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Correlation and regression studies on wood properties of jack (*Artocarpus heterophyllus* Lam.) for effective timber utilization

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Abstract

The interrelationships between different wood properties were carried out to check the dependence of one character over the other which defines the overall quality and performance of the jack wood. Highly significant and positive correlation was noticed for a^* value with ash content; volumetric shrinkage with green specific gravity; tangential shrinkage with radial shrinkage; holocellulose content with hemicellulose content. The negative and significant correlation has been recorded for L^* value with a^* value; green specific gravity with NaOH soluble extractives content. Highly significant and positive correlation was noticed for volumetric shrinkage with tangential shrinkage and radial shrinkage; tangential shrinkage with radial shrinkage; oven dry specific gravity with vessel area and ray width. The negative and significant correlation has been recorded for L^* value with a^* value, tangential shrinkage with fibre diameter. Highly significant and positive correlation was noticed for parameters related to physical and mechanical wood parameters except for. The negative and significant correlation has been recorded for L^* value with a^* value, tangential shrinkage with fibre diameter. Regression studies also showed considerable relationships between the physical, chemical, anatomical and mechanical properties.

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) ^[11]. 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) ^[12]. 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) ^[6].

Artocarpus heterophyllus Lam. popularly known as jack or Ceylon Jack tree belonging to the family Moraceae is one of the important and commonly found trees in the homegardens of certain parts of India and Bangladesh (Bose, 1985) ^[2]. The place of origin of jack tree is unknown, however it is believed to be indigenous to the rainforests of the Western Ghats (Morton, 1987) ^[10]. It is a medium sized, evergreen tree that typically attains a height of 8m–25m and a stem diameter of 30cm–80 cm. The canopy shape is usually conical or pyramidal in young trees and becomes spreading and domed in older trees. It is monoecious and both male and female inflorescences are found on the same tree (Bose, 1985; Morton, 1987) ^[2, 10]. The assessment of the timber quality may involve the consideration of a large number of physical, chemical, anatomical and mechanical properties of wood. Though the jack wood has been used extensively, little information is available on its properties. Thus, the study of wood physical properties of jack wood is important and very timely for the further effective utilization in future. 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

The present study was carried out to investigate the zonal variations in wood properties of Jack trees (*Artocarpus heterophyllus* Lam.) grown in three different altitudinal zones of Thrissur district, Kerala. The samples were collected from the local markets based on three different girth classes i.e., 30 cm - 60 cm, 60 cm - 90 cm and 90 cm - 120 cm. Three samples of each girth classes from different sites were collected which constitute 27 wood samples. Wood property studies were conducted in the department of Forest Products

and Utilization, College of Forestry, Kerala Agricultural University, Vellanikkara.

Materials

The study area and geographical location

The experimental materials for the study consisted of 27 *Artocarpus heterophyllus* wood collected from different saw mills of Thrissur considering the girth classes.

The present work was carried out in Thrissur district, Kerala (10°31'49.2420" N, 76°12'53.0244" E)

Table 1: Details of sites and coordinates for Jack wood procurement

Zones	Girth classes	Sites	Latitude	Longitude
Lowland	30cm - 60cm	Puvathur	10°32'51.5" N	76°04'35.9" E
		Thalikulam	10°26'23.1" N	76°05'20.4" E
		Peringotukara	10°24'52.5" N	76° 07'23.9" E
	60cm - 90cm	Engadiyoor	10°30'33.4" N	76° 03'23.0" E
		Karayamuttam	10°22'42.8" N	76° 06'52.2" E
		Edathirinja	10°19'56.4" N	76°10'21.7" E
	90cm - 120cm	Parappur	10°33'32.9" N	76°07'31.7" E
		Mannalamkunnu	10°39'57.0" N	75° 58'25.8" E
		Chavakkad	10°34'50.6" N	76° 01'20.0" E
Midland	30cm - 60cm	Kunnankulam	10°38'57.8" N	76°04'22.0" E
		Avinissery	10°28'12.6" N	76° 13'51.3" E
		Cherpu	10°26'45.8" N	76° 12'39.9" E
	60cm - 90cm	Padavarad	10°29'51.3" N	76° 15'19.1" E
		Kuttanellur	10°30'21.6" N	76° 15'06.4" E
		Ollur	10°28'14.4" N	76° 14'02.4" E
	90cm - 120cm	Eyyal	10°39'49.0" N	76° 06'49.5" E
		Karikad	10°41'42.9" N	76°05'28.6" E
		Kuriachira	10°29'46.6" N	76° 14'50.6" E
Highland	30cm - 60cm	Pazhayannur	10°41'52.7" N	76°25'30.0" E
		Kallingalpadam	10°35'28.2" N	76°25'12.9" E
		Vettilapara	10°17'29.2" N	76°30'41.8" E
	60cm - 90cm	Cheerakuzhi	10° 42'14.4" N	76°25'34.9" E
		Ottupara	10°40'25.5" N	76°15'23.9" E
		Athirapilly	10°17'31.7" N	76°30'53.6" E
	90cm - 120cm	Mayannur	10°45'15.2" N	76°22'34.8" E
		Elanad	10°37'37.9" N	76°23'38.0" E
		Nattiyanchira	10°41'36.1" N	76°21'57.9" E

i) Simple correlation coefficients and multiple regression analysis

The present study was to observe the variation in wood properties of Jack trees collected from three different altitudinal zones of Thrissur district, Kerala (ENVIS, 2017). The sampling and sub sampling gives rise to nested or hierarchical classification. Therefore, to analyze the data on different wood properties and their interrelationships with one another, the model for analysis followed was NESTED ANOVA which was carried out using SPSS (Ver. 21). 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 wood properties of *Artocarpus heterophyllus*

The data pertaining to the correlation coefficient values between physical and chemical wood properties of *Artocarpus heterophyllus* are shown in Table 1. Out of total 153 combinations of simple correlation coefficients obtained between physical and chemical parameters, three were found to be positive and significant at 1% level of significance, three were found to be positive and significant at 5% level of significance whereas, one was reported as negatively correlated and significant at 1% and one was reported as negatively correlated and significant at 5% level of significance.

Table 2: Simple correlation coefficients between physical and chemical properties of *Artocarpus heterophyllus* wood

	L*value	a*value	B*valu	MC	VS	GSG	OSG	TS	RS	CWS	HWS	ALBZ	LGN	HCE	CLE	HCLE	NaOH	Ash
L*value																		
a*value	-0.851**																	
b*value	.509	-.618																
MC	.410	-.200	.220															
VS	-.397	.209	.222	-.094														
GSG	-.393	.237	.273	-.557	.707*													
OSG	-.305	.334	.059	-.135	.177	.239												
TS	-.419	.021	.020	-.434	.677*	.662	.073											
RS	-.575	.231	-.130	-.399	.817**	.649	.123	.919**										
CWS	.186	-.037	-.091	.080	-.303	-.025	-.442	.005	-.257									
HWS	-.094	.418	-.440	-.010	-.051	.066	.121	-.018	-.071	.641								
ALBZ	.478	-.175	.091	.598	-.205	-.234	.185	-.311	-.322	.087	.227							
LGN	.077	-.362	.265	.211	.021	-.073	.343	.429	.219	-.034	-.204	.252						
HCE	.055	.085	-.338	-.006	.434	.205	-.131	.272	.429	.007	.434	.296	-.275					
CLE	.479	-.301	-.075	-.130	-.118	.060	-.022	.100	-.062	.489	.664	.344	.004	.566				
HCLE	-.365	.370	-.331	.110	.619	.188	-.134	.231	.562	-.431	-.084	.041	-.328	.673*	-.229			
NaOH	.186	.095	-.342	.641	-.587	-.778*	-.330	-.589	-.627	.508	.365	.263	-.055	-.162	.006	-.196		
Ash	-.663	.861**	-.322	.065	.275	.308	.428	-.041	.170	-.137	.262	.216	-.207	.082	-.365	.425	.020	

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

- MC - Moisture content
- VS - Volumetric shrinkage
- GSG - Green Specific gravity
- OSG - Oven dry specific gravity
- TS - Tangential shrinkage
- RS - Radial shrinkage
- CWS - Cold water solubility
- HWS - Hot water solubility
- ALBZ - Alcohol benzene extractives
- LGN - Klason lignin content
- HCE - Holocellulose content
- CLE - Cellulose content
- HCLE - Hemicellulose content
- NaOH - Sodium hydroxide solubility

L* value of the color component was found to be negatively correlated and significant with the color component a* value (- 0.851**). a* value was found to have significant and positive correlation with ash content (0.861). The values of rest of the correlation coefficients were noticed to be non - significant. Volumetric shrinkage was observed to be positive and significantly correlated with green specific gravity (0.707), tangential shrinkage (0.677) and radial shrinkage (0.817). Rests of the values for correlation coefficient were found to be non - significant. Green Specific Gravity elucidated negative and significant correlation with NaOH soluble extractives content (- 0.778). Rest of the values for correlation coefficient were found to be non - significant. Tangential Shrinkage was found positive and significantly correlated with radial shrinkage (0.919). All the remaining correlation values were found to be non - significant with moisture content. Holocellulose content of wood revealed positive and significant relationship with hemicellulose content (0.673). For rest of the values the correlation

coefficient values were non - significant. Schumann (1973) [13] has found no correlation between specific gravity and total TAPPI extractive contents, but Hiller *et al.* (1972) [5] determined that specific gravity of fibrous tissue and extractive content are related to wood color. Simple correlation coefficients between physical and anatomical properties of *Artocarpus heterophyllus* wood shows the data pertaining to the correlation coefficient values between physical and anatomical properties of *Artocarpus heterophyllus* are shown in Table 2. Out of total 153 combinations of simple correlation coefficients obtained between physical and anatomical parameters, three were found to be positive and significant at 1% level of significance, two were found to be positive and significant at 5% level of significance whereas, one was reported as negatively correlated and significant at 1% and one was reported as negatively correlated and significant at 5% level of significance.

Table 3: Simple correlation coefficients between physical and anatomical properties of *Artocarpus heterophyllus* wood

	L*value	a*value	b*value	MC	VS	GSG	OSG	TS	RS	FL	FD	VD	VA	VL	VF	RW	RH	RF
L*value																		
a*value	- .851**																	
b*value	.509	-.618																
MC	.410	-.200	.220															
VS	-.397	.209	.222	-.094														
GSG	-.393	.237	.273	-.557	.707*													
OSG	-.305	.334	.059	-.135	.177	.239												
TS	-.419	.021	.020	-.434	.677*	.662	.073											
RS	-.575	.231	-.130	-.399	.817**	.649	.123	.919**										
FL	-.227	.444	-.503	-.077	-.086	-.270	.215	-.260	-.152									
FD	-.027	.312	-.259	.304	-.450	-.540	.455	-.737*	-.540	.284								
VD	-.385	.320	.352	-.326	.578	.612	.367	.092	.283	-.003	.065							
VA	-.513	.578	.096	-.239	.049	.327	.715*	-.155	-.090	.136	.459	.633						
VL	.307	-.177	-.441	-.247	-.650	-.488	.100	-.371	-.363	.267	.446	-.410	-.186					

VF	-.450	.619	-.549	-.159	-.210	.017	-.096	-.268	-.070	-.120	.414	.108	.289	.136				
RW	-.260	.254	.058	-.074	.539	.279	.812**	.188	.382	.305	.315	.524	.406	.028	-.219			
RH	-.392	.536	-.535	-.332	.088	.412	-.214	.226	.272	-.071	-.222	-.101	-.031	-.030	.665	-.283		
RF	.125	-.425	.211	.028	-.170	-.320	-.507	-.086	-.071	-.391	-.052	.051	-.244	-.035	.015	-.388	-.435	

**Correlation is significant at the 0.01 level (2 - tailed).

*Correlation is significant at the 0.05 level (2 - tailed).

- MC - Moisture content
- VS - Volumetric shrinkage
- GSG - Green Specific gravity
- OSG - Oven dry specific gravity
- TS - Tangential shrinkage
- RS - Radial shrinkage
- FL - Fibre length
- FD - Fibre diameter
- VD - Vessel diameter
- VA - Vessel area
- VL - Vessel length
- VF - Vessel frequency
- RW - Ray width
- RH - Ray height
- RF - Ray frequency

Tangential Shrinkage was found to have significant and negative correlation with fibre diameter (- 0.737**). The values of rest of the correlation coefficients were noticed to be non - significant. Volumetric shrinkage was observed to be positive and significantly correlated with green specific gravity (0.707), tangential shrinkage (0.677) and radial shrinkage (0.817). Rests of the values for correlation coefficient were found to be non - significant. Oven dry Specific Gravity elucidated positive and significant correlation with vessel area (0.715) and ray width (0.812). Rest of the values for correlation coefficient were found to be non - significant. Radial Shrinkage was found positive and significantly correlated with Tangential shrinkage (0.919). All the remaining correlation values were found to be non - significant with moisture content. Wang *et al.* (1996) [14] studied the correlation between growth characteristic and wood quality characteristics of 7 years old poplar (*Populus*) and observed relatively high positive correlation between plant height and DBH, fibre length and length width ratio and wood specific gravity and DBH. Dinwoodie (2000) [4] has

stated that density is the best predictor of timber strength. Beery *et al.* (1983) [1] have observed 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. Fibre length usually does not directly contribute to density (Mansfield and Weineisen, 2007) [9] and vessel dimensions and vessels frequency had no influence in wood basic density (Carrillo *et al.*, 2015) [3]. Simple correlation coefficients between physical and mechanical properties of *Artocarpus heterophyllus* wood observed the data pertaining to the correlation coefficient values between physical and mechanical properties of *Artocarpus heterophyllus* are shown in Table 3. Out of total 210 combinations of simple correlation coefficients obtained between physical and mechanical parameters, twenty were found to be positive and significant at 1% level of significance, ten were found to be positive and significant at 5% level of significance whereas, one was reported as negatively correlated and significant at 1%.

Table 4: Simple correlation coefficients between physical and mechanical properties of *Artocarpus heterophyllus* wood

	L*value	a*value	b*value	MC	VS	GSG	OSG	TS	RS	MOR	HS at ML	HSat LP	FSat LP	MO EB	TS at ML	CSPLat LP	CSPLat ML	MOEC SPL	CSPR at LP	CSPR at 2.5mm	MOE CSPR	
L*value																						
a*value	-.851**																					
b*value	.509	-.618																				
MC	.410	-.200	.220																			
VS	-.397	.209	.222	-.094																		
GSG	-.393	.237	.273	-.557	.707*																	
OSG	-.305	.334	.059	-.135	.177	.239																
TS	-.419	.021	.020	-.434	.677*	.662	.073															
RS	-.575	.231	-.130	-.399	.817*	.649	.123	.919**														
MOR	-.375	.456	-.226	.026	.333	.337	-.467	.225	.235													
HS at ML	-.383	.464	-.186	.031	.340	.324	-.458	.198	.216	.996**												
HS at LP	-.219	.368	-.158	.068	.259	.289	-.274	.213	.133	.911**	.896**											
FS at LP	-.225	.339	-.082	-.058	.318	.422	-.281	.276	.187	.920**	.902**	.984**										
MOEB	-.270	.417	-.097	.088	.344	.239	-.435	.008	.080	.934**	.940**	.835**	.844**									
TS at ML	-.389	.523	-.350	-.028	.307	.339	-.414	.089	.273	.697*	.704*	.450	.469	.606								
CSPL at LP	-.127	.431	.139	.391	.391	.352	.015	-.145	-.009	.543	.583	.514	.507	.592	.674*							
CSPL at ML	-.199	.451	.143	.422	.461	.309	-.068	-.129	.033	.626	.672*	.551	.541	.714*	.672*	.968**						
MOECS PL	-.131	.536	-.054	.169	.232	.165	.185	-.445	-.206	.357	.371	.338	.337	.562	.433	.751*	.755*					
CSPR at LP	-.216	.043	.155	.025	.822*	.574	-.355	.670*	.712*	.648	.648	.537	.583	.575	.537	.423	.502	.067				

CSPR at 2.5mm	-.262	.022	.303	-.255	.842*	.801*	-.206	.758*	.747*	.570	.564	.468	.567	.494	.420	.333	.393	.029	.929**		
MOECS PR	-.214	.110	.341	.031	.874*	.763*	-.029	.633	.664	.520	.533	.483	.544	.454	.487	.616	.627	.216	.903**	.908**	

** . Correlation is significant at the 0.01 level (2 - tailed).

* . Correlation is significant at the 0.05 level (2 - tailed).

- MC - Moisture content
- VS - Volumetric shrinkage
- GSG - Green Specific gravity
- OSG - Oven dry specific gravity
- TS - Tangential shrinkage
- RS - Radial shrinkage
- MOR - Modulus of Rupture
- HS at ML - Horizontal Stress at Maximum Load
- CSPR at ML - Compression perpendicular to grain at Maximum Load
- HS at LP - Horizontal Stress at Limit of Proportionality
- FS at LP - Fibre Stress at Limit of Proportionality
- MOEB - Modulus of Elasticity Bending
- TS at ML - Tensile Strength at Maximum Load
- CSPL at LP - Compression parallel to grain at Limit of Proportionality
- CSPL at ML - Compression parallel to grain at Maximum Load
- MOE CSLP - Modulus of Elasticity Compression parallel to grain
- MOE CSPR - Modulus of Elasticity Compression perpendicular to grain
- CSPR at LP - Compression perpendicular to grain at Limit of Proportionality

L* value of the color component was found to be negatively correlated and significant with the color component a* value (-0.851**). Volumetric shrinkage was observed to be positive and significantly correlated with green specific gravity (0.707), tangential shrinkage (0.677), radial shrinkage (0.817), Compression strength perpendicular to grain at Limit of Proportionality (0.822), Compression strength perpendicular to grain at 2.5mm (0.842) and Modulus of Elasticity for Compression strength perpendicular to grain (0.874). Rests of the values for correlation coefficient were found to be non - significant. Green Specific Gravity elucidated positive and significant correlation with Compression strength perpendicular to grain at 2.5mm (0.801) and Modulus of Elasticity for Compression strength perpendicular to grain (0.763). Rests of the values for correlation coefficient were found to be non - significant. Tangential Shrinkage was found positive and significantly correlated with radial shrinkage (0.919). All the remaining correlation values were found to be non - significant with moisture content. Modulus of Rupture was found positive and significantly correlated with Horizontal stress at Maximum Load (0.996), Horizontal stress at Limit of Proportionality (0.911), Fibre Stress at Limit of Proportionality (0.920), Modulus of Elasticity Bending (0.934) and Tensile Strength at Maximum Load (0.697). All the remaining correlation values were found to be non - significant with moisture content. Horizontal stress at Maximum Load was found positive and significantly correlated with Horizontal stress at Limit of Proportionality (0.896), Fibre Stress at Limit of Proportionality (0.902), Modulus of Elasticity Bending (0.940), Tensile Strength at Maximum Load (0.704) and Compression strength parallel to grain at Maximum Load (0.672). All the remaining correlation values were found to be non - significant with moisture content.

Horizontal stress at Limit of Proportionality was found positive and significantly correlated with Fibre Stress at Limit of Proportionality (0.984), Modulus of Elasticity Bending (0.835) and Tensile Strength at Maximum Load (0.704). All the remaining correlation values were found to be non - significant with moisture content. Fibre Stress at Limit of Proportionality was found positive and significantly correlated with Modulus of Elasticity Bending (0.844). All the remaining correlation values were found to be non - significant with moisture content. Modulus of Elasticity Bending was found positive and significantly correlated with Compression strength parallel to grain at Maximum Load (0.714). All the remaining correlation values were found to be non - significant with moisture content. Tensile Strength at Maximum Load was found positive and significantly correlated with Compression strength parallel to grain at

Maximum Load (0.672) and Compression strength parallel to grain at Limit of Proportionality (0.674). All the remaining correlation values were found to be non - significant with moisture content. Compression strength parallel to grain at Limit of Proportionality was found positive and significantly correlated to Compression strength parallel to grain at Maximum Load (0.968) and Modulus of Elasticity for Compression strength parallel to grain (0.751). All the remaining correlation values were found to be non - significant with moisture content. Compression strength parallel to grain at Maximum Load was found positive and significantly correlated to Modulus of Elasticity for Compression strength parallel to grain (0.755). All the remaining correlation values were found to be non - significant with moisture content. Compression strength perpendicular to grain at Limit of Proportionality was found positive and significantly correlated to Compression strength perpendicular to grain at 2.5mm (0.929) and Modulus of Elasticity for Compression strength perpendicular to grain (0.903). All the remaining correlation values were found to be non - significant with moisture content. Compression strength perpendicular to grain at 2.5mm was found positive and significantly correlated to Modulus of Elasticity for Compression strength perpendicular to grain (0.908). All the remaining correlation values were found to be non - significant with moisture content.

ii) Regression analysis

Table 4 presents the estimated linear relationships between the physical {(Moisture Content (X_1), Green Specific Gravity (Y_1), Oven dry Specific Gravity (Y_1), Tangential Shrinkage(Y_1), Radial Shrinkage(Y_1) and Volumetric Shrinkage(Y_1)} and chemical characteristics {Cold water - soluble extractives (X_2), Hot water - soluble extractives (X_3), Alcohol Benzene soluble extractives (X_4), Klason lignin (X_5), cellulose (X_6) and hemicellulose (X_7)}. Table 5 shows the estimated linear relationships between the physical and anatomical characteristics {Fibre length (X_2), Vessel diameter (X_3), Vessel length (X_4), Ray width (X_5)}. The linear relationships between the physical and mechanical characteristics {Modulus of Rupture (X_2), Modulus of elasticity bending (X_3), Compression parallel to grain Modulus of elasticity (X_4) and Compression perpendicular to grain Modulus of elasticity (X_5)} are given in table 6. Multiple regression analysis between physical and anatomical properties shows that R^2 value for Green Specific Gravity (GSG) when regressed with chemical characters was found 0.45 which indicates that 45 per cent of variability in GSG was due to parameters under study. Cellulose content (-0.003) was negatively related, whereas rest of the parameters

were positively related. R^2 was observed to be 0.93 for Oven dry Specific Gravity (OSG) which reveals that 93 per cent of variability in OSG was due to parameters under study. Cold water solubility (- 0.020), cellulose content (- 0.003) and hemicellulose content (- 0.003) were negatively correlated whereas rest of the parameters were positively related. R^2 value for Tangential shrinkage (TS) when regressed with chemical characters was found 0.92 which indicates that 92 per cent of variability in SB was due to parameters under study. Hot water solubility (- 0.094) and alcohol benzene soluble extractives (0.001) were negatively related whereas rest of the parameters were positively related. R^2 value for Radial shrinkage (RS) when regressed with chemical parameters was found 0.94 which represents that 94 per cent of variability in RS was due to parameters under study. Except alcohol benzene soluble extractives (- 0.124) other

parameters were positively correlated. Coefficient of determination was observed to be $R^2 = 0.57$ for Volumetric shrinkage (VS) and chemical parameters, which indicates that 57 per cent of variability in VS was due to parameters under study. Cold water extractives (- 0.068) and alcohol benzene extractives (- 0.149) were negatively correlated. Multiple regression analysis between physical and anatomical properties (Table 6) revealed that R^2 value for Green Specific Gravity (GSG) when regressed with anatomical characters was found 0.848 which indicates that 84.8 per cent of variability in GSG was due to parameters under study. Vessel diameter (- 0.001) and vessel length (- 0.004) were negatively related, whereas rest of the parameters were positively related. R^2 was observed to be 1.00 for Oven dry Specific Gravity (OSG) and anatomical parameters, which reveals that 67.9 per cent of variability in OSG was due to parameters under study.

Table 5: Multiple regression analysis between physical and chemical parameters

Parameters	Green specific gravity (Y ₁)	Oven dry specific gravity (Y ₂)	Tangential shrinkage (Y ₃)	Radial shrinkage (Y ₄)	Volumetric shrinkage (Y ₅)
Intercept	0.810	0.695	- 7.665	- 4.640	- 3.780
Moisture Content (X ₁)	- 0.012	- 0.002	- 0.205	- 0.122	0.005
CWS (X ₂)	0.013	- 0.020	0.529	0.135	- 0.068
HWS (X ₃)	0.001	0.016	- 0.094	0.045	0.090
ALBZ (X ₄)	0.005	0.002	- 0.195	- 0.124	- 0.149
LGN (X ₅)	0.003	0.002	0.345	0.184	0.094
CLE(X ₆)	- 0.003	- 0.003	0.082	0.023	0.040
HCLE(X ₇)	0.006	- 0.003	0.322	0.252	0.183
R ²	0.454	0.932	0.918	0.940	0.577

*significant at 5 percent level of significance

Table 6: Regression equations for physical and chemical parameters

$Y_1 = 0.810 - 0.012 X_1 + 0.013 X_2 + 0.001 X_3 + 0.005 X_4 + 0.003 X_5 - 0.003 X_6 + 0.006 X_7$
$Y_2 = 0.695 - 0.002 X_1 - 0.020 X_2 + 0.016 X_3 + 0.002 X_4 + 0.002 X_5 - 0.003 X_6 - 0.003 X_7$
$Y_3 = - 7.665 - 0.205 X_1 + 0.529 X_2 - 0.094 X_3 - 0.195 X_4 + 0.345 X_5 + 0.082 X_6 + 0.322 X_7$
$Y_4 = - 4.640 - 0.122 X_1 + 0.135 X_2 + 0.045 X_3 - 0.124 X_4 + 0.184 X_5 + 0.023 X_6 + 0.252 X_7$
$Y_5 = - 3.780 + 0.005 X_1 - 0.068 X_2 + 0.090 X_3 - 0.149 X_4 + 0.094 X_5 + 0.040 X_6 + 0.183 X_7$

CWS - Cold water solubility HCLE - Hemicellulose content

HWS - Hot water solubility CLE - Cellulose content

ALBZ - Alcohol benzene extractives LGN - Klason lignin content

Fibre length (- 3.436E - 005) was negatively related, whereas rest of the parameters were positively related. R^2 value for Tangential shrinkage (TS) when regressed with anatomical characters was found 0.924 which indicates that 92.4 per cent of variability in TS was due to parameters under study. Fibre length (- 0.011), vessel diameter (- 0.176) and vessel length (- 0.168) were negatively related. R^2 value for Radial shrinkage (RS) when regressed with anatomical parameters was found 0.753 which represents that 75.3 per cent of variability in RS was due to parameters under study. Fibre length (- 0.006), vessel diameter (- 0.082) and vessel length (- 0.093) were negatively correlated. R^2 was observed to be 0.807 for Volumetric shrinkage (VS) and anatomical parameters, which indicates that 80.7 per cent of variability in VS was due to parameters under study. Fibre length (- 0.002), vessel diameter (- 0.022) and vessel length (- 0.083) were negatively correlated. Kiae and Samariha (2011) [7] 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.

Multiple regression analysis between physical and mechanical properties (Table 8) observed that R^2 value for Green Specific

Gravity (GSG) when regressed with mechanical characters was found 0.951 which indicates that 95.1 per cent of variability in GSG was due to parameters under study. Modulus of Rupture (- 8.440E - 007) was negatively related. R^2 was observed to be 0.538 for Oven dry Specific Gravity (OSG) and mechanical parameters, which reveals that 53.8 per cent of variability in OSG was due to parameters under study. Modulus of Rupture (- 1.450E - 006) was negatively related. R^2 value for Tangential shrinkage (TS) when regressed with mechanical characters was found 0.887 which indicates that 88.7 per cent of variability in TS was due to parameters under study. Modulus of Rupture (- 1.808E - 005) was negatively related. R^2 value for Radial shrinkage (RS) when regressed with mechanical parameters was found 0.707 which represents that 70.7 per cent of variability in RS was due to parameters under study. Modulus of Rupture (- 9.336E - 006) and Bending Modulus of Elasticity (- 3.303E - 005) were negatively related. R^2 was observed to be 0.857 for Volumetric shrinkage (VS) and mechanical parameters, which indicates that 85.7 per cent of variability in VS was due to parameters under study. Modulus of Elasticity Compression perpendicular to grain (- 0.004) and Bending modulus of elasticity (- 9.940E - 006) were negatively related. Zhang (1995) [15] have observed a significant linear relationship between density and mechanical properties of wood.

According to Dinwoodie (1996) [4] the modulus of rupture and the maximum crushing strength in compression parallel to the grain are most closely and almost linearly related to wood density whereas, modulus of elasticity is poorly and least linearly related to wood density. Ling *et al.* (2015) [8] have given regression equation for basic density, modulus of

rupture, compression parallel to grain, hardness of transverse section, hardness of radial section and hardness of tangential section for major tree species in China and found that all coefficients of regression equations (R^2) have been higher than 0.75.

Table 7: Multiple regression analysis between physical and anatomical parameters

Parameters	Green specific gravity (Y ₁)	Oven dry specific gravity (Y ₂)	Tangential shrinkage (Y ₃)	Radial shrinkage (Y ₄)	Volumetric shrinkage (Y ₅)
Intercept	2.269	0.544	99.876	50.284	29.105
Moisture Content (X ₁)	- 0.011	- 0.001	- 0.389	- 0.209	- 0.076
Fibre Length (X ₂)	0.000	- 3.436E - 005	- 0.011	- 0.006	- 0.002
Vessel Diameter (X ₃)	- 0.001	0.000	- 0.176	- 0.082	- 0.022
Vessel Length (X ₄)	- 0.004	2.147E - 005	- 0.168	- 0.093	- 0.083
Ray Width (X ₅)	0.004	0.003	0.213	0.144	0.110
R ²	0.848	0.679	0.924	0.753	0.807

*significant at 5 percent level of significance

Table 8: Regression equations for physical and anatomical parameters

$Y_1 = 2.269 - 0.011 X_1 + 0.000 X_2 - 0.001 X_3 - 0.004 X_4 + 0.004 X_5 - 0.005 X_6$
$Y_2 = 0.554 - 0.001 X_1 - 3.436E - 005 X_2 + 0.000 X_3 + 2.147E - 005 X_4 + 0.003 X_5$
$Y_3 = 99.876 - 0.389 X_1 - 0.011 X_2 - 0.176 X_3 - 0.168 X_4 + 0.213 X_5$
$Y_4 = 50.284 - 0.209 X_1 - 0.006 X_2 - 0.082 X_3 - 0.093 X_4 + 0.144 X_5$
$Y_5 = 29.105 - 0.076 X_1 - 0.002 X_2 - 0.022 X_3 - 0.083 X_4 + 0.110 X_5$

Table 9: Multiple regression analysis between physical and mechanical parameters

Parameters	Green specific gravity (Y ₁)	Oven dry specific gravity (Y ₂)	Tangential shrinkage (Y ₃)	Radial shrinkage (Y ₄)	Volumetric shrinkage (Y ₅)
Intercept	0.650	0.589	7.603	3.977	1.254
Moisture content (X ₁)	- 0.009	- 0.001	- 0.139	- 0.096	- 0.049
MOR (X ₂)	- 8.440E - 007	- 1.450E - 006	- 1.808E - 005	- 9.336E - 006	4.900E - 005
MOEB (X ₃)	1.545E - 006	2.012E - 006	0.000	- 3.303E - 005	- 9.940E - 006
MOECSPL (X ₄)	1.111E - 005	1.173E - 006	0.000	0.000	0.000
MOECSPL (X ₅)	8.819E - 006	1.298E - 005	0.001	0.000	- 0.004
R ²	0.951	0.538	0.887	0.707	0.857

*significant at 5 percent level of significance

Table 10: Regression equations for physical and mechanical parameters

$Y_1 = - 0.650 - 0.009 X_1 - 8.440E - 007 X_2 + 1.545E - 006 X_3 + 1.111E - 005 X_4 + 8.819E - 006 X_5$
$Y_2 = 0.589 - 0.001 X_1 - 1.450E - 006 X_2 + 2.012E - 006 X_3 + 1.173E - 006 X_4 + 1.298E - 005 X_5$
$Y_3 = 7.603 - 0.139 X_1 - 1.808E - 005 X_2 + 0.000 X_3 + 0.000 X_4 + 0.001 X_5$
$Y_4 = 3.977 - 0.096 X_1 - 9.336E - 006 X_2 - 3.303E - 005 X_3 + 0.000 X_4 + 0.000 X_5$
$Y_5 = 1.254 - 0.049 X_1 + 4.900E - 005 X_2 - 9.940E - 006 X_3 + 0.000 X_4 - 0.004 X_5$

MOR - Modulus of Rupture

MOEB - Modulus of Elasticity Bending

MOE CSLP - Modulus of Elasticity Compression parallel to grain

MOE CSPR - Modulus of Elasticity Compression perpendicular to grain

Conclusion

Based on the studies and observations that were done, out of total 153 combinations of simple correlation coefficients obtained between physical and chemical parameters, six were found to be positive and significant whereas, two were reported as negatively correlated. Out of total 153 combinations of simple correlation coefficients obtained between physical and anatomical parameters, six were found to be positive and significant whereas two were reported as negatively correlated and significant. Out of total 210 combinations of simple correlation coefficients obtained between physical and mechanical parameters, thirty were found to be positive and significant whereas one was reported as negatively correlated. R^2 value for Radial shrinkage was noticed to be highest (0.940) and lowest for Green Specific

Gravity (0.454) when regressed between physical and chemical properties. When physical and anatomical properties were taken into account, R^2 value was recorded highest for tangential shrinkage (0.924) and the lowest for oven dry specific gravity (0.679). R^2 value for Green Specific Gravity was noticed to be highest (0.951) and lowest for Oven dry Specific Gravity (0.538) when regressed between physical and mechanical properties. All these interrelationships between the wood properties of Jackwood could be put to utilization in order to get the best possible output in the future.

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