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Correlation and regression analysis of wood properties of *Dalbergia sissoo* Roxb. *ex* DC. Procured from local markets of Himachal Pradesh, India

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Abstract
The relationships between different wood properties were being carried out to check the dependence of one character over the other which defines the overall quality and performance of the wood which is being subjected to utilization. The correlation was found positive and highly significant for specific gravity with fibre diameter, bending strength with modulus of rupture, tensile strength with tension modulus of elasticity. The correlation was observed negative for tensile strength with fibre length, tension modulus of elasticity with vessel diameter and fibre length, bending modulus of elasticity with modulus of elasticity compression parallel to grain followed by modulus of rupture with vessel diameter. Coefficient of determination (R^2) was observed to be more than 0.70 for specific gravity (0.883) and tensile modulus of elasticity (0.894) when regressed with other wood parameters.

Keywords: Wood, fibre, vessel, elasticity

Introduction
Wood has been used as the most versatile constructional material for thousands of years because of its unique properties (Rowell, 2013) [6]. It is highly anisotropic *i.e.* it has different properties in different planes. This is due to its cellular structure and physical organization of cellulose chains within the cell walls (Schniewind, 1989) [7]. Plainly, wood is a natural, renewable cellular resource of botanical origin with unique structural and chemical characteristics that render its desirable end uses for variety of purposes with excellent strength-to-weight properties (Hingston *et al*., 2001) [2].

Dalbergia sissoo commonly known as shisham belongs to the family Fabaceae and is a medium to large-sized deciduous tree up to 30 m in height and 80 cm diameter under favourable growth conditions. The species grows well in subtropical to tropical climate which occurs throughout sub Himalayan tract and outer Himalayan valleys from the Indus to the Assam, usually upto 900msl, but occasionally ascending to 1500msl. It is a strong light demander, requires full overhead light for successful regeneration and establishment. It has been grown since long times in combination with agricultural crops, field boundaries around the fruit orchard, as wind breaks and shelter belts and as scattered trees in the fallow lands.

The timber of this species is strong and very elastic in nature. The physical and anatomical properties of the wood are comparable to teak. Heartwood of Shisham is highly durable, both in exposed and sheltered conditions than sapwood. The heartwood is golden to dark brown whereas sapwood is white to pale brownish white. The wood has straight grain, though it can be sometimes interlocked. The wood is suitable for handles for striking tools, scooping, cutting and shaping tools (Luna, 2005) [4]. The correlation and regression analysis were done in order to find out the interdependence between the various wood parameters which defines the suitability of its utilization for different purposes.

Materials and Methods
Wood samples of *Dalbergia sissoo* were randomly collected from ten different market sites of Himachal Pradesh for analyzing the different wood properties. Details of sites with their coordinates from the local market sites have been given below:

Table 1: Details of market sites, their elevation and coordinates

S. No.	Sites	Elevation (m)	Latitude	Longitude
i.	Andreta (Kangra)	988	32° 2' 24.4854" N	76° 34' 3.3846" E
ii.	Baroh (Kangra)	756	31° 36' 13.821" N	76° 26' 54.7292" E
iii.	Galore (Hamirpur)	753	31° 41' 7.335" N	76° 30' 56.0988" E
iv.	Kangu (Hamirpur)	1103	31° 6' 42.03" N	76° 57' 54.7014" E
v.	Nalagarh (Solan)	348	31° 2' 40.4118" N	76° 42' 17.244" E
vi.	Chowkiwala (Solan)	346	31° 2' 45.4842" N	76° 42' 9.054" E
vii.	Dattowal (Solan)	394	31° 2' 27.7404" N	76° 43' 16.4814" E
viii.	Ghumarwin (Bilaspur)	609	31° 26' 56.922" N	76° 42' 17.244" E
ix.	Sundernagar (Mandi)	849	31° 31' 59.6634" N	76° 53' 32.1828" E
x.	Sarahan (Sirmaur)	1589	30° 43' 33.0882" N	77° 11' 7.6338" E
xi.	Control (Teak) From Solan market			

Simple correlation coefficients, Multiple Regression analysis and Coefficient of determination

The correlation and regression analysis between different wood properties of *Dalbergia sissoo* Roxb. *ex* DC. were performed using IBM SPSS (Ver. 21) software.

Multiple regression equations were fitted for different mechanical and physical properties. The average relationship between the mechanical properties { tensile strength (Y_2), bending strength (Y_3), bending modulus of rupture (Y_4), compression parallel to grain (Y_5), compression perpendicular to grain (Y_6), modulus of elasticity perpendicular to grain (Y_7), modulus of elasticity parallel to grain (Y_8), bending modulus of elasticity (Y_9) and tension modulus of elasticity (Y_{10})}, physical{specific gravity (Y_1), moisture content (X_1)} and anatomical properties {fibre diameter (X_2), vessel diameter (X_3) and fibre length (X_4)}.

The straight line trend between the dependent variable (Y) and the independent variables (X_i) was given by the equation:

$$Y = \alpha + \beta (X_i)$$

Where,

α = is the Y- intercept

β = is the slope of line

An important measure of amount of the variation about the mean explained by the model is defined as coefficient of determination *i.e.* R^2, which is called the square of correlation between response values and the predicted response and is called the square of multiple correlation coefficients or the coefficients of multiple determination. R^2 is defined as the ratio of sum of squares of deviation and the total sum of squares. R^2 can take any value between 0 to 1. The closer the value of R^2 to 1, smaller is the scatter of the points about the regression plane and better is the fit.

Results and Discussion

i) Simple correlation coefficients between physical, anatomical and mechanical properties of *Dalbergia sissoo* wood

Correlation coefficient is a statistical tool that helps to measure and analyze the degree of relationship between two variables. The data pertaining to the correlation coefficient values between physical, anatomical and mechanical properties of *Dalbergia sissoo* are shown in Table 2. Out of total 91combinations of simple correlation coefficients obtained between physical and mechanical parameters, 3 were found to be positive and significant at 1% level of significance whereas, 5 were reported as negatively correlated and significant at both 1% and 5% level of significance. Out of 5 negative and significant correlation coefficients, one was significant at 1 per cent level of significance while, four was significant at 5 per cent level of significance. While, rest of the combinations were found to be non-significant.

Table 2. Simple correlation coefficients between important physical, anatomical and mechanical characteristics of *Dalbergia sissoo* wood collected from different local market sites

Characters	MC	SG	FD	VD	FL	BS	TS	COMP PR	COMP PL	MOE PR	MOE PL	MOE T	MOE B	MOR B
MC	1.000													
SG	-0.526^{NS}	1.000												
FD	-0.155^{NS}	0.790**	1.000											
VD	0.045^{NS}	-0.521^{NS}	-0.293^{NS}	1.000										
FL	-0.257^{NS}	0.026^{NS}	0.048^{NS}	0.343^{NS}	1.000									
BS	0.049^{NS}	0.244^{NS}	0.296^{NS}	-0.610^{NS}	0.173^{NS}	1.000								
TS	0.271^{NS}	-0.013^{NS}	0.226^{NS}	-0.487^{NS}	-0.661*	0.387^{NS}	1.000							
COMP PR	0.334^{NS}	-0.161^{NS}	0.045^{NS}	-0.009^{NS}	-0.359^{NS}	-0.272^{NS}	0.304^{NS}	1.000						
COMP PL	-0.192^{NS}	0.171^{NS}	0.007^{NS}	-0.421^{NS}	0.133^{NS}	0.370^{NS}	0.005^{NS}	-0.034^{NS}	1.000					
MOE PR	0.029^{NS}	-0.291^{NS}	-0.329^{NS}	0.322^{NS}	0.273^{NS}	-0.002^{NS}	-0.253^{NS}	-0.029^{NS}	0.490^{NS}	1.000				
MOE PL	0.499^{NS}	0.047^{NS}	0.102^{NS}	-0.083^{NS}	0.187^{NS}	0.268^{NS}	-0.133^{NS}	-0.434^{NS}	-0.087^{NS}	0.193^{NS}	1.000			
MOE T	0.175^{NS}	0.357^{NS}	0.387^{NS}	-0.809**	-0.668*	0.538^{NS}	0.826**	0.159^{NS}	0.299^{NS}	-0.239^{NS}	0.035^{NS}	1.000		
MOE B	-0.456^{NS}	0.305^{NS}	0.457^{NS}	-0.175^{NS}	0.146^{NS}	0.231^{NS}	0.331^{NS}	0.279^{NS}	0.052^{NS}	-0.403^{NS}	-0.663*	0.149^{NS}	1.000	
MOR B	-0.039^{NS}	0.358^{NS}	0.407^{NS}	-0.695*	0.232^{NS}	0.916**	0.385^{NS}	-0.170^{NS}	0.557^{NS}	-0.026^{NS}	0.174^{NS}	0.551^{NS}	0.394^{NS}	1.000

** Significant at the 0.01 level (2-tailed).	
• Significant at the 0.05 level (2-tailed).	
• MC - Moisture content • MMC - Maximum moisture content • SG - Specific gravity • FL - Fibre length	• COMP PL - Compression parallel to grain • COMP PR - Compression perpendicular to grain • MOE PL - Modulus of elasticity parallel • MOE PR - Modulus of elasticity perpendicular

• FD - Fibre diameter • VD - Vessel diameter • BS - Bending strength • TS - Tensile strength	• MOE T - Tensile modulus of elasticity • MOE B - Bending modulus of elasticity • MOR B - Modulus of rupture bending

For moisture content all the correlation were found to be non-significant. Specific gravity was found to have highly significant and positive correlation with fibre diameter (0.790). The values of rest of the correlations coefficient were noticed to be non-significant. Vessel diameter was observed to be negative and significantly correlated with tension modulus of elasticity (-0.809) and bending modulus of rupture (-0.695). Rests of the values for correlation coefficient were found to be non-significant. Fibre length elucidated negative and significant correlation with tensile strength (-0.661) and highly significant with modulus of elasticity tension (-0.668). Rest of the values for correlation coefficient were found to be non-significant. Bending strength of wood revealed positive and highly significant relationship with bending modulus of rupture (0.916). For rest of the values the correlation coefficient values were non-significant. Tensile strength of wood recorded highly significant and positive correlation coefficient with tension modulus of elasticity (0.826) and the rest of values were found to be non-significant. All the correlation coefficient values between compression parallel to grain and other values were found to be non-significant. All the correlation coefficient values between compression perpendicular to grain and other values were found to be non-significant. Modulus of elasticity parallel elucidated negative and significant correlation with bending modulus of elasticity (-0.663). Modulus of elasticity tension was found significant and positive correlation with tensile strength (0.826). The parameter was negatively and significantly correlated with specific gravity (-0.999) and fibre diameter (-0.818).

Beery *et al*. (1983) [1] have also reported differences between the tangential and radial compression strength among hardwood species and have revealed that the between-species differences of lateral compression strength occur because of the ray volume. A significant linear relationship between wood density and mechanical properties of timber has been reported by Shepard and Shottafer (1992) [8]. Zhang (1995) [10] have shown that modulus of rupture and the maximum crushing strength in compression parallel to the grain are most closely and almost linearly related to wood specific gravity, whereas, modulus of elasticity was poorly and least linearly related to specific gravity.

Table 3: Multiple regression analysis between physical, anatomical and mechanical parameters

Parameters	Specific gravity (Y_1)	Tensile strength (Y_2)	Bending strength (Y_3)	Bending modulus of rupture (Y_4)	Compression parallel to grain (Y_5)	Compression perpendicular to grain (Y_6)	Modulus of elasticity perpendicular to grain (Y_7)	Modulus of elasticity parallel to grain (Y_8)	Bending modulus of elasticity (Y_9)	Tensile modulus of elasticity (Y_{10})
Intercept	1.119	0.324	0.036	0.589	0.273	-0.017	-0.855	0.438	11.97	10.495
Moisture content(X_1)	-0.006	0.001	7.113E-005	0.001	0.000	0.001	0.004	0.010	-0.155	0.013
Fibre diameter (X_2)	8.652	1.698	0.026	0.712	-5.03	0.281	-30.40	1.876	150.910	26.753
Vessel diameter(X_3)	4.876	-2.321	-0.273	4.324	-1.684	0.317	17.814	-4.086	-29.734	-69.458
Fibre length (X_4)	0.000	-0.025	0.001	0.014	0.005	-0.004	0.147	0.039	0.120	0.268
R^2	0.883	0.573	0.583	0.775	0.307	0.217	0.212	0.426	0.365	0.894

Table 4: Regression equations for different parameters

Y_1=	$1.119 - 0.006\ X_1 + 8.652\ X_2 + 4.876\ X_3 + 0.000\ X_4$
Y_2=	$0.324 + 0.001\ X_1 + 1.698\ X_2 - 2.321\ X_3 - 0.025\ X_4$
Y_3=	$0.036 + 7.113E\text{-}005\ X_1 + 0.026\ X_2 - 0.273\ X_3 + 0.001\ X_4$
Y_4=	$0.589 + 0.001\ X_1 + 0.712\ X_2 + 4.324\ X_3 - 0.014\ X_4$
Y_5=	$0.273 + 0.000\ X_1 - 5.03\ X_2 - 1.684\ X_3 + 0.005\ X_4$
Y_6=	$-0.017 + 0.001\ X_1 + 0.281\ X_2 + 0.317\ X_3 - 0.004\ X_4$
Y_7=	$-0.855 + 0.004\ X_1 - 30.40\ X_2 + 17.814\ X_3 + 0.147\ X_4$
Y_8=	$0.438 + 0.010\ X_1 + 1.876\ X_2 - 4.086\ X_3 + 0.039\ X_4$
Y_9=	$11.97 - 0.155 X_1 + 150.910\ X_2 - 29.734\ X_3 + 0.120\ X_4$
Y_{10}=	$10.495 + 0.013\ X_1 + 26.753\ X_2 - 69.458\ X_3 - 0.268\ X_4$

Wang *et al.* (2006) [9] studied the correlation between growth characteristic and wood quality characteristics of 7 years old poplar and found relatively high positive correlation between plant height and DBH, fibre length and length width ratio and wood specific gravity and DBH.

ii) Regression analysis

Regression analysis is a method by which estimates are made for the value of variables from the knowledge of the values of one or more other variables and to the measurement of errors involved in estimation process. The parameters Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7, Y_8, Y_9 and Y_{10} are dependent variables whereas X_1, X_2, X_3 and X_4 are independent variables. The average relationships between the mechanical, physical and anatomical wood properties {tensile strength (Y_2), bending strength (Y_3), bending modulus of rupture (Y_4), compression parallel to grain (Y_5), compression perpendicular to grain (Y_6), modulus of elasticity perpendicular to grain (Y_7), modulus of elasticity parallel to grain (Y_8), bending modulus of elasticity (Y_9) and tension modulus of elasticity (Y_{10})}; {specific gravity (Y_1), moisture content (X_1)} and {fibre diameter (X_2), vessel diameter (X_3, fibre length (X_4)} respectively are presented in Table 3.

Coefficient of determination for specific gravity (Y_1) was noticed to be 0.883 with physical and anatomical parameters which mean that 88.3 per cent variability in (Y_1) was due to these parameters. The coefficient of determination (R^2) was observed to be 0.573 for tensile strength (Y_2) which means that 57.3 per cent variability of tensile strength (Y_2) was due to studied parameters. The R^2 value for bending strength (Y_3) when regressed was found to be 0.583 which means that 58.3 per cent of the variability in Y_3 was due to the observed parameters. The coefficient of variation **(**R^2) value for bending modulus of rupture (Y_4) when regressed was found to be 0.775 which depicted that 77.5 per cent variability in (Y_4) was due to the studied physical and anatomical parameters. The coefficient of determination **(**R^2) value for tension modulus of elasticity (Y_{10}) when regressed was found to be 0.894 which depicted that 89.4 per cent variability in (Y_{10}) was due to the studied physical and anatomical parameters. Kiae and Samariha (2011) [3] had conducted the studies on fibre dimensions, physical and mechanical properties of five important hardwood plants and the obtained results which showed a positive correlation between wood density and

MOR (R^2=0.709), modulus of elasticity (R^2=0.792), and compression parallel to the grain (R^2=0.693) at species levels. Okoh (2014) [5] studied the physical and mechanical properties of Ghanaian hardwoods and found that there was positive correlations between wood density and compression parallel to grain (R^2=0.644), modulus of rupture (R^2= 0.680) and Modulus of Elasticity (R^2= 0.646) at four different species level. The results of study showed a significant linear relationship between wood density and mechanical strength properties of timber.

Conclusion

Based on the studies and observations that were done, out of total 91 combinations of simple correlation coefficients obtained between physical, anatomical and mechanical parameters, 3 were found to be positive and significant whereas, 5 were reported as negatively correlated and significant. R^2 value for Tension modulus of elasticity has been noticed to be highest (0.894) due to different wood parameters under study. All these interrelationships between the wood properties could be put to use when the wood would being subjected for a desired purpose in order to get the best possible product in the future.

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