Indian Journal of Ecology (2023) 50(2): 408-416
DOI: https://doi.org/10.55362/IJE/2023/3912

Manuscript Number: 3912
NAAS Rating: 5.79

Genetic Variability and Correlation Estimates for Morpho-Physiological Characteristics in Half Sib Progenies of *Toona ciliata*

Ranjeet Singh, Sapna Thakur*, Neha Gupta[1] and Gurvinder Pal Singh Dhillon

Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana-141004, India
[1]Department of Botany, Punjab Agricultural University, Ludhiana-141 004, India
**E-mail: sapnathakur@pau.edu*

***Abstract*:** The study was conducted to evaluate the growth performance and physiological behaviour of half sib progenies of twenty-four genotypes of *Toona ciliata* M. Roem, under field conditions. On the basis of mean performance, seed source S5 (Salouni), S6 (Chabutra) and S2 (Kamahi Devi) exhibited outstanding performance 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 superior for morphological and physiological characteristics. High heritability and moderate genetic gain were observed for leaf area, petiole length, clear bole height, carotenoids, chlorophyll a and total chlorophyll content and suggests that genotypic selection would be most effective for these traits. Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height and total chlorophyll with carotenoids and needs to be taken into consideration while doing indirect selection for the associated characters. Further, total chlorophyll, should be given weightage while selection along with other traits (carotenoids, chlorophyll a and plant height), since they are the largest contributors towards total genetic diversity in the genotypes.

***Keywords*:** Correlation, Genotype, Heritability, Principal component, Progenies, Seed source

Genus *Toona* belongs to family Meliaceae and consists of five species i.e., *Toona sinensis*, *T. sureni*, *T. fargesii*, *T. calantas* and *T. ciliata* (Edmonds 1995). *Toona ciliata* commonly known as toon or red cedar is highly valued for its quality timber and ease of cultivation in plantations (Uppal and Singh 2010). It is a large fast growing deciduous or semi-deciduous tree commonly attaining a height of 20-30 m and a girth of 1.83 m (Orwa et al 2009). 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 1200m in Western Peninsula. Toon is one of the prominent species that dominates the agricultural landscapes of the subtropical and sub-temperate Himalayas of the 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. *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 serving the same purpose as the pines of north temperate zones. Toon possesses important economic characteristics including a relatively short 15-year cycle; straight clean bole, good yields, and high value in the internal and external markets (Murakami 2008). The species has high potential to achieve an average annual increase of 30 m^3 ha^{-1} yr^{-1} under good cultivation conditions and management practices (Vilela and Stehling 2012). Toon wood has moderate weight, quality and hardness, and is widely used in various wood-based industries. In addition, toon leaves are excellent source of fodder during the lean period, the flowers are rich source of red dye and the bark has astringent and medicinal properties. *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 (Liu et al 2011a, 2012, Jiang et al 2012). Similarly, ethyl acetate extracts have anti-cancer effects on human breast cancer cell lines (Liu et al 2011b).

Estimating the genetic variability existing in the seed sources and among genotypes within seed sources through progeny evaluation is a prerequisite for isolating elite genotypes/ progenies which are much desired for mass propagation and achieving maximum gain in the productivity. Assessment of quantitative traits contributing towards high biomass or timber production as well as gaining an insight to the complex traits association and extracting traits with highest contribution towards the genetic variability in the population can be effective towards selection and obtaining higher genetic gain in each cycle of any tree improvement programme.

MATERIAL AND METHODS

The study was conducted at Punjab Agricultural University, Ludhiana. The area is situated at 30° 54' 26 " N latitude and 75° 47' 38" E longitude at an elevation of 247m above mean sea level, representing the central zone of Punjab. The assessment of morpho-physiological traits was performed on progeny trial of *T. ciliata* established in the year 2018, using randomized complete block design 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 score, leaf area and petiole length) were recorded at the age of three years. The pigment concentration (chlorophyll a, chlorophyll b, chlorophyll a/b ratio, total chlorophyll and carotenoids) was done using dimethyl sulphoxide (DMSO) non maceration method of Hiscox and Israelstam (1979) and sugar accumulation (total soluble sugars and starch) was done using standard procedure of Dubois et al (1956). Starch content was calculated by multiplication of total glucose content from dried residue with a constant factor of 0.9. Sucrose content was determined following the method of Roe et al (1949). The genetic parameters, genotypic and phenotypic correlation coefficients and PCA were performed using online software OPSTAT.

RESULTS AND DISCUSSION

Significant variation was observed among seed sources for all the traits except stem straightness, chlorophyll a/b and sucrose content (Table 2, 3, 4). On the basis of overall performance for morphological and physiological character, seed sources S5 (Salouni) observed maximum plant height, clear bole height, collar diameter, leaf area, chlorophyll a, chlorophyll a/b, total chlorophyll, total soluble sugar and

Table 1. Details of *T. ciliata* seed sources and genotypes

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

starch followed by S6 (Chabutra) for collar diameter, chlorophyll a, total chlorophyll, carotenoid content, total soluble sugar and starch and S2 (Kamahi Devi) for clear bole height, stem straightness, petiole length, sucrose and starch.

In case of genotypes among seed sources progenies of S_6G_{16} recorded maximum mean value for plant height, collar diameter, straightness, chlorophyll a, total chlorophyll, carotenoid content, total soluble sugar and starch followed by

Table 2. Effect of seed source and genotypes within seed sources on growth traits of *T. ciliata* progeny

Seed source	Genotype	Growth traits					
		Plant height (m)	Clear bole height (m)	Collar diameter (cm)	Stem Straightness (1-5)	Leaf area (cm^2)	Petiole length (cm)
S1 (Talwara)	G1	3.52	1.21	7.55	4.13	47.00	8.38
	G2	3.56	1.36	7.28	4.38	43.00	9.09
	G3	3.30	1.10	7.83	4.21	50.00	10.30
	Mean	3.46	1.22	7.55	4.24	46.67	9.25
S2 (Kamahi Devi)	G4	4.01	1.99	7.19	4.88	59.00	15.24
	G5	3.35	1.33	7.25	4.15	40.00	10.08
	G6	3.32	1.47	6.68	4.31	37.00	9.46
	Mean	3.56	1.60	7.04	4.44	45.33	11.59
S3 (Ludhiana)	G7	3.64	1.11	7.15	4.19	36.00	9.30
	G8	3.73	1.11	8.88	4.31	55.00	10.98
	G9	3.58	1.26	7.93	4.38	53.00	9.63
	Mean	3.65	1.16	7.98	4.29	48.00	9.97
S4 (Sujanpur)	G10	3.43	1.57	6.28	4.00	50.00	10.04
	G11	3.49	1.43	6.73	3.94	35.00	10.53
	G12	3.25	1.29	6.10	4.31	34.00	8.48
	Mean	3.39	1.43	6.37	4.08	39.67	9.68
S5 (Salouni)	G13	4.30	1.96	9.18	4.00	46.00	10.25
	G14	3.51	1.35	6.55	4.56	54.00	9.50
	G15	4.12	1.87	7.24	4.25	55.00	11.25
	Mean	3.98	1.73	7.66	4.27	51.67	10.33
S6 (Chabutra)	G16	3.64	1.34	9.01	4.31	51.00	9.48
	G17	3.73	1.32	7.18	4.19	30.00	10.93
	G18	3.08	1.19	6.10	3.88	31.00	9.90
	Mean	3.48	1.28	7.43	4.13	37.33	10.10
S7 (Shah Talai)	G19	3.39	1.56	6.53	4.13	44.00	7.95
	G20	3.36	1.42	6.78	4.31	49.00	10.26
	G21	3.24	1.41	6.16	4.13	33.00	10.30
	Mean	3.33	1.46	6.49	4.19	42.00	9.50
S8 (Suhari Takoli)	G22	3.40	1.05	6.73	4.25	36.00	14.50
	G23	3.63	1.46	7.38	3.88	39.00	10.38
	G24	3.30	1.15	7.56	4.13	35.00	10.25
	Mean	3.44	1.22	7.22	4.08	36.67	11.71
Mean		3.54	1.39	7.22	7.22	43.42	43.42
Range		3.08-4.30	1.05-1.99	6.10-9.18	6.10-9.18	30-59	30-59
CD (p=0.05)							
Seed source		0.27	0.20	0.84	NS	3.82	3.82
Interaction (Seed source × Genotype)		0.47	0.34	1.46	0.44	6.61	6.61

S_5G_{15}, S_6G_{17}, S_2G_4 and S_5G_{13}. 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 genotypic variation existing in these genotypes or due to genotype x environment interactions. Min et al (2017) reported that the western provenances progenies of *T. ciliata* exhibited better growth performance in terms of tree height and basal diameter in comparison to the progenies from eastern provenances.

Table 3. 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	Total chlorophyll	Carotenoids content
S1 (Talwara)	G1	1.84	0.471	3.94	2.61	0.105
	G2	1.83	0.483	3.85	2.61	0.108
	G3	1.56	0.427	3.70	2.48	0.104
	Mean	1.74	0.460	3.83	2.57	0.106
S2 (Kamahi Devi)	G4	1.96	0.489	4.02	2.77	0.114
	G5	1.68	0.396	4.25	2.13	0.104
	G6	1.87	0.481	3.90	2.66	0.115
	Mean	1.84	0.455	4.06	2.52	0.111
S3 (Ludhiana)	G7	1.75	0.381	4.62	2.41	0.109
	G8	1.77	0.360	4.96	2.40	0.111
	G9	1.86	0.397	4.78	2.55	0.111
	Mean	1.80	0.379	4.79	2.46	0.110
S4 (Sujanpur)	G10	1.69	0.332	5.35	2.29	0.106
	G11	2.10	0.475	4.76	2.91	0.129
	G12	2.04	0.418	4.92	2.77	0.119
	Mean	1.94	0.408	5.01	2.66	0.118
S5 (Salouni)	G13	2.03	0.404	5.76	2.75	0.122
	G14	1.91	0.378	5.34	2.59	0.120
	G15	2.00	0.469	4.62	2.79	0.121
	Mean	1.98	0.417	5.24	2.71	0.121
S6 (Chabutra)	G16	2.03	0.477	4.33	2.83	0.125
	G17	2.19	0.494	4.95	3.03	0.130
	G18	2.06	0.403	5.47	2.79	0.137
	Mean	2.10	0.458	4.92	2.88	0.130
S7 (Shah Talai)	G19	1.89	0.512	3.89	2.71	0.118
	G20	2.15	0.656	3.30	3.16	0.135
	G21	1.88	0.493	3.84	2.68	0.121
	Mean	1.97	0.554	3.68	2.85	0.125
S8 (SuhariTakoli)	G22	1.62	0.473	3.57	2.37	0.105
	G23	1.85	0.601	3.22	2.76	0.130
	G24	1.83	0.430	4.42	2.55	0.114
	Mean	1.77	0.501	3.74	2.56	0.117
Mean		1.89	0.454	4.41	2.65	0.117
Range		1.56-2.19	0.332-0.656	3.22-5.76	2.13-3.16	0.104-0.137
CD (p=0.05)						
Seed sources		0.14	0.07	0.82	0.19	0.006
Interaction (Seed source× genotype)		0.24	0.12	NS	0.33	0.012

Partitioning of phenotypic variation is important to understand the underlying causes of variation and thus, provides opportunities for their effective utilization for the genetic improvement of the species. The genetic variation which is heritable can be exploited for further improvement programme. The genotypic coefficient of variance (GCV %) (Table 5) was maximum for clear bole height (16.34 %) and minimum for stem straightness (3.61%) whereas the

Table 4. 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	0.010	0.096
	G2	0.156	0.012	0.073
	G3	0.101	0.009	0.082
	Mean	0.125	0.011	0.084
S2 (Kamahi Devi)	G4	0.112	0.012	0.094
	G5	0.092	0.013	0.113
	G6	0.107	0.012	0.102
	Mean	0.104	0.012	0.103
S3 (Ludhiana)	G7	0.152	0.013	0.108
	G8	0.115	0.010	0.118
	G9	0.105	0.013	0.108
	Mean	0.124	0.012	0.111
S4 (Sujanpur)	G10	0.146	0.015	0.111
	G11	0.130	0.011	0.097
	G12	0.134	0.010	0.085
	Mean	0.137	0.012	0.097
S5 (Salouni)	G13	0.121	0.012	0.090
	G14	0.154	0.012	0.102
	G15	0.129	0.011	0.101
	Mean	0.135	0.012	0.097
S6 (Chabutra)	G16	0.166	0.012	0.113
	G17	0.143	0.013	0.074
	G18	0.133	0.012	0.101
	Mean	0.147	0.012	0.096
S7 (Shah Talai)	G19	0.148	0.011	0.105
	G20	0.100	0.011	0.082
	G21	0.134	0.009	0.118
	Mean	0.127	0.011	0.102
S8 (Suhari Takoli)	G22	0.097	0.009	0.092
	G23	0.092	0.011	0.055
	G24	0.113	0.009	0.087
	Mean	0.101	0.010	0.078
Mean		0.125	0.011	0.096
Range		0.092-0.166	0.009-0.015	0.055-0.118
CD (p=0.05)				
Seed sources		0.0248	NS	0.021
Interaction (Seed source × genotype)		0.0430	0.003	0.035

phenotypic coefficient of variation (PCV) was maximum (27.65 %) for starch content and minimum for stem straightness (8.26 %). In the present study, phenotypic coefficient of variance values was higher than genotypic coefficient of variance (GCV) for all the parameters which indicate that the expression of these traits are largely influenced by the environment, as evidenced in *Azadirachta indica* (Dhillon et al 2009) and *Melia dubia* (Kumar et al 2013).

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. 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 with moderate genetic gain was for leaf area (76.37% and 35.01%.), petiole length (46.93% and 19.87%), clear bole height (46.30 % and 23.06 %) and carotenoids (42.89 % and 9.71 %), chlorophyll a (38.75% and 9.77%) and total chlorophyll (38.15% and 9.55%) suggesting that maximum weightage should be given to these traits during selection. Dhillon et al (2009), in their study on *Azadirachta indica* seed sources, reported moderate to high heritability and genetic gain for field emergence, clear bole height, basal diameter and stem straightness indicating the effectiveness of these characters in selection for enhancing productivity in agroforestry.

Strong genotypic and phenotypic correlation was observed for plant height with clear bole height (0.832 and 0.680); total chlorophyll with carotenoid continent (0.854 and 0.817). Table 6 indicates that the magnitude of genotypic correlation was higher than the corresponding phenotypic correlation for majority of 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. Lastin et al (2019) also 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 Parthiban (2019), Deepanjli (2018) and Kundal et al (2020) in *Toona ciliata*, suggesting that traits with strong inter relationship must be given due emphasis for indirect selection of the below ground or biomass characters without undergoing destructive sampling of the plants.

The principal component analysis revealed that five out of thirteen components had eigen value more than unity which explained 80.74 % of the total variation (Fig. 1). The first principal component (λ1= 3.548) explicated 27.29 % of the total variability with maximum loading for variables total chlorophyll (0.963), carotenoid content (0.890), chlorophyll a

Table 5. Variability and genetic estimates for growth and physiological characters of *T. ciliata* progenies

Parameter	Mean	Range	Coefficient of variation (%)		$H^2_{b.s}$ (%)	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
Leaf area (cm^2)	43.42	30.00-59.00	19.44	22.25	76.37	15.20	35.01
Petiole length (cm)	10.27	7.95-15.24	14.07	20.54	46.93	2.04	19.87
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
Chlorophyll a/b	4.41	3.22-5.76	11.19	25.25	19.64	0.45	10.22
Total Chlorophyll (mg/g FW)	2.65	2.13-3.16	7.50	12.14	38.15	0.252	9.55
Carotenoid content (mg/g FW)	0.117	0.104-0.137	7.20	10.99	42.89	0.011	9.71
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	0.0091-0.0153	6.68	22.02	9.20	0.001	4.17
Starch (g starch/g FW)	0.096	0.055-0.118	9.83	27.65	12.63	0.007	7.20

(0.882) and chlorophyll b (0.717). Second principal component (λ2= 2.803) elucidated 21.56 % total variability with maximum loading for traits plant height (0.865), leaf area (0.787), clear bole height (0.685). Third principal component (λ3= 1.914) explained 14.73 % with maximum loading for total soluble sugar (0.813). Fourth principal component (λ4= 1.194) explained 9.19 per cent of total variation whereas, the fifth component (λ5= 1.036) explicated 7.97 per cent of the

Table 6. Correlation among morphological and physiological characters of *T. ciliata*

		Clear bole height	Collar diameter	Straightness score	Petiole length	Leaf area	Chlorophyll index (chl a/b)	Total chl	Carotenoid content	Total soluble sugar	Sucrose	Starch
Plant height	P	0.680**	0.613**	0.405**	0.281**	0.293**	0.006^{NS}	0.193^{NS}	0.059^{NS}	-0.045^{NS}	0.170^{NS}	0.033^{NS}
	G	0.832**	0.580**	0.039^{NS}	0.388**	0.651**	0.594**	0.116^{NS}	-0.043^{NS}	0.220*	0.371**	0.263**
Clear bole	P		0.090^{NS}	0.151^{NS}	0.121^{NS}	0.290**	-0.029^{NS}	0.107^{NS}	0.053^{NS}	-0.019^{NS}	0.055^{NS}	0.033^{NS}
	G		0.048^{NS}	0.239*	0.328**	0.448**	0.334**	0.494**	0.356**	0.154^{NS}	0.734**	-0.144^{NS}
Collar diameter	P			0.370**	0.099^{NS}	0.262**	0.084^{NS}	0.033^{NS}	-0.045^{NS}	-0.066^{NS}	0.074^{NS}	0.033^{NS}
	G			-0.332**	-0.003^{NS}	0.584**	0.144^{NS}	-0180^{NS}	-0.274**	-0.145^{NS}	0.394**	0.020^{NS}
Straightness score	P				0.277**	0.315**	-0.094^{NS}	0.073^{NS}	-0.154^{NS}	-0.097^{NS}	-0.048^{NS}	-0.036^{NS}
	G				0.511**	0.835**	-0.192^{NS}	0.104^{NS}	-0.260*	0.303**	0.198^{NS}	0.414**
Petiole length	P					0.093^{NS}	-0.209*	0.048^{NS}	-0.069^{NS}	-0.282**	-0.030^{NS}	-0.015^{NS}
	G					0.229*	-0.098^{NS}	0.018^{NS}	-0.064^{NS}	-0.523**	-0.224*	-0.184^{NS}
Leaf area	P						0.067^{NS}	0.016^{NS}	-0.141^{NS}	0.026^{NS}	0.030^{NS}	0.117^{NS}
	G						-0.002^{NS}	0.116^{NS}	-0.318**	-0.072^{NS}	0.284**	0.398**
Chlorophyll index (chl a/b)	P							-0.063^{NS}	0.100^{NS}	0.288**	0.086^{NS}	0.323**
	G							0.078^{NS}	0.360**	0.658**	0.980**	0.395**
Total chl	P								0.817**	0.167^{NS}	0.040^{NS}	-0.159^{NS}
	G								0.854**	0.318**	-0.571**	0.554**
Carotenoids	P									0.107^{NS}	0.026^{NS}	-0.059^{NS}
	G									0.359**	-0.252*	0.315**
Total soluble sugar	P										0.374**	0.326**
	G										0.155^{NS}	0.080^{NS}
Sucrose	P											0.272**
	G											0.141^{NS}

*Denotes significant at 5% level of significance **Denotes significant at 1% level of significance NS: Non-significant
G denotes genotypic correlation coefficient P denotes phenotypic correlation coefficient

Table 7. 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 (1-5)	-0.109	0.583	-0.130	0.429	0.568
Leaf area (cm^2)	-0.213	0.787	-0.040	-0.062	0.303
Petiole length (cm)	-0.004	0.446	-0.535	0.428	-0.127
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

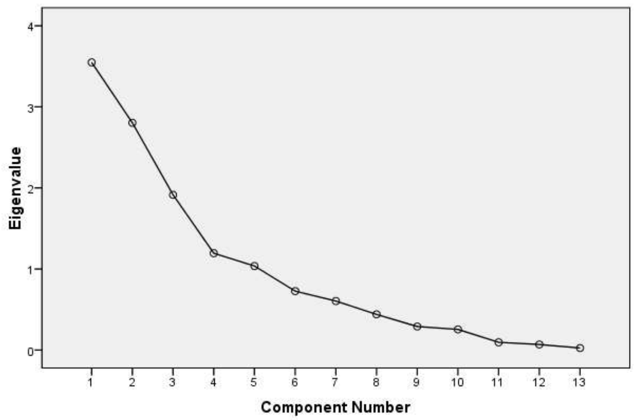

Fig. 1. Screen plot based on principal component analysis

variability. Thus, maximum weightage should be given to total chlorophyll for selection along with other traits (carotenoids, chlorophyll a and plant height), since it contributed largest variation in the total genetic variability. Principal component analysis extracted the most important traits contributing towards genetic variability in *T. ciliata* which could be used to distinguish between the genotypes and effective selection of genotypes. Danquah et al (2011) 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 and ecological zones level whereas in case of *Khaya anthotheca* at population level only. Similarly, Kundu et al (2000) 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.

CONCLUSION

Among seed sources, Salouni, Chabutra and Kamahi Devi whereas, among genotypes within seed sources, progenies of S_6G_{16} (Chabutra), S_5G_{15} (Salouni), S_6G_{17} (Chabutra), S_2G_4 (Kamahi Devi) and S_5G_{13} (Salouni) outperformed for various growth and physiological traits and needs to be further evaluated for performance stability. High heritability and moderate genetic gain were observed for leaf area, petiole length, clear bole height, carotenoid content, chlorophyll and total chlorophyll content. Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height and total chlorophyll with carotenoid content and thus may be utilized for indirect selection of the associated characters. Total chlorophyll must be given due weightage while selection, owing to maximum variable loading, along with other morphological and physiological traits (carotenoids, chlorophyll a and plant height), since they are giving maximum contribution towards total genetic diversity in *T. ciliata* progenies and would be conclusive to distinguish between the progenies and effective selection of genotypes.

REFERENCES

Danquah JA, Appiah M and Ari P 2011. Leaf morphometric variation in two species of African mahoganies: *Khaya ivorensis* and *Khaya anthotheca* (Meliaceae). *European Journal of Scientific Research* **54**: 325-338.

Deepanjli 2018. *Studies on variabilities and propagation techniques of Toona ciliata M. Roem under Punjab condition*. M.Sc. thesis, Punjab Agricultural University, Ludhiana, India.

Dhillon GPS, Sidhu DS and Singh A 2009. Genetic variation among open pollinated progenies of *Melia azedarach* under nursery and field conditions. *Indian Forester* **135**: 84-88.

Dubois M, Guilles KA, Hamilton JK, Rebers PA and Smith F 1956. Calorimetric method for the determination of sugars and related substances. *Analytical Chemistry* **18**: 350-356.

Edmonds JM 1995. *Toona*. In: Meliaceae, by Mabberley D J, Pannell C M, Sing A M (eds.) *Flora Malesiana, Series Spermatophyta*. Leiden, the Netherland. **12:** 358-371.

Haseena K and Bhardwaj SK 2018. Performance evaluation of selected tree species growing alongside state highway, Himachal Pradesh, India. *International Journal of Academic Research and Development* **3**: 68-73.

Hiscox JD and Israelstam GF 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**: 1332-1334.

Jiang JM, Liu J, Sun ZX and Chen YT 2012. Isolation and characterization of microsatellite loci from an endangered tree species, *Toona ciliata* var. pubescens. *Genetics and Molecular Research* **11**: 4411-4417.

Kumar P, Parthiban KT and Saravanan V 2013. Genetic variations among open pollinated families of selected better trees in *Melia Dubia*. *Research Journal of Recent Sciences* **2**: 189-194.

Kundal M, Thakur S and Dhillon GPS 2020. Evaluation of growth performance of half sib progenies of *Toona ciliata* M. Roem under field conditions. *Genetika* **52**: 651-660.

Kundu S K 2000. Evaluation of provenance variation on early growth and survival of neem (*Azadirachta indica*) in Bangladesh and India. *Journal of Tropical Forest Science* **12**: 509-523.

Lastin T, Hernawan E, Rosmiati M, Putra RE and Rahmayunita I 2019. Estimation and correlation of surian leaves (*Toona sinensis*) weight with the tree parameters. *IOP conference Series: Earth and Environmental Sciences* **466**: 012006.

Liu J, Yang SP, Su ZS, Lin BD, Wu Y and Yue JM 2011a. Limonoids from the stems of *Toona ciliata* var. henryi (Meliaceae). *Phytochemistry* **72**: 2189-2196.

Liu JQ, Wang CF, Li Y, Chen JC, Zhou L and Qiu MH 2012. Limonoids from the leaves of *Toona ciliata* var. yunnanensis. *Phytochemistry* **76**: 141-149.

Liu YB, Cheng XR, Qin JJ, Yan SK, Jin HZ and Zhang WD 2011b. Chemical constituents of *Toona ciliata* var. pubescens. *Chinese Journal of Natural Medicines* **9**: 115-119.

Min QQ, Ying WL, Qin Z and Yang CX 2017. Growth rhythms of *Toona ciliata* seedlings for different provenances. *Journal of South China Agricultural University* **38**: 96-102.

Murakami CHG 2008. Australian cedar: Valorization of noble species. *Forest Bulletin São Paulo* **7**: 1-6.

Orwa C, Mutua A, Kindt R, Jamnadass R and Anthony S 2009. *Agroforestry Database: A tree reference and selection guide version 4.0*. World Agroforestry Centre, Kenya.

Parthiban KT, Krishnakumar N, Karthick M and Thirumurugan M 2019. Improvement of toon (*Toona ciliata* M. Roem) genetic resources through growth and evaluation. *Indian Journal of Agroforestry* **21**: 60-68.

Roe JH, Epstein JH and Goldstein NP 1949. A photometric method for the determination of insulin in plasma and urine. *Journal of Biological Chemistry* **178**: 839-845.

Received 08 November, 2022; Accepted 18 February, 2023

Uppal R and Singh C 2010. Effect of seed source variation on seed and seedling characteristics of *Toona ciliata*: A promising timber tree species of western Himalaya. *Indian Journal of Soil Conservation* **38**: 132-136.

Vilela ES and Stehling EC 2012. *Planting recommendations for Australian cedar - clonal seedlings*. Bela Vista Florestal, Campo Belo, Brazil.

Yogeshwari 2013. *Crop production and physico-chemical characteristics of soils under Toona ciliata M. Roem. trees in mid hill conditions of Himachal Pradesh*. M.Sc. thesis, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India.