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Genotypic and Phenotypic Association Studies in *Melia composita* Benth. Progenies Grown in Different Agroclimatic Conditions in Punjab

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Abstract: The present study was conducted on 5-year-old progenies of *Melia composita* Benth. in 2022 to assess the association among traits under two different climatic conditions in Punjab, where the central plain zone (Ludhiana) is an irrigated plain and the western plain zone (Bathinda) is a semiarid region. Significant variation among progenies was observed for all growth parameters. The genotypic correlation coefficients for all traits were higher than the phenotypic correlation coefficients at both sites, indicating that there were inherent associations between the traits. Volume showed a highly significant positive correlation with almost all traits at both genotypic and phenotypic levels, with the exception of the number of branches per meter of crown length and crown length. Path analysis revealed that diameter at breast height was the most important trait due to its highest positive direct and indirect effects on tree volume. The study also revealed that the magnitude of relationships among traits changed with environmental conditions, reflecting significant genotype × environment interactions.

Keywords: *Melia composita* Benth., Genotypic correlation, Phenotypic correlation, Path analysis

India is under tremendous pressure to meet the rising demand for wood and wood-based products. With supplies of high-quality timber from conventional, long-rotation species declining, industries are increasingly turning to fast-growing tree species as a sustainable source of raw material (Sharma 2019). Plantation-grown wood is therefore becoming indispensable for meeting future needs, particularly for industrial and structural applications. Among these species, Burma dek (*Melia composita*) has emerged as a promising agroforestry tree owing to its fast growth, straight bole, and adaptability to diverse climatic conditions. Its favourable physical and mechanical properties make it suitable for furniture, joinery, and other value-added applications, thereby serving as a viable alternative to traditional timbers such as shisham, mango, and teak (Kumar et al., 2018). Moreover, *Melia composita* is increasingly recognized as a potential diversifier in the poplar eucalyptus dominated agroforestry systems of north-western India. The multipurpose utility including pulp and paper production, bioenergy generation, construction, furniture, and even musical instruments has further increased its popularity and commercial demand (Parthiban et al., 2009, Chinnaraj et al., 2011). The species also thrives in a wide range of soil types and requires relatively low water input, which enhances its suitability for large-scale cultivation.

The improvement of such plantation species depends heavily on the availability of genotypic variability for yield-related traits across agro-climatic conditions (Ahmad et al., 2018). In this context, trait association studies provide essential insights for breeding and selection. Correlation analysis is widely used to evaluate relationships among yield attributes and to identify traits contributing directly or indirectly to productivity (Ali et al., 2003). However, correlation alone does not partition the magnitude of direct and indirect effects of traits (Silva et al., 2009). Path coefficient analysis, first proposed by Wright and later applied in forestry and crop breeding (Larik 1979, Baye et al., 2020), overcomes this limitation by decomposing correlations into direct and indirect effects, thereby offering greater reliability in identifying causal relationships and formulating effective selection strategies. Despite the increasing importance of *Melia composita*, very limited research has been conducted in India on trait associations and their temporal or spatial variations. This knowledge gap restricts efforts toward systematic improvement and genetic enhancement of the species. The present study was therefore undertaken to evaluate different progenies of *M. composita*, with the objectives of assessing the relationships between timber volume and its contributing traits, and determining the direct and indirect effects of these traits on volume production through path analysis.

MATERIAL AND METHODS

Experimental site: The study was conducted in the year 2022 at two different sites in the Indian state of Punjab. The first location was situated at Research farm of department of Forestry & Natural Resources (30°54'30.6''N, 75°48'43.8''E), Punjab Agricultural University, Ludhiana (Fig. 1) and second at Ruldu Singh Wala Farm (30°01'15.22''N, 74°78'19.27''E), Regional Research Station**,** Punjab Agricultural University, Bathinda (Fig. 2). These sites lie in two different agroclimatic zones of Punjab in which Ludhiana (First site) comes in central plain zone (irrigated plain) and the Bathinda (second site) in the western plain zone (semi-arid zone).

Cultural practices and experimental design: The progeny trial was established in the year 2016 using 14 progenies of *Melia composita* collected from different parts of northern Punjab and Uttarakhand region. The same cultural and management practices i.e. irrigation, ploughing, pruning etc. were performed as and when needed at both the sites. The tree species at both the sites were exposed to same treatment and cultural operations during the entire study duration. The experiment was laid out in completely randomised block design with four replications at both the sites. The progenies were planted with five plants per progeny with the line to line spacing of 4m and the plant to plant spacing of 3m.

Fig. 1. Overview of *Melia composita* progeny trial at PAU, Ludhiana

Fig. 2. Overview of *Melia composita* progeny trial at RRS, Bathinda

The measurements for traits, tree height (m), diameter (cm), clear bole height (m), stem straightness, crown length (m), crown width (m), number of branches per meter crown length and tree volume were recorded at 5 years age. The volume was calculated by using the regression equation.

Volume per tree (VPT) = $0.000137 * D^{2.48}$ (Choudhary et al., 2024)

Where, D is the diameter at breast height in cm.

Statistical analysis: Statistical analysis was carried out using the R software (version 4.2.1). Analysis of variance for completely randomized block design was carried out by following the method given by Panse and Sukhatme (1989).

Phenotypic correlation coefficient (PCC)

$$\text{PCC } (rp_{12}) = \frac{\sigma p_{12}}{\sqrt{\sigma^2 p1 . \sigma^2 p2}}$$

Where,

$\sigma^2 p1$ = Phenotypic Variance of observation X_1.

$\sigma^2 p2$ = Phenotypic Variance of observation X_2.

σ p12 = Phenotypic Covariance between the observations, X_1 and X_2

Genotypic correlation coefficient (GCC)

$$\text{GCC } (rg_{12}) = \frac{\sigma g_{12}}{\sqrt{\sigma^2 g1 . \sigma^2 g2}}$$

Where,

$\sigma^2 g1$ = Genotypic Variance of observation X_1.

$\sigma^2 g2$ = Genotypic Variance of observation X_2.

σ g12 = Genotypic Covariance between the observations, X_1 and X_2

To test the level of significance, the phenotypic correlation co-efficient was compared by the 'r' value given by Fisher and Yates (1963) at (n-2) degrees of freedom at 1% and 5% level of significance simultaneously.

Path coefficients analysis: The path coefficient analysis was carried out as suggested by Wright (1921) and demonstrated by Dewey and Lu (1959). The path analysis was calculated by solving the following set of n simultaneous equations:

$Py_1 + Py_2 r_{12} + \ldots\ldots. + P_{yn} r_{in} = ry_1$

$Py_1 r_{12} + Py_2 + \ldots\ldots. + P_{yn} r_{2n} = ry_2$

$Py_1 r_{1n} + P_{y2} r_{2n} + \ldots. + P_{yn} r_{2n} = ry_n$

Where,

$Py, Py_2 \ldots\ldots.. Py_n$, are the direct path effects of 1, 2....n independent variables affecting dependent variable 'y'.

$r_{12}, r_{13} \ldots\ldots r_{in} \ldots\ldots r_n$ (n-1) are the correlation coefficients between various independent variables. The indirect effects of the i^{th} variables via j^{th} variables were worked out as (Pyj + rij). From the simultaneous equations, it is clear that the correlation coefficient is the sum of direct and indirect path coefficient. The residual effect was calculated as follows:

Degree of determination $R^2 = P^2_{y1} + 2Py_1, Py_2, r_{12} + 2Py_1, Py_3, r_{13} + ... P^2_{y2} + 2Py_2, Py_3, r_{23} + ... P_{yn}$

Residual variation = $1-R^2$

Residual = $\sqrt{1-R^2}$

RESULTS AND DISCUSSION

Significant variations were observed in all tree growth parameters at both sites among 14 progenies of *Melia composite*. Tree volume ranged from 0.055 to 0.166 m³ at Ludhiana and from 0.080 to 0.240 m³ at Bathinda, with slightly higher mean volume at Bathinda (0.141 m³) than Ludhiana (0.124 m³) as mentioned in Table 1. Mean DBH and total height followed a similar pattern, being marginally higher at Bathinda than at Ludhiana. Crown-related traits showed a contrasting site response. Mean crown width was greater at Ludhiana (4.40 m) than at Bathinda (3.47 m), whereas, crown length was higher at Bathinda (9.48 m) than at Ludhiana (8.67 m). Number of branches was also higher at Ludhiana (1.78) than Bathinda (1.42), while mean stem straightness scores were comparable between sites (3.54 at Ludhiana and 3.51 at Bathinda). The ranges (minimum–maximum) for all traits were relatively wide at both locations, confirming marked within-progeny and among-progeny variability in volume, diameter, height, crown attributes (CL & CW), and number of branches. Significant variation in *Melia composita* was also reported by Kaur et al. (2023). Similar finding was also reported by Chauhan et al. (2018) in *Melia azedarach.*

Genetic and phenotypic correlation studies: The genotypic correlation coefficients for all the characters were higher than the phenotypic correlation coefficient at both the sites (Fig. 3 & 4), this indicates that there was inherent association between the characters (Al-Tabbal and Al-Fraihat 2012); its phenotypic expression may deflect by the influence of environment (Shahid 2002). The higher magnitude of genotypic correlations than phenotypic correlations were also reported in earlier studies on various crops i.e. in rice by Nithya et al., (2020) and Karim et al., (2014), in barley by Al-Tabbal and Al-Fraihat (2012), in Egyptian bread wheat by Abd El-Mohsen (2012) and in poplar by Jha (2012).

Volume had a highly significant positive correlation with almost all of the characters at both the genotypic and phenotypic levels, with the exception of number of branches per meter crown length, and the crown length, out of these two characters the NOB has non-significant correlation at both the sites but the crown length had showed variation in correlation among the two sites, at Ludhiana site the CL has a non-significant positive correlation with volume but at Bathinda the correlation was reported positive and highly significant, these variation can be attributed to genotypic environmental interaction because the climate and soil conditions of the both the regions are different. At Bathinda, where water stress due to longer duration of dry spell and low average rainfall (Singh et al., 2022), is anticipated to be higher, trees with longer crowns (Table 1) might capture more light/use water more effectively, yielding a strong positive CL−volume correlation. At Ludhiana, higher water availability might weaken this dependency. A study on *Pinus contorta*

Fig. 3. Genotypic (above diagonal) and phenotypic (below diagonal) correlation among different characters of *Melia composita* progenies grown at Ludhiana (** significant at 1%, * significant at 5%)

and *Picea glauca* across moisture-limited forest landscapes in western Canada reported that tree radial growth became strongly influenced by precipitation, especially in water−stressed sites (Lopez et al., 2019). This assumption could also be true for similar other different relationships at both different sites. Jha (2012) in his study on poplar also reported highly significant positive correlation of juvenile wood volume with DBH, CBH and plant hight. Indirect selection for these traits will also be rewarding for volume, which is our main commercially important trait.

Strong correlation of tree height with DBH, CBH, crown width and crown length at genotypic level revealed the existence of pleiotropy or linkage or both between the correlated traits. Therefore, these characters must be given proper emphasis during selection programme and can be exploited for indirect selection. Similar findings were also supported by Thakur and Thakur (2015) in *Melia azedarach*. Parthiban et al. (2019) and Kundal et al. (2020) in *Toona ciliata*, Singh et al. (2015) in *Populus deltoides*. But NOB and stem straightness has shown contrasting correlations with tree hight at both the sites and also genotypically and phenotypically. Stem straightness has showed positive significant correlation genotypically at Ludhiana and positive highly significant genetic and phenotypic correlation at Bathinda but non-significant positive correlation at Ludhiana, whereas NOB has shown non-significant negative genetic

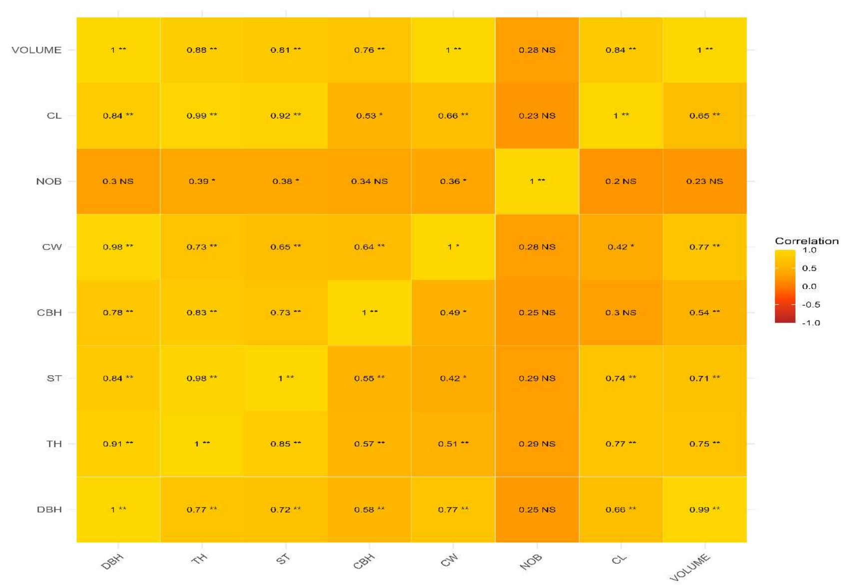

Fig. 4. Genotypic (above diagonal) and phenotypic (below diagonal) correlation among different characters of *Melia composita* progenies grown at Bathinda (**significant at 1%, * significant at 5%)

Table 1. Preliminary information on tree growth parameters among 14 progenies of *Melia composita* planted at two different sites

Parameters	Minimum		Maximum		Mean ± SD	
	Ludhiana	Bathinda	Ludhiana	Bathinda	Ludhiana	Bathinda
Volume (m^3)	0.055	0.080	0.166	0.240	0.124 ± 0.032	0.141±0.049
DBH (cm)	11.13	12.60	17.47	20.08	15.40 ±1.78	16.06±2.31
TH (m)	13.00	12.35	15.24	16.85	14.18±0.63	14.84±1.14
CBH (m)	4.69	4.64	6.15	6.08	5.50 ±0.46	5.44 ±0.43
CW (m)	3.09	2.82	4.96	4.29	4.40±0.50	3.47 ±0.42
CL (m)	7.53	8.27	9.24	10.77	8.67 ±0.47	9.48±0.72
NOB	1.24	1.06	2.44	1.75	1.78 ±0.32	1.42±0.19
ST	2.85	2.58	4.23	4.09	3.54 ±0.38	3.51±0.43

DBH: Diameter at breast height, TH: Total height, ST: Stem straightness CBH: Clear bole height, CS: Crown spread, NOB: Number of branches per meter crown length, CL: Crown length and phenotypic correlation at Ludhiana, whereas at Bathinda it has shown significant and non-significant positive genotypic and phenotypic correlation with tree height, respectively. Number of branches per meter crown length has reported non-significant association with most of the traits at both the sites. Number of branches per meter crown length at PAU Ludhiana trial indicated highly significant negative correlation with crown length and significant correlation with clear bole height. The number of branches per meter crown length at RRS, Bathinda showed non-significant association with crown length and positive phenotypic association with total height, straightness, and crown spread. Non-significant association of number of branches with any of the morphological traits was also reported by Kumar et al. (2022) in *Melia dubia*. Dhillon et al. (2000) in *Dalbergia sissoo* Roxb observed that seedling height, leaf weight, and height up to first branch correlated more directly to collar diameter, a key trait in forest trees at the seedling stage.

Path coefficient analysis: In the present study, at the Research Farm, PAU, Ludhiana, diameter at breast height (DBH), total height, exhibited a positive direct effect on timber volume both genotypically and phenotypically (Table 2). Additionally, DBH showed a positive indirect effect through total height, straightness, and the number of branches per meter of crown length. Traits such as total height, straightness, clear bole height (CBH), crown spread, and crown length also exerted a positive indirect effect on tree volume via DBH. Parthiban et al. (2017) in *Melia dubia* reported the positive direct and indirect of effect (via tree height) of DBH on tree volume. Jha (2012) in similar study on poplar also reported the positive direct effect of DBH and tree height on the juvenile wood volume and also reported positive indirect effect of DBH on juvenile wood volume via plant height, diameter of branches, crown diameter, and survival.

At the Regional Research Station, Bathinda, DBH was the only trait that exhibited a significant positive direct effect on timber volume at both the genotypic and phenotypic levels (Table 3). However, other traits including total height, straightness, CBH, crown spread, number of branches, and crown length contributed positively to volume indirectly through DBH. Espahbodi et al. (2018) in *Sorbus tarminalis* (L.) Crantz concluded that collar diameter had strong positive direct effect on plant height at phenotypic level. Similar findings were also reported by Sharma et al. (2024) in which high positive direct effect of DBH on volume and negative direct effect of tree height on volume. Parthiban et al. (2017) also reported negative direct effect of tree height on tree volume in *Melia dubia*. DBH exerted positive indirect effect via tree height whereas; tree height expressed negative indirect effect via DBH on tree volume.

The highly significant positive genotypic and phenotypic correlation between volume and DBH is due to high positive direct effect of DBH, which reveals true relationship between them and therefore direct selection for this trait would be

Table 2. Direct and indirect effect of all the independent components on volume (m^3 $tree^{-1}$) of *Melia composita* progenies grown at Ludhiana

		DBH	TH	ST	CBH	CW	NOB	CL	GC and PC with volume
DBH (cm)	G	0.841	0.011	-0.024	-0.012	0.254	-0.060	-0.018	0.995 **
	P	1.057	0.163	0.003	-0.118	-0.052	-0.004	-0.060	0.9914 **
TH (m)	G	0.542	0.018	-0.007	-0.012	0.126	0.063	-0.060	0.671 **
	P	0.610	0.283	0.002	-0.127	-0.029	0.002	-0.147	0.5835 **
ST	G	0.592	0.004	-0.034	-0.011	0.193	-0.085	0.025	0.6865 **
	P	0.468	0.095	0.006	-0.183	-0.028	-0.006	0.079	0.4247 **
CBH (m)	G	0.722	0.015	-0.025	-0.014	0.251	-0.069	-0.023	0.8579 **
	P	0.432	0.125	0.004	-0.288	-0.023	-0.007	0.119	0.385 **
CW (m)	G	0.813	0.009	-0.025	-0.013	0.262	-0.119	0.007	0.9345 **
	P	0.836	0.122	0.002	-0.101	-0.066	-0.007	-0.018	0.781 **
NOB	G	0.251	-0.006	-0.014	-0.005	0.156	-0.200	0.058	0.2408 NS
	P	0.260	-0.026	0.002	-0.111	-0.028	-0.017	0.132	0.2042 NS
CL (m)	G	0.221	0.016	0.013	-0.005	-0.026	0.174	-0.067	0.327 NS
	P	0.225	0.149	-0.002	0.122	-0.004	0.008	-0.281	0.2377 NS

Genotypic residual effect = 0.0133; Phenotypic residual effect = 0.0039. *G & P in the table indicate the genotypic and phenotypic path coefficient respectively. GC-Genotypic correlation; PC- Phenotypic correlation

Table 3. Direct and indirect effect of all the independent components on volume (m^3 $tree^{-1}$) of *Melia composita* progenies grown at Bathinda

		DBH	TH	ST	CBH	CW	NOB	CL	GC and PC with volume
DBH (cm)	G	1.1050	0.1145	-0.0665	-0.0654	-0.0123	-0.0046	-0.0734	0.9968**
	P	0.9250	-0.0264	0.0876	-0.0531	0.0801	-0.0186	-0.0079	0.9911**
TH (m)	G	1.0066	0.1256	-0.0775	-0.0698	-0.0091	-0.0059	-0.0859	0.8835**
	P	0.7084	-0.0344	0.1036	-0.0518	0.0533	-0.0215	-0.0092	0.7541**
ST	G	0.9255	0.1226	-0.0794	-0.0616	-0.0081	-0.0058	-0.0804	0.8121**
	P	0.6650	-0.0293	0.1216	-0.0502	0.0436	-0.0210	-0.0089	0.7105**
CBH (m)	G	0.8608	0.1046	-0.0583	-0.0839	-0.0079	-0.0051	-0.0456	0.7640**
	P	0.5363	-0.0195	0.0668	-0.0914	0.0506	-0.0192	-0.0036	0.5443**
CW (m)	G	1.0857	0.0914	-0.0516	-0.0533	-0.0125	-0.0055	-0.0574	0.9962**
	P	0.7120	-0.0176	0.0511	-0.0445	0.1041	-0.0210	-0.0050	0.7701**
NOB	G	0.3339	0.0485	-0.0303	-0.0281	-0.0044	-0.0154	-0.0196	0.2845
	P	0.2295	-0.0098	0.0341	-0.0234	0.0292	-0.0748	-0.0024	0.2272
CL (m)	G	0.9331	0.1241	-0.0734	-0.0440	-0.0083	-0.0034	-0.0869	0.8409**
	P	0.6080	-0.0264	0.0903	-0.0277	0.0435	-0.0154	-0.0120	0.6528**

Genotypic residual effect = 0.006, Phenotypic residual effect = 0.0132

rewarding for volume improvement. It also shows positive indirect effect through total height on tree volume. Other traits such as total height, straightness, CBH, crown spread and crown length showed significant indirect effect so these traits would be considered for selection. Kumar and Dhillon (2016) in *Eucalyptus* clones reported the highest positive phenotypic and genotypic direct effect of collar diameter on volume index followed by plant height. He also reported that plant height exerted positive indirect effect via collar diameter. Number of branches showed negative direct effect on volume.

CONCLUSIONS

The present study provides important insights about significant variability and correlations among growth and volume characteristics in *Melia composita* progenies grown in two different climatic conditions. The study concluded that DBH and tree height was the most important trait due to its highest positive direct and indirect effects on tree volume. The study also revealed that relationships among traits change with environmental conditions, as evident by the differing correlation coefficients at the two sites, reflecting significant genotype × environment interactions.

AUTHOR'S CONTRIBUTIONS

RC: Data curation, Formal analysis and Interpretation, Writing - original draft, Writing - review & editing; RISG: Conceptualization, Methodology, Investigation, Resources, Writing - review & editing; AKD: Data curation, Formal analysis and Interpretation, Methodology, Supervision, Validation, Writing - original draft, Writing - review & editing; GPSD: Conceptualization, Investigation, Resources, Writing - review & editing .

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