88	3.61	8.26	19.16	0.14	3.32
Petiole length (cm)	10.27	7.95-15.24	14.07	20.54	46.93	2.04	19.87
Leaf area (cm^2)	43.42	30.00-59.00	19.44	22.25	76.37	15.20	35.01
Chlorophyll a (mg/g FW)	1.89	1.56-2.19	7.61	12.23	38.75	0.184	9.77
Chlorophyll b (mg/g FW)	0.454	0.332-0.656	12.09	22.42	29.07	0.061	13.43
Total chlorophyll (mg/g FW)	2.65	2.13-3.16	7.50	12.14	38.15	0.252	9.55
Carotenoids (mg/g FW)	0.117	0.104-0.137	7.20	10.99	42.89	0.011	9.71
Chlorophyll index (chl a/b)	4.41	3.22-5.76	11.19	25.25	19.64	0.45	10.22
Total soluble sugar (g glucose/g FW)	0.125	0.092-0.166	12.60	27.55	20.92	0.02	11.87
Sucrose (g sucrose/g FW)	0.0114	.0091-0.0153	6.68	22.02	9.20	0.001	4.17
Starch (g starch/g FW)	0.096	.055-0.118	9.83	27.65	12.63	0.007	7.20

Heritability was recorded highest (76.37%) for leaf area. Moderate values for heritability were recorded for petiole length (46.93%), clear bole height (46.30%), carotenoid content (42.89%), chlorophyll a (38.75%), total chlorophyll (38.15%), plant height (32.91%) and collar diameter (30.98%) which indicated that these characters were strongly influenced by the additive gene action, whereas low heritability was observed for chlorophyll b (29.07%), total soluble sugar (20.92%), chlorophyll index (a/b) (19.64%), stem straightness (19.16%), starch (12.63%) and sucrose(9.20%) which indicated that these characters were under the influence of non-additive gene action.

Genetic advance was recorded highest for leaf area (15.20) and lowest for sucrose content (0.001).

Highest genetic gain was recorded for leaf area (35.01%), whereas moderate genetic gain was observed for clear bole height (23.06%), petiole length (19.87%), chlorophyll b (13.43%), total soluble sugar (11.87%), collar diameter (11.08%) and chlorophyll index (a/b) (10.22%).

However, minimum genetic gain was recorded for chlorophyll a (9.77%), carotenoid content (9.71%), total chlorophyll (9.55%), plant height (7.92%), starch (7.20%), sucrose (4.17%) and stem straightness (3.32%).

High heritability reflects the effectiveness of phenotypic selection for a particular trait; however, it does not guarantee higher genetic gains or improvement for that trait. High heritability coupled with high to moderate genetic gain indicates that the characters were governed by additive gene action whereas, high heritability coupled with low genetic gain or low heritability with low genetic gain reflects that the traits were governed by non-additive gene action (Panse 1957). Therefore, selection encompassing high heritability along with high or moderate genetic gain gives more realistic results as they were governed by additive type of gene action and are heritable to the next generation.

High heritability coupled with high genetic gain was observed for leaf area whereas, high heritability with moderate genetic gain was revealed by petiole length; clear bole height, carotenoid content, chlorophyll a, total chlorophyll, plant height and collar diameter suggesting that maximum weightage should be given to these traits during selection.

Similar types of finding were obtained by Kundal *et al* (2020) and Jun *et al* (2008) indicating moderate heritability and genetic gain for growth traits viz., plant height, collar diameter and stem straightness in *T. ciliata*. Wu *et al* (2015) recorded high heritability for plant height and diameter at breast height in *T. ciliata* whereas Uppal and Singh (2010)

recorded high heritability and genetic gain for root length and shoot length in *T. ciliata*. Dhillon *et al* (2009) recorded high heritability and genetic gain for collar diameter (40.76 to 85.08%; 24.51%) and plant height (52.07 to 76.25%; 35.34%) in *Melia azedarach*.

4.5 Correlation analysis

The association between different growth and physiological traits represents a complex genetic system in plants and thus selection of one trait might bring simultaneous change in the associated traits. The inter-relationship among different qualitative and quantitative traits is of prime importance and must be given due weightage while formulating the selection criteria in any tree improvement programme as it provides baseline for indirect selection in below ground or biomass characters where the destructive sampling is required or other qualitative characters. The magnitude and direction of such association can be measured in terms of coefficients of correlation and has been presented as genotypic and phenotypic coefficient of correlation in the present studies.

4.5.1 Estimation of genotypic correlation coefficient among different morphological and physiological characters

Plant height

The critical rummage of Table 14 depicted that plant height exhibited highly significant positive genotypic correlation with collar diameter (0.832) and leaf area (0.651), whereas, positive significant genotypic correlation with chlorophyll a/b (0.594), collar diameter (0.580) petiole length (0.388), sucrose (0.371), starch (0.263), total soluble sugar (0.220) and chlorophyll a (0.213).

Clear bole height

Positive and highly significant genotypic correlation was found for clear bole height with sucrose (0.734) while positive significant genotypic correlation with chlorophyll a (0.566), total chlorophyll (0.494), leaf area (0.448), carotenoids (0.356), chlorophyll a/b (0.334), petiole length (0.328), chlorophyll b (0.262) and stem straightness (0.239).

Collar diameter

Collar diameter showed significant genotypic correlation with leaf area (0.584), and sucrose (0.394), whereas significant negative genotypic correlation with stem straightness (-0.332), carotenoid content (-0.274), chlorophyll b (-0.238) and chlorophyll a (-0.212).

Stem straightness

Highly significant genotypic correlation was observed for stem straightness with leaf area (0.835) and significant genotypic correlation with petiole length (0.511), starch (0.414)

and total soluble sugar (0.303). Significant negative genotypic correlation was showed by stem straightness with collar diameter and carotenoids (-0.260).

Petiole length

Petiole length revealed significant genotypic correlation with leaf area (0.229) while, significant negative correlation with total soluble sugar (-0.523) and sucrose (-0.224).

Leaf area

Leaf area showed positive genotypic correlation with starch (0.398) and sucrose (0.284) while negative significant genotypic correlation with carotenoids (-0.318).

Chlorophyll a

Chlorophyll a had highly positive and significant genotypic correlation with total chlorophyll (0.915) and carotenoids (0.895) while moderate significant positive genotypic correlation with total soluble sugar (0.505), chlorophyll a/b (0.404) and chlorophyll b (0.393). Significant negative genotypic correlation was reported between chlorophyll a and starch (-0.223).

Chlorophyll b

Highly positive and significant genotypic correlation was registered for chlorophyll b with starch (0.858) and total chlorophyll (0.656) while significant genotypic correlation between chlorophyll b and carotenoids (0.420).

Total chlorophyll

Total chlorophyll showed highly positive significant genotypic correlation with carotenoids (0.854) and significant genotypic correlation with starch (0.554) and total soluble sugar (0.318), whereas significant negative correlation with sucrose content (-0.571).

Carotenoids

Significant genotypic correlation was found for carotenoids with total soluble sugar (0.359), chlorophyll a/b (0.360) and starch (0.315) were recoded whereas negative significant genotypic correlation with sucrose (-0.252).

Chlorophyll index (a/b)

Highly positive significant genotypic correlation was recorded for chlorophyll a/b with sucrose (0.980) and total soluble sugar (0.658) while significant genotypic correlation with starch (0.395) was observed.

Total soluble sugar and sucrose

Total soluble sugar showed non-significant genotypic correlation with sucrose and

starch while sucrose shows non-significant genotypic correlation with starch.

4.5.2 Estimation of phenotypic correlation coefficient among different morphological and physiological characters

Plant height

Plant height showed highly positive significant phenotypic correlation with clear bole height (0.680) and collar diameter (0.613) whereas significant phenotypic correlation with, stem straightness (0.405), leaf area (0.293), petiole length (0.281) and chlorophyll a (0.223).

Clear bole height

Positive phenotypic correlation was reported for clear bole height with leaf area (0.290), whereas non-significant phenotypic correlation with all other morphological and physiological traits.

Collar diameter

Collar diameter showed significant positive phenotypic correlation with stem straightness (0.370) and leaf area (0.262) while non-significant phenotypic correlation with other characters.

Stem straightness

Significant phenotypic correlation was observed for stem straightness with lea area (0.315) and petiole length (0.277), whereas non-significant phenotypic correlation with chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, chlorophyll a/b, total soluble sugar, sucrose and starch.

Petiole length

Petiole length showed negative significant phenotypic correlation with chlorophyll a/b (-0.209) and total soluble sugar (-0.282) while non-significant phenotypic correlation with leaf area, chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, sucrose and starch.

Leaf area

Non-significant phenotypic correlation was found for leaf area with chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, chlorophyll a/b, total soluble sugar, sucrose and starch.

Chlorophyll a

Chlorophyll a showed highly positive significant phenotypic correlation with total chlorophyll (0.882) and carotenoids (0.804) while moderate significant positive phenotypic correlation with chlorophyll b (0.325), chlorophyll a/b (0.276) and total soluble sugar (0.237).

Chlorophyll b

Highly positive significant phenotypic correlation was recorded between chlorophyll b and total chlorophyll (0.611) and moderate significant phenotypic correlation was recorded with carotenoids (0.452) and starch (.300) while negative significant phenotypic correlation with chlorophyll a/b (-0.755).

Total chlorophyll

Highly positive significant phenotypic correlation was recorded between total chlorophyll and carotenoids (0.817) while non-significant phenotypic correlation with chlorophyll a/b, total soluble sugar, sucrose and starch.

Carotenoids

Carotenoids showed non-significant phenotypic correlation with chlorophyl a/b, total soluble sugar, sucrose and starch.

Chlorophyll index (a/b)

Significant phenotypic correlation was recorded in chlorophyll a/b with total soluble sugar (0.288) and starch (0.323) while non-significant phenotypic correlation with sucrose.

Total soluble sugar

Total soluble sugar depicted positive significant phenotypic correlation with sucrose (0.374) and starch (0.326).

Sucrose

Significant positive phenotypic correlation was recorded between sucrose and starch (0.272).

Among all the growth and physiological traits, highly significant positive genotypic and phenotypic correlation was observed for chlorophyll a with total chlorophyll (0.915 and 0.882) and carotenoid content (0.895 and 0.804); total chlorophyll with carotenoid content (0.854 and 0.817); chlorophyll b with total chlorophyll (0.656 and 0.611) and plant height with clear bole height (0.832 and 0.480).

It was clearly evident from the Table 14 that the magnitude of genotypic correlation was higher than the corresponding phenotypic correlation for all the traits which might be due to strong inherent linkage of traits at gene level or pleiotropic effect of a gene, suggested that any change in the gene locus of one trait may alter the genetic expression of the associated traits.

Table 14: Correlation among morphological and physiological characters of *T. ciliata*

		Clear bole height	Collar diameter	Stem straightness	Petiole length	Leaf area	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid content	Chlorophyll index (chl a/b)	Total soluble sugar	Sucrose	Starch
Plant height	**P**	0.680**	0.613**	0.405**	0.281**	0.293**	0.223**	0.108NS	0.193NS	0.059NS	0.006NS	-0.045NS	0.170NS	0.033NS
	G	0.832**	0.580**	0.039NS	0.388**	0.651**	0.213**	-0.193NS	0.116NS	-0.043NS	0.594**	0.220*	0.371**	0.263**
Clear bole	**P**		0.090NS	0.151NS	0.121NS	0.290**	0.114NS	0.108NS	0.107NS	0.053NS	-0.029NS	-0.019NS	0.055NS	0.033NS
	G		0.048NS	0.239*	0.328**	0.448**	0.566**	0.262**	0.494**	0.356**	0.334**	0.154NS	0.734**	-0.144NS
Collar diameter	**P**			0.370**	0.099NS	0.262**	0.078NS	-0.054NS	0.033NS	-0.045NS	0.084NS	-0.066NS	0.074NS	0.033NS
	G			-0.332**	-0.003NS	0.584**	-0.212*	-0.238*	-0180NS	-0.274**	0.144NS	-0.145NS	0.394**	0.020NS
Stem straightness	**P**				0.277**	0.315**	0.075NS	0.061NS	0.073NS	-0.154NS	-0.094NS	-0.097NS	-0.048NS	-0.036NS
	G				0.511**	0.835**	0.072NS	0.036NS	0.104NS	-0.260*	-0.192NS	0.303**	0.198NS	0.414**
Petiole length	**P**					0.093NS	-0.110NS	0.156NS	0.048NS	-0.069NS	-0.209*	-0.282**	-0.030NS	-0.015NS
	G					0.229*	-0.074NS	0.073NS	0.018NS	-0.064NS	-0.098NS	-0.523**	-0.224*	-0.184NS
Leaf area	**P**						-0.041NS	-0.101NS	0.016NS	-0.141NS	0.067NS	0.026NS	0.030NS	0.117NS
	G						-0.157NS	-0.104NS	0.116NS	-0.318**	-0.002NS	-0.072NS	0.284**	0.398**
Chlorophyll a	**P**							0.325**	0.882**	0.804**	0.276**	0.237*	0.114NS	0.017NS
	G							0.393**	0.915**	0.895**	0.404**	0.505**	-0.027NS	-0.223*
Chlorophyll b	**P**								0.611**	0.452**	-0.755**	-0.134NS	0.034NS	0.300**
	G								0.656**	0.420**	-0.698**	-0.341**	-0.174**	0.858**
Total chl	**P**									0.817**	-0.063NS	0.167NS	0.040NS	-0.159NS
	G									0.854**	0.078NS	0.318**	-0.571**	0.554**
Carotenoids	**P**										0.100NS	0.107NS	0.026NS	-0.059NS
	G										0.360**	0.359**	-0.252*	0.315**
Chlorophyll index (chl a/b)	**P**											0.288**	0.086NS	0.323**
	G											0.658**	0.980**	0.395**
Total soluble sugar	**P**												0.374**	0.326**
	G												0.155NS	0.080NS
Sucrose	**P**													0.272**
	G													0.141NS

*Significant at 5% level of significance **significant at 1% level of significance NS: Non-significant

G denotes genotypic correlation coefficient; P denotes phenotypic correlation coefficient

The results are in agreement with the findings of Lastin *et al* (2019), who observed that the genotypic correlation coefficient was higher than the phenotypic correlation coefficient and reported highly positive genotypic and phenotypic significant correlation of diameter at breast height with total height, crown height and crown diameter in *T. sinensis*; Similar findings were reported by Kundal *et al* (2020) in *Toona ciliata* ; Thakur *et al* (2015) in *Melia azedarach*; Sangram and Keerthika (2013) in *Leuceaena lucocephala*; Wani *et al* (2012) in *Albizzia lebbeck* and Jun *et al* (2008) in *T. ciliata*.

4.6 Principal component analysis

The perusal of Table 15 depicted the factor pattern and summary of principal component analysis on data recorded for growth and physiological traits. It was observed that five out of thirteen components had Eigen value more than unity which explained 80.74% of the total variation. Eigen values are presented in Fig 1.

The first principal component explained 27.295 per cent of the total variability, with maximum loadings for variables; total chlorophyll (0.963), carotenoid content (0.890), chlorophyll a (0.882) and chlorophyll b (0.717).

Second principal component explicated 21.561 per cent of the total variation, with maximum loadings for the variables *viz.,* plant height (0.865) followed by leaf area (0.787), clear bole height (0.685), straightness score (0.583), collar diameter (0.533) and petiole length (0.446). Similarly, third principal component explained 14.73 per cent of the total variability with maximum loadings for total soluble sugar (0.813), sucrose (0.566) and starch (0.495).

Fourth principal component explained 9.187 per cent of total variation with maximum loading for stem straightness (0.429) and petiole length (0.428), whereas the fifth component explicated 7.971 per cent of the variability with highest loading for stem straightness (0.568).

Maximum weightage should be given to total chlorophyll for selection along with other traits present in first principal component since it contributed largest variation in the total genetic variability. Thus, principal component analysis brought out some important components associated with growth and physiological characteristics in *T. ciliata* which could be used to distinguish between the genotypes and effective selection of genotypes.

The results are in conformity with the findings of Danquah *et al* (2011) who observed that 97.50 and 98.00 per cent of the total variation was explained by four principal components while working on *Khaya ivorensis* and *Khaya anthotheca,* respectively. Significant differences were found for leaf morphology in *K. ivorensis* at both, populations ($P<0.001$) and ecological zones level ($P<0.001$), whereas in case of *Khaya anthotheca* at population level ($P<0.001$) only.

Table 15: Principal components for growth and physiological characteristics in *T. ciliata*

Characters	Principal components				
	1	2	3	4	5
Plant height (m)	0.172	0.865	0.033	-0.255	-0.252
Clear bole height (m)	0.391	0.685	0.154	0.193	-0.307
Collar diameter (cm)	-0.130	0.533	-0.147	-0.768	0.027
Straightness score	-0.109	0.583	-0.130	0.429	0.568
Petiole length (cm)	-0.004	0.446	-0.535	0.428	-0.127
Leaf area (cm^2)	-0.213	0.787	-0.040	-0.062	0.303
Chlorophyll a (mg/g FW)	0.882	0.108	0.314	-0.015	0.115
Chlorophyll b (mg/g FW)	0.717	-0.073	-0.458	0.095	0.065
Total chlorophyll (mg/g FW)	0.963	0.054	0.025	-0.028	0.193
Carotenoid content (mg/g FW)	0.890	-0.131	0.164	-0.048	-0.001
Total soluble sugar (g glucose/g FW)	0.107	0.016	0.813	-0.028	0.277
Sucrose (g sucrose/g FW)	-0.115	0.303	0.566	0.332	-0.501
Starch (g starch/g FW)	-0.505	0.118	0.495	0.081	0.253
Eigen value	3.548	2.803	1.914	1.194	1.036
Percent of variability	27.295	21.561	14.727	9.187	7.971
Cumulative percent of variability	27.295	48.855	63.582	72.769	80.740

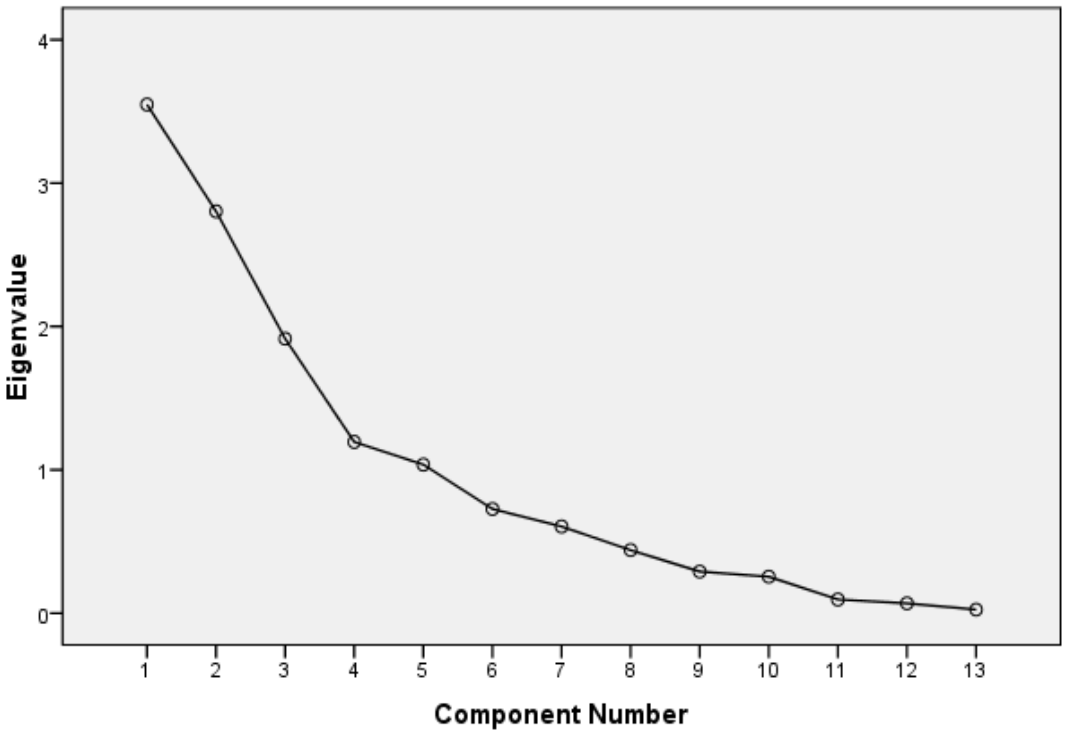

Fig. 1 Scree plot based on principal component analysis

Similarly, Kundu *et al* (2000) while evaluating provenance variation in *Azadirachta indica* reported that principal component analysis revealed distinct population differentiation associated with variability for plant height and survival rate of neem populations at three different sites. Further, ecoclimatic conditions at different provenances played a vital role in the differentiation of *A. indica* populations and thereby affected their survival and growth during the early stages of plant establishment. Isik and Toplu (2004) observed that 90 per cent of the total variation was explained by three principal components in *Populus nigra* with maximum loading for plant height along with other traits and these traits must be given due importance while selection.

CHAPTER-V

SUMMARY

The present examination entitled "Assessment of genotypic variation for morpho-physiological characteristics of *Toona ciliata* M. Roem" was conducted in 2019-20, with the objective of evaluation of genotypes on the basis of morphological and physiological characters in the field and selection of superior genotypes of *T. ciliata* from already established two-year-old progeny trial of *T. ciliata* established at Teaching area, Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. The progeny trial was established using selected half sib progenies of three genotypes each from eight different seed sources representing the states of Punjab and Himachal Pradesh viz., Talwara (Hoshiarpur), Kamahi Devi (Hoshiarpur), Ludhiana, Sujanpur (Hamirpur), Salouni (Hamirpur), Chabutra (Hamirpur), Shah Talai (Bilaspur) and Suhari Takoli (Una) in RCBD with 4 replications (spacing: 4 x 3 m) in east-west (row distance) direction. In the present investigation, the observation on growth parameter were recorded under field condition at an interval of six-month from April, 2019 to October, 2019 for plant height, clear bole height, collar diameter, straightness score and petiole length and during October, 2019 for leaf area while the observation for the physiological parameters (pigment concentration and sugar accumulation content) were recorded in the laboratory of Department of Plant Breeding and Genetics.

The mean values for growth traits ranged between 3.08-4.30 m for plant height, 1.05 - 1.99 m for clear bole height, 6.10-9.18 cm for collar diameter, 3.88-4.88 for stem straightness, 7.95-15.24cm for petiole length and 30.00-59.00 cm^2 for leaf area, whereas the mean values for the physiological parameters ranged between 1.56-2.19 mg/g FW for chlorophyll a, 0.332-0.656 mg/g FW for chlorophyll b,3.22-5.76 for chlorophyll index (a/b),2.13-3.16 mg/g FW for total chlorophyll, 0.104-0.137 mg/g FW for carotenoid, 0.092-0.166g glucose/g FW for total soluble sugar, 0.0091-0.0153g sucrose/g FW for sucrose and 0.055-0.118g starch/g FW for starch content.

The mean values for growth characters viz., plant height, clear bole height, collar diameter, stem straightness, petiole length and for leaf area were 3.54 m, 1.39 m, 7.22 cm, 4.22, 10.27 cm and 43.42 cm^2, respectively. For the physiological traits the mean values recorded were 1.89mg/g FW, 0.454mg/g FW, 4.41,2.65mg/g FW, 0.117 mg/g FW, 0.125 glucose/g FW, 0.0114 g sucrose/g FW and 0.096g starch/g FW for chlorophyll a, chlorophyll b, chlorophyll index (a/b), total chlorophyll, carotenoid content, total soluble sugar, sucrose and starch, respectively.

On the basis of overall performance for morphological and physiological character, seed sources S_5 (Salouni) was found outstanding for plant height (3.98 m), clear bole height (1.73 m), collar diameter (7.66 cm), leaf area (51.67 cm^2), chlorophyll a (1.98 mg/g FW), chlorophyll a/b (5.24), total chlorophyll (2.71 mg/g FW), total soluble sugar (0.135 g glucose/g FW) and starch (0.097 g starch/ g FW) followed by S_6 (Chabutra) for collar diameter (7.43 cm), chlorophyll a (2.10 mg/g FW), total chlorophyll (2.88 mg/g FW), carotenoid content (0.130 mg/g FW), total soluble sugar (0.147 g glucose/g FW) and starch (0.096 g starch /g FW) and S_2 (Kamahi Devi) for clear bole height (1.60 m), stem straightness (4.44), petiole length (11.55 cm), sucrose (0.0123 g sucrose/g FW) and starch (0.103 g starch/g FW).

In case of genotypes among seed sources S_6G_{16} was outstanding for plant height (3.64 m), collar diameter (9.01 cm), straightness (4.31), chlorophyll a (2.03 mg/g FW), total chlorophyll (2.83 mg/g FW), carotenoid content (0.125 mg/g FW), total soluble sugar (0.166 g glucose/g FW) and starch (0.133 g starch/g FW) followed by S_5G_{15} for plant height (4.12 m), clear bole height (1.73 m), leaf area (55 cm^2), chlorophyll a (2.00 mg/g FW), total soluble sugar (0.129 g glucose/g FW) and starch (0.101 g starch/g FW); S_6G_{17} for chlorophyll a (2.19 mg/g FW), total chlorophyll (3.03 mg/g FW), carotenoid content (0.130 mg/g FW), chlorophyll a/b (4.95) total soluble sugar (0.143 g glucose/g FW) and sucrose (0.0131 g sucrose/g FW) ; S_2G_4 for plant height (4.01 m), clear bole height (1.99 m), straightness (4.88), petiole length (15.24 cm), leaf area (59 cm^2), chlorophyll a(1.96 mg/g FW) and starch (0.094 g starch/g FW) and S_5G_{13} for plant height (4.30 m), clear bole height (1.96 m), collar diameter (9.18 cm), chlorophyll a (2.03 mg/g FW), chlorophyll a/b (5.76), sucrose (0.0199 g sucrose/g FW) and starch (0.090 g starch/g FW).

Index score analysis deciphered that the genotypes S_2G_4, S_5G_{13} and S_5G_{15} obtained maximum index score of 15 for important morphological traits (plant height, collar diameter, clear bole height and stem straightness) followed by genotypes S_3G_8 and S_6G_{16} with index score of 13.

Highest value for GCV and PCV were observed in leaf area (19.44%; 22.25%) followed by clear bole height (16.34%; 23.99%), petiole length (14.07%; 20.54%), total soluble sugar (12.60%; 27.55%), chlorophyll b (12.09%; 22.42%) and starch (9.83%; 23.50%).

High heritability (broad sense) coupled with high genetic gain was revealed by leaf area (76.37%; 35.01%) whereas, high heritability and moderate genetic gain was recorded

in petiole length (46.93%; 19.87%), clear bole height (46.30%; 23.06%) and collar diameter (30.98%; 11.08%).

Highly significant positive genotypic and phenotypic correlation was found between plant height with clear bole height (0.832 and 0.680), chlorophyll a with total chlorophyll (0.882 and 0.915) and carotenoid (0.804 and 0.895); chlorophyll b with total chlorophyll (0.611 and 0.656) and total chlorophyll with carotenoids (0.817 and 0.854).

Principal component analysis revealed that five out of thirteen components had Eigen values more than unity and elucidated a significant amount of variation i.e., 80.740 per cent of the total variation. The first principal component explained 27.295% of the total variation with maximum loadings for four characters namely total chlorophyll (0.963), carotenoids (0.890), chlorophyll a (0.882) and chlorophyll b (0.717). The second principal component explicated 21.561% of the total variation with highest loadings for plant height (0.865), leaf area (0.787), clear bole height (0.685) and stem straightness (0.583). The third principal component explained 14.727 percent variation of total variation where maximum loading was observed by total soluble sugar (0.813) whereas, the fourth and fifth components explained 9.187 and 7.971 per cent of the total variation.

Conclusion

From the critical rummage of the observations recorded on morphological and physiological traits, it is hereby concluded that:

- On the basis of overall performance, seed source S_5 (Salouni), S_6 (Chabutra) and S_2 (Kamahi Devi) exhibited outstanding performance for growth and physiological traits.
- Among genotypes within seed sources, half sib progenies of genotypes S_6G_{16}, S_5G_{15}, S_6G_{17}, S_2G_4 and S_5G_{13} were found superior for morphological and physiological characters.
- Index score analysis revealed that the genotypes S_2G_4, S_5G_{13} and S_5G_{15} obtained maximum index score of 15 for important morphological traits and thus can be selected for high wood production.
- GCV was observed maximum in leaf area followed by clear bole height whereas PCV was observed maximum in starch content followed by total soluble sugar and chlorophyll index.
- Moderate to high heritability and genetic gain were recorded for leaf area followed by petiole length, clear bole height and carotenoid content.

- Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height; chlorophyll a with chlorophyll b, total chlorophyll and carotenoids; chlorophyll b with total chlorophyll and carotenoids and total chlorophyll with carotenoid. Therefore, selection for any of these characters would be a reliable measure for the associated character.

- Principal component analysis concluded that total chlorophyll must be given due weightage owing to maximum variable loading, along with other morphological and physiological traits present in component first and second, since they are the largest contributors towards total genetic diversity in *T. ciliata*. Further, the traits with high variable loadings could be used to distinguish between the progenies and effective selection of genotypes.

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