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PHYSICO-MECHANICAL PROPERTIES OF SHISHAM (DALBERGIA SISSOO) WOOD GROWN IN KHYBER PAKHTUNKHWA, PAKISTAN

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Abstract

Shisham *(Dalbergia sissoo)* is considered the most valuable commercial timber in Pakistan due to its better strength, wood working properties and attractive figure. Wood quality is affected by the climate in which wood is grown. Wood is a natural material and many continually evolving factors, which may contribute and affects the individual characteristics of wood, such as MoE, MoR, hardness and other properties. It is important to have the knowledge about the physical and strength properties of the Shisham (*Dalbergia sissoo*) wood to identify the particular forest type where it can grow better for production of valuable timber resources and rational utilization. In this study Shisham (*Dalbergia sissoo*) wood samples were collected from three different forest types of Khyber Pakhtunkhwa i.e., Sub-Tropical Broad Leaved, Tropical Thorn and Tropical Dry Deciduous Forests and tested for Physico-mechanical properties. Random sites were selected from each forest types i.e. Dera Ismail Khan from Tropical Thorn Forest, Kohat from Tropical Dry

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Deciduous Forests while Swabi & Peshawar from Sub-Tropical Broad Leaved Forest. The wood samples were adopted for testing and evaluated tests for its various Physico-mechanical properties on Amsler Universal Wood Testing Machines in Wood Mechanics laboratory of Pakistan Forest Institute, Peshawar by following BS-373 British Standard Institute. Wilks test Multivariate Analysis of Variance MANOVA was run by R-Package and Homogeneous subsets on SPSS to determine statistically significant effects of different sites on strength properties of Shisham (*Dalbergia sissoo*) wood grown in three different forest types and to assess correlation between density and strength properties. Post hoc multiple pair-wise comparisons were performed using Games Howell and Tukey HSD test $p < 0.05$. Based upon the results of the present study, it has been revealed that the wood grown in Dera Ismail Khan Site has relatively high value of density and superior in strength properties than Kohat, Swabi and Peshawar sites. It is recommended that the Shisham (*Dalbergia sissoo*) wood from Tropical Thorn Forest has better production and utilization potential in wood based industries particularly furniture industries of Pakistan with valuable hardwood timber. Whereas, the stiffness property (MoE) is of prime concern, Shisham (*Dalbergia sissoo*) wood from Tropical Dry Deciduous Forest i.e. Kohat site was the best choice amongst the studied sites. Therefore, wood density is recommended as a wood quality indicator for assessing the preliminary quality and other wood properties in wood based industries and domestic use of wood.

Keywords: Physico-mechanical properties, Wood Density, Shrinkage, Equilibrium Moisture Content, Shisham (Dalbergia sissoo), Pakistan

1. INTRODUCTION

Due to the rapid increase in population, which is estimated as 2.50 percent per annum in Pakistan, the demand of wood is also increasing day by day. According to a recent survey of the Government of Pakistan, the total population of Pakistan is 212.2 million for the current year (Census of Pakistan 2017). Pakistan is deficient in forest cover and according to a recent survey; the existing forest area is 5.2 percent (PDCP, 2010). The uncertainties of the environment and the emission levels of nonrenewable resources have compelled humanity to develop sustainable energy savers and sustainable materials. One of the most abundant and versatile bio-based structural materials is wood. Wood has several promising advantages, including high toughness, low thermal conductivity, low density, high Young's modulus, biodegradability, and non-toxicity. (Chutturi *et al*., 2023)

In order to assess its strength and longevity and to prescribe its final use, wood mechanics are also of prime importance. On wood testing machines, these properties can be calculated, providing rationale for advance use of any wood as the. The action and design of wood is dependent on it. For potential uses, these values are important. A study of wood boring by insects offers unique insights into the bioengineering principles that drive evolutionary adaptations. A scaling model based on a fracture mechanics framework shows the importance of the mandible shape in generating optimal chip sizes. These findings contain general principles in tool design and put in focus interactions of insects and their woody hosts. (Kundanati *et al*., 2020)

The mechanical properties of wood are affected by natural variability, such as holes, galleries, degradation extent and defects (Verbist *et al*., 2020). The climate restricts the growth and distribution of plants. If any of the environmental conditions is less than optimum, plant growth may become a limiting factor. Timber quality depends on environmental factors such as soil water availability, climate and rainfall, site factors, land

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conditions and method of forest management. Wood's output in the grain direction is very strong but poor against forces that tear the grain apart (Convas.umm.edu).

Dalbergia sissoo widely known as Shisham corresponds to the Family Fabaceae and is standout amongst deciduous tree, which grows up to 30 meters in height and reaches 80-centimeters diameter under favorable circumstances. Shisham grows well in subtropical to warm or tropical regions. It is strong light demander and needs a complete overhead light to regenerate and establish successfully right from the seedling stage. Consequently, it is found in roads and rivers.

It has long been cultivated in conjunction with crops, field lines, all around fruit gardens, wind breaks, cover belts and dispersed trees (Sunny, 2017). Due to the outstanding and rich qualities of Shisham wood, the utilization of wood products is constantly increasing and thus the various wood processing industries consume huge quantities resulting in declination of Shisham wood. We could therefore reduce the overuse of best-adapted timber such as Shisham by using alternative and substitute wood as timber for other purposes. It is therefore suggested and required to expedite the afforestation and reforestation practices of Shisham plantation in the study area under developmental projects like 10 BTTAP and farm forestry in Pakistan.

Objectives of this research work was to observe different parameters and to find out the physical and strength properties of local commercial Shisham species grown in different climatic zones, identifying the potential sites where it showed better production, utilization and strength properties and correlation of density with strength property. This research will also explore whether the physical and mechanical properties of Shisham can be significantly influenced by variations in rising conditions within different locations. It will only be possible by studying wood characteristics and provide final recommendations for their best and advanced end uses by researching different physical and mechanical/strength of wood.

2. MATERIAL AND METHOD

2.1 Study Area

The current study was conducted in three different forest types of Khyber Pakhtunkhwa i.e., Sub-Tropical Broad Leaved, Tropical Thorn and Tropical Dry Deciduous Forests and tested for Physico-mechanical properties. Random sites were selected from each forest type's i.e., Dera Ismail Khan District for Tropical Thorn Forest, Kohat District for Tropical Dry Deciduous Forests while Swabi & Peshawar District for Sub-Tropical Broad-Leaved Forest.

2.2 Collection of Shisham Wooden Samples

In order to collect, test and evaluate the material to be used in the current trials in accordance with the minimum standard required by British Standard Institute BS-373, four defect free Shisham (*Dalbergia sissoo*) log with dbh (30±5cm) were brought and purchased from the local timber depot and Provincial Forest Departments and converted

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into 2 m long planks for carrying out their physical and mechanical tests. All logs were numbered and brought to Pakistan Forest Institute Peshawar, Pakistan for stacking at seasoning shed in Solar Kiln for four weeks to attain Equilibrium Moisture Content (EMC). In order to determine the proportional wood properties of all timbers, defect free specimens of 2×2 cm cross sectional area (n = 10 for each species) were cut from the side of timber up to the pith. Measurements of specimens for various physical and mechanical properties are given in Table 01 (Dinwoodie, 2016).

Table 1: Dimensions of Wood Specimens used for Physical & Mechanical Tests

Property	Specimen size
Density	6 cm x 2cm x 2cm
Static bending (MoR & MoE)	30 cm x 2 cm x 2 cm
Impact bending	30 cm x 2 cm x 2 cm
Compression parallel to grain	6 cm x 2 cm x 2 cm
Compression perpendicular to grain	4 cm x 4cm x 4cm
Tensile strength perpendicular to grain	6 cm x 2 cm x 2 cm
Cleavage	4.5 cm x 2 cm x 2 cm
Hardness	5 cm x 5 cm x 5 cm

2.3 Physical Properties

The measurable features of wood and its performance towards external stimuli other than practical forces are the physical properties. It includes color, moisture content, odour, shrinkages, heating/ calorific value, taste, dimensional constancy, density, chemical and electrical resistance etc. Information of physical properties is significant because they can affect meaningfully the strength and performance of wood used in organizational applications (ASTM, 2013).

2.3.1 The moisture content (MC) is the proportion of the total sum of water lost compared to the oven-dry weight of wooden material. Calculation of moisture content can be determined by using the formula given below (Dinwoodie, 2016).

$$MC = \frac{ww - ow}{ow} X\, 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 01$$

Whereas MC = moisture content

ww = wet weight

ow = oven dry weight

2.3.2 Wood density is the quantity of weight of a wooden sample to the per unit volume the wooden samples (Physical and Related Properties of 145 Timbers by Jan F. Rijsdijk and Peter B. Laming). The 6x2x2 cm wooden samples collected were oven-dried for 24 hours at 103oC ± 2 to a constant weight and the weight was recorded afterwards. The volume of wooden sample is always 24 cm3.

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The unit of density is gm/cm3. Wood density can be calculated as:

$$D = \frac{w}{v} \text{………………………………………………...02}$$

D = density. w = oven-dried weight, v = volume

2.3.3 Specific density/gravity is the proportion of material's density or wood density to the density of water (Physical and Related Properties of 145 Timbers by Jan F. Rijsdijk and Peter B. Laming).

$$SG = \frac{Ovendry\ density\ weight}{\text{volume}} \div density\ of\ water \text{………..03}$$

Density of water = 1g/cm^3, 1000kg/m^3

2.3.4 Wood shrinkage is the calculation of the reduction in each direction of the test sample when extreme moisture is extracted from green to the dry air condition. Before addressing shrinkage, it would be important to know about the following points, as discussed below:

2.3.4.1 Fiber Saturation Point

The theoretical stage in which the cavity eliminates all moisture, and some water is still retained in the cell-wall is termed as Fiber Saturation Point (FSP). A wood's moisture content at 25-30% is called the green condition/state of wood or Fiber Saturation Point. At this stage the wood cell will not shrink and large variations in many physical and strength properties of wood begin to take a place (Dry Kiln Operator's Manual).

2.3.4.2 Equilibrium Moisture Content

Seasoned wood is other name of air dry conditioned. Wood gains or loses the moisture until the volume it holds in the surrounding atmosphere is in accordance with that. At this point of balance, the volume of moisture is referred to as the equilibrium moisture content (EMC). Whenever moisture content (MC) is in between 10-15% is called EMC (Dry Kiln Operator's Manual). At Equilibrium Moisture Content the wood is dimensionally stable, and no shrinkage occurs.

2.3.5 Volumetric shrinkage in percentage can be calculated from the formula given below: (Forest Products Laboratory, 2010 Handbook: Wood as an Engineering Material).

$$So = \frac{26.5 \times Po}{Pw + 0.265 \times Po} \text{…………………………………..………04}$$

So = Percent volumetric shrinkage

Po = Oven-dry density

Pw = Water density

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2.3.6 Swelling can be calculated as:

$$\boldsymbol{\alpha = \frac{100 \times \beta}{100 - \beta}} \ldots\ldots 05$$

α = Volumetric swelling, β = Volumetric shrinkage

2.3.7 Wood heat/calorific value is the method in which the quantity of heat produced by the full combustion of the wood substance of unit mass. In contrast to oven dry or seasoned dry wood, the wood with excessive moisture contents has less calorific value. The calorific value is expressed in Btu/lb, cals/gm and Kcal/kg. The following Goutel formula can be used for determination of Calorific/ Heating value by empirical or indirect method: (Applied Chemistry Theory and Practice Second Edition by O.P. Vermani and A.K. Narula)

$$\boldsymbol{Q = 82 * Fixed\ carbon\ \% + \alpha * Volatile\ matter\ \%} \ldots\ldots 06$$

α = is a constant and taken as 82

2.3.7.1 Volatile matter is the percentage loss in weight of wood (minus % of moisture) when it is heated in the absence of air for exact 7 minutes at 950 ± 20oC in a crucible of standard dimensions. Volatile matter in percentage can be calculated as:

$$\boldsymbol{volatile\ matter\ \% = \frac{B-C}{B-A}\ X\ 100 - Moisture\ \%} \ldots\ldots 07$$

Where A = weight of empty crucible in gram

B = weight of crucible + sample before heating/ ignition

C = weight of crucible + sample after heating/ ignition

2.3.7.2 Fixed carbon is the part of coal that remains a residue after distillation of volatile matter, ash content and moisture in the coal is subtracted. Following is the formula used for calculation of fixed carbon in percentage.

$$\boldsymbol{Fixed\ Carbon\ \% = 100 - [Volatile\ matter\% + Ash\ content\% + Mositure\ Content\%]} \ldots\ldots 08$$

2.3.7.3 For the measurement of the ash content of wood, the following technique is adopted:

$$\boldsymbol{Ash\ content\ \% = \frac{Weight\ of\ ash}{Oven\ dried\ weight\ of\ specimen}\ X\ 100} \ldots\ldots 09$$

2.4 Mechanical Properties

For mechanical properties, the logs of Shisham (*Dalbergia sissoo*) wood species from each site were collected and converted into planks of 2 cm thickness. The planks from each log were used for the determination of strength properties in air dry condition. Specimens of 2 x 2 cm cross sectional area were cut initially from the side of timber up to

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the pith. One set of wooden samples of the following dimensions was prepared from each plank. All the strength properties were accurately determined in accordance with British Standard Institute BS-373 (Method of Testing Small Clear Specimens of Timber).

Mechanical properties are the top significant feature of wood products to be used for furniture, infrastructural and building construction. The word strength is often used to mention all mechanical properties. Strength is the capacity of material to carry practical loads or forces (ASTM, 2013).

2.4.1 Hardness is the resistance to indentation (Book: Timber H.E Desch revised by J. M. Dinwoodie, 2016). The resistance to indentation (to make dents) offered by wooden samples. Resistance is tested against a type of electronic hard steel rod device called as Janka. The diameter of the steel bar, according to the Janka method is 11.28 mm. The Janka can reach a specific depth of 5.04 mm. The hardness of wooden samples measured along two sides i.e Radial R and Tangential T while side resistance = R + T / 2 and expressed in unit Kg.

2.4.2 Modulus of Rupture MOR is the fiber stress that splits the wooden specimens at maximum load (www.forestrypedia.com). Modulus of rupture is the maximum load (ultimate building strength) determines the load a beam (a wooden member laid horizontally) will carry. Unit of MOR is kg/cm3 and can be calculated as:

$$MOR = {}^{3PL}/_{2BT^2} \ldots\ldots\ldots\ldots\ldots 10$$

Where P = maximum load

L = length of specimen

B = breadth of specimen

T = thickness of specimen

2.4.3 The fiber stress of wooden samples at elastic limit is the Modulus of Elasticity (MoE). This can be comprehended by the Hook’s law and can be expressed in kg/cm2.

$Stress\ \alpha\ Strain$

$Stress = Y\ Strain$

$Y = {}^{Stress}/_{Strain}$

$$MOE = {}^{PL^3}/_{4DBT^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

Where P = Load at elastic limit

D = deflection/ deformation of strain

B = breadth

T = thickness

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2.4.4 Compression is a collection of forces acting equal in magnitude on identical piece of wood and acting in a similar direction (Book: Timber H.E Desch revised by J. M. Dinwoodie, 2016).The load a beam will bear is determined by compression parallel to grain (crushing strength)expressed in unit kg/cm2 and calculated as:

$$\textit{Compression parallel or perpendicular to grain} = \textit{Maximum load at elastic limit} / \textit{Cross sectional area} \quad \text{.................12}$$

2.4.5 The ability of a wood to give resistance against splitting is cleavage (Book: Timber H.E Desch updated by J. M. Dinwoodie, 2016). The splitting force is applied at a speed of 0.04 mm/sec and resistance force cleavage resistance per unit width kg/cm is applied per resistance to cleavage is expressed in force per unit width kg/cm.

$$\textit{cleavage} = \textit{maximum load} / \textit{width of specimen} \quad \text{.....................13}$$

2.4.6 Tensile is a group of forces acting equal in magnitude and acting in the opposite direction on a wood sample. In designing the relation between wood members Tensile strength is vital in planning of construction between the wood supporters in building. It can be expressed in unit kg/cm2 (www.forestrypedia.com).

$$\textit{Tension perpendicular to grain} = \text{maximum } \textit{load} / \textit{cross section area} \quad \text{.................................14}$$

2.4.7 The confrontation offered by the wooden specimens to rapid shocks. The weight of a hammer is 8.5 kg while the height D 1.2 meter is the height from which a hammer is dropped (www.forestrypedia.com).

Energy or work = w = F × D = 8.5 × 1.2 = 10 m/kg.......................15

Here energy implies the hammer's striking energy. Residual energy is the energy with which the hammer hits the wooden samples and resistance offered by wooden samples. The amount of striking energy is 10 m/kg if there is a sample present in the way any amount of energy is transferred.

2.5 Procedure for Testing Properties of Wood

All the tests were carried out on "Amsler Universal Wood Testing Machine" with a total 4000 kg loading capacity at Pakistan Forest Institute Peshawar, Pakistan in accordance with British International Standard in Wood Mechanics Laboratory of Forest Product Research Division.

2.6 Statistical Analysis

The data was statistically analyzed by the following formulae of mean, standard deviation and coefficient of variation formulae of International Standards.

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The mean value can be calculated as:

$$\boldsymbol{X = \sum xi/n} \quad \textbf{15}$$

Standard Deviation:

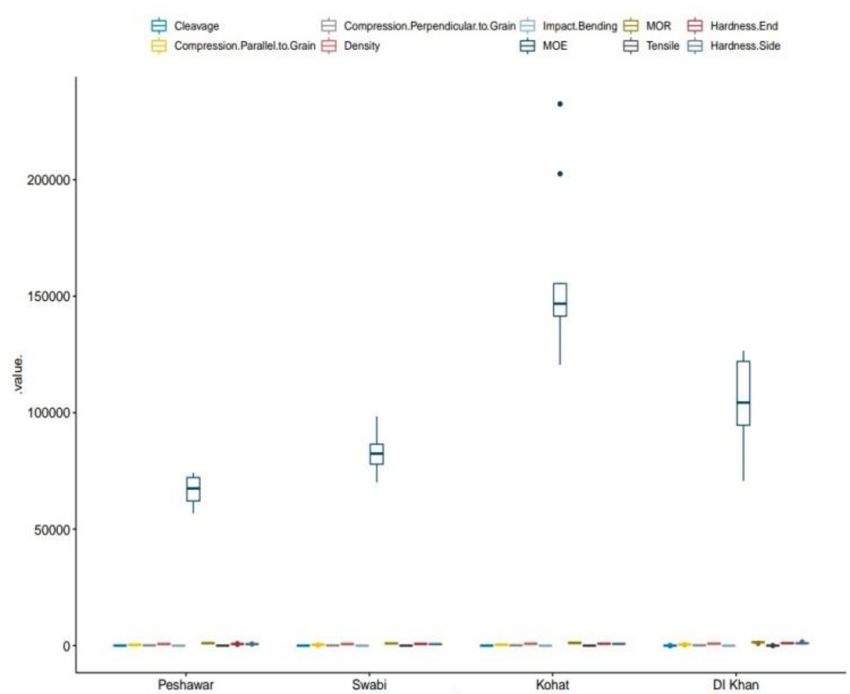
$$\boldsymbol{S.D = \pm\sqrt{\sum (xi - x)^2/(n-1)}} \quad \textbf{16}$$

For co-efficient of variation values were put in following formula:

$$\boldsymbol{C.o.V = \frac{S.D}{X} \times 100} \quad \textbf{17}$$

All the collected data for strength properties were firstly visualized with the help of R-Package as shown in Figure 1. The univariate normality assumption was checked by Shapiro-Wilk test for each outcome variable at each level of grouping variable. QQ plots were drawn, and all the points fall approximately along the reference line for each group and assumed that the data was normal as shown in the Figure 2. Mean plots for each property were also depicted in the Figure 3. Moreover, Wilks MANOVA a one-way multivariate analysis of variance was performed and sketched in Figure 4 to determine the effects of different sites on Shisham *(Dalbergia sissoo)* wood and to assess relationship between density and strength properties of Shisham *(Dalbergia sissoo)* wood by using R- Package software and SPSS for Homogenous subsets.

Figure 1: Data Visualization of 10 Dependent Variables



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3. RESULTS

Results of physical and strength properties have been discussed separately. In order to make the results comprehensive, tables and graphs have been depicted for different properties. A one-way multivariate analysis of variance was performed to determine if there was a significant difference among the strength properties of Shisham (*Dalbergia sissoo*) wood collected from the four different sites i.e Dera Ismail Khan, Kohat, Swabi and Peshawar. Results of Wilks MANOVA are given below in the Table 2.

As shown in the Table 2 there was a statistically significant difference in the wood samples among the four sites of the two regions on combined 10 dependent variables (properties) (F (30, 79.926) = 19.34, p < 0.0001) highlighted with * in the model summary. A significant p-value indicates that some of the group means are different.

Table 2: Manova Tests Wilks test statistic of 10 Dependent Variables

Df test	Stat	Approx F	num Df	den Df	Pr (>F)
Site 3	0.0020357	19.338	30	79.926	2.2e-16 ***
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

The one-way MANOVA was then followed by univariate one-way Welch ANOVA to identify the specific dependent variables that contribute to significant variation effect as given below in the Table 3.

Table 3: Univariate Welch ANOVA Statistics of 10 Dependent Variables

S. No	Variable	N	F	DFn	DFd	P
1	Cleavage	40	13.57	3	19.24557285	5.46E-05
2	Compression Parallel to Grain	40	23.75	3	19.07914403	1.18E-06
3	Compression Perpendicular to Grain	40	48.42	3	19.26752751	3.66E-09
4	Density	40	42.89	3	19.74722926	7.74E-09
5	Hardness End	40	52.41	3	19.12226609	2.05E-09
6	Hardness Side	40	21.81	3	16.90673198	4.76E-06
7	Impact Bending	40	30.15	3	16.59911775	6.03E-07
8	MoE	40	32.17	3	18.37387052	1.60E-07
9	MoR	40	13.71	3	19.42911948	4.91E-05
10	Tensile	40	50.67	3	19.47873367	2.18E-09

Follow up univariate ANOVA, using a Bonferroni adjusted alpha level of 0.005, results showed that there was a statistically significant difference among various strength properties as p value for each variable is less than the significance level among sites of two regions.

Statistically significant univariate ANOVA was then followed by multiple pairwise comparisons to determine which sites were significantly differed among each other. As the data violated the assumption of homogeneity of variances, so Games-Howell post-hoc test was the only possible way to perform multiple pairwise comparisons between

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specific pairs of groups. Results of the output values can be seen and depicted graphically from the Table 04 and Figure 04 respectively.

Table 4: Multiple Pair-wise Comparison of 10 Dependent Variables

S. No	Variables	Site 1	Site 2	P. adj	P. Adj signif
1	Cleavage	DI Khan	Kohat	0.000416	***
2	Cleavage	DI Khan	Peshawar	0.129	Ns
3	Cleavage	DI Khan	Swabi	0.002	**
4	Cleavage	Kohat	Peshawar	0.004	**
5	Cleavage	Kohat	Swabi	0.524	Ns
6	Cleavage	Peshawar	Swabi	0.003	**
7	Compression Parallel to Grain	DI Khan	Kohat	0.186	Ns
8	Compression Parallel to Grain	DI Khan	Peshawar	1.18E-06	****
9	Compression Parallel to Grain	DI Khan	Swabi	0.000808	***
10	Compression Parallel to Grain	Kohat	Peshawar	0.09	Ns
11	Compression Parallel to Grain	Kohat	Swabi	0.761	Ns
12	Compression Parallel to Grain	Peshawar	Swabi	0.082	Ns
13	Compression Perpendicular to Grain	DI Khan	Kohat	0.998	Ns
14	Compression Perpendicular to Grain	DI Khan	Peshawar	0.068	Ns
15	Compression Perpendicular to Grain	DI Khan	Swabi	3.38E-09	****
16	Compression Perpendicular to Grain	Kohat	Peshawar	0.461	Ns
17	Compression Perpendicular to Grain	Kohat	Swabi	0.00045	***
18	Compression Perpendicular to Grain	Peshawar	Swabi	5.71E-05	****
19	Density	DI Khan	Kohat	0.105	Ns
20	Density	DI Khan	Peshawar	2.95E-06	****
21	Density	DI Khan	Swabi	1.87E-06	****
22	Density	Kohat	Peshawar	2.93E-06	****
23	Density	Kohat	Swabi	1.10E-06	****
24	Density	Peshawar	Swabi	0.962	Ns
25	Hardness End	DI Khan	Kohat	2.69E-05	****
26	Hardness End	DI Khan	Peshawar	7.45E-08	****
27	Hardness End	DI Khan	Swabi	3.03E-07	****
28	Hardness End	Kohat	Peshawar	0.004	**
29	Hardness End	Kohat	Swabi	0.059	Ns
30	Hardness End	Peshawar	Swabi	0.107	Ns
31	Hardness Side	DI Khan	Kohat	0.005	**
32	Hardness Side	DI Khan	Peshawar	0.00045	***
33	Hardness Side	DI Khan	Swabi	0.000176	***
34	Hardness Side	Kohat	Peshawar	0.001	***
35	Hardness Side	Kohat	Swabi	0.000967	***
36	Hardness Side	Peshawar	Swabi	0.698	Ns
37	Impact Bending	DI Khan	Kohat	7.04E-05	****
38	Impact Bending	DI Khan	Peshawar	0.004	**
39	Impact Bending	DI Khan	Swabi	6.62E-05	****
40	Impact Bending	Kohat	Peshawar	0.008	**
41	Impact Bending	Kohat	Swabi	0.396	Ns
42	Impact Bending	Peshawar	Swabi	0.001	***
43	MoE	DI Khan	Kohat	0.004	**

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44	MoE	DI Khan	Peshawar	0.000592	***
45	MoE	DI Khan	Swabi	0.031	*
46	MoE	Kohat	Peshawar	6.68E-05	****
47	MoE	Kohat	Swabi	0.000302	***
48	MoE	Peshawar	Swabi	0.00069	***
49	MoR	DI Khan	Kohat	0.187	Ns
50	MoR	DI Khan	Peshawar	0.000196	***
51	MoR	DI Khan	Swabi	5.33E-05	****
52	MoR	Kohat	Peshawar	0.74	Ns
53	MoR	Kohat	Swabi	0.341	Ns
54	MoR	Peshawar	Swabi	0.555	Ns
55	Tensile	DI Khan	Kohat	4.07E-09	****
56	Tensile	DI Khan	Peshawar	0.000659	***
57	Tensile	DI Khan	Swabi	1.28E-06	****
58	Tensile	Kohat	Peshawar	0.257	Ns
59	Tensile	Kohat	Swabi	0.564	Ns
60	Tensile	Peshawar	Swabi	0.814	Ns

The Table 5 below illustrated the relationship between the density and strength properties of wood. There is strong positive correlation between density and strength properties at 0.05 and 0.01 level of confidence. As the density increases, the strength properties also increase.

Table 5: Correlation between Density and Strength Properties

		Den	**Clvg**	**Tensl**	**Impct**	**H. End**	**H. Sides**	**Comp. Parll**	**Comp. Perp**	**MoR**	**MoE**
Density	Pearson Correlation	1	.320*	.432**	.507**	.766**	.704**	.567**	.618**	.477**	.445**
	Sig. (2-tailed)		.044	.005	.001	.000	.000	.000	.000	.002	.004
	N	40	40	40	40	40	40	40	40	40	40

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

3.1 Physical Properties

The physical properties of Shisham *(Dalbergia sissoo)* wood for arid and semi-arid regions have been shown below in Table: 06. The table provided average values of tested wood samples for each site of two regions i.e arid and semi-arid regions.

The physical properties of Shisham *(Dalbergia sissoo)* wood for four different sites have been shown below in Table 05. The table provided average values of tested wood samples for each site of three forest types.

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Table 6: Average Values for Physical Properties of Shisham (Dalbergia sissoo) Wood Collected from Four Different Sites

S. No	Physical Properties	Forest Types			
		S.T.B.L. Forest		T.D.D. Forest	T.T. Forest
		Peshawar	Swabi	Kohat	D.I Khan
		Avg. Value	Avg. Value	Avg. Value	Avg. Value
1	Basic Density*	707.66	700.58	826.74	878.47
2	Specific Density**	0.679	0.669	0.790	0.788
3	Moisture Content % Green (Maximum)	78	83	76	73
4	Moisture content % Air-dry Moisture content % Oven-dry	7.3 6.0	10.2 6.8	7.6 6.0	7.2 6.5
5	Volumetric Shrinkage %	15.25	15.06	17.31	17.27
6	Volumetric Swelling %	17.99	17.73	20.93	20.87
7	Heating/ Calorific Value Btu/lb	7611	7375	7598	7568

*Air-dry weight divided by Air-dry volume of sample
**Oven-dry weight divided by green volume of sample

The means for groups in homogeneous subsets of Density were provided in the Table: 07 and varied in order as, Dera Ismail Khan > Kohat > Peshawar > Swabi. It was obvious that density values in kg/cm3 of Dera Ismail Khan Site with 878.48 were higher than that of Kohat, Peshawar and Swabi sites where the lowest values 826.75, 707.66 and 700.58 respectively for density were recorded. Table 7 results indicated a statistical difference among the various four sites at 0.05 level of significance. A significant difference was found between Shisham (*Dalbergia sissoo*) wood from Kohat and Dera Ismail Khan Sites while the wood samples from Swabi and Peshawar sites had no significant difference and were found alike.

Table: 7 Means for groups in Homogeneous subsets of Density

	Site	N	Subset		
			1	2	3
Tukey HSD	Swabi	10	700.58		
	Peshawar	10	707.66		
	Kohat	10		826.75	
	DI Khan	10			878.48
	Sig.		.979	1.000	1.000
Alpha = .05					

As far as the variation in wood density of studied sites is concerned, it may be due to geographic position, anatomical building, annual ring width, temperature, humidity, ground condition, site factor, fertilization and genetic characteristics (Europeanwood.org.cn). There was no such significant difference found in the other properties i.e., calorific value, volumetric shrinkage and swelling among the four sites of the three different forest types.

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3.2 Mechanical Properties

The results of different mechanical properties were given below in Table 08 and each property discussed separately. For each property an average value, standard deviations and coefficient of variation was calculated.

Table: 8 Average Value for Strength Properties of Shisham *(Dalbergia sissoo)* Wood Collected from Four Different Forest Types

S. No	Strength Properties	Forest Types			
		S.T.B.L. Forest		T.D.D. Forest	T.T. Forest
		Peshawar	Swabi	Kohat	D. I Khan
		Avg. Value	Avg. Value	Avg. Value	Avg. Value
1	Modulus of Rapture: kg/cm^2	1034.5	939.8	1154.24	1416.93
2	Modulus of Elasticity: kg/cm^2	66778.8	82690.2	156781.6	104227.2
3	Compression strength parallel to grain: kg/cm^2	345.5	391.8	422.75	489.25
4	Compression perpendicular to grain: kg/ cm^2	132.49	98.87	145.48	146.87
5	Cleavage: kg/cm	35.5	30.15	27.6	40.8
6	Tensile strength perpendicular to grain: kg/cm^2	28.45	25.35	22.1	45.77
7	Impact bending: m-kg/4cm^2	2.66	0.61	1.04	6.14
8	Hardness: Kg Side: End:	 675 708	 649 752	 796.5 839	 1084 1088

3.2.1 Modulus of Rupture-MoR (kg/cm^2)

Means for groups in homogeneous subsets of MoR were set out in Table 09 in order as, Dera Ismail Khan > Kohat > Peshawar > Swabi. Higher values of MOR 1416.93 and 1154.25 were recorded among the tested wood samples in the sites Dera Ismail Khan and Kohat while lowest values of 1034.5 and 939.8 for MoR property in Peshawar and Swabi sites respectively were recorded. It can also be seen from the Table 09 given below that the Shisham (*Dalbergia sissoo*) wood from Swabi, Peshawar and Kohat group had no significant difference in their MoR values at 0.05 significance level and can be used alternatively. Similarly, Kohat and Dera Ismail Khan group had no significant difference and can be used interchangeably while a significant difference in the MoR was found between Shisham (*Dalbergia sissoo*) wood from Swabi, Peshawar and Dera Ismail Khan.

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Table 9: Means for groups in Homogeneous subsets of Modulus of Rupture MoR

	Site	N	Subset	
			1	2
Tukey HSD	Swabi	10	939.94	
	Peshawar	10	1034.44	
	Kohat	10	1154.25	1154.25
	DI Khan	10		1416.94
	Sig.		.158	.057
Alpha = .05				

3.2.2 Modulus of Elasticity-MoE (kg/cm^2)

The means for groups in homogeneous subsets of MoE were observed in the order, Kohat > Dera Ismail Khan > Swabi > Peshawar as presented in the Table 10. Results indicated that modulus of elasticity MoE value 156781.6 for Shisham (*Dalbergia sissoo*) wood of site Kohat was higher than that of and 104227.2, 82690.2 and 66778.8 observed in Dera Ismail Khan, Swabi and Peshawar sites respectively. This means that the wood from Peshawar and Swabi were weak and has low tendency to bear fiber stress at elastic limit. Results also indicated that Shisham (*Dalbergia sissoo*) wood from Peshawar & Swabi, and Dera Ismail Khan & Swabi group had no significant difference in their MoE values, while there was a significant difference at 0.05 level of significance found among Shisham (*Dalbergia sissoo*) wood samples from Peshawar & Dera Ismail Khan, Peshawar & Kohat, Swabi & Kohat, and Dera Ismail Khan & Kohat groups.

Table 10: Means for groups in Homogeneous subsets of Modulus of Elasticity MoE

	Site	N	Subset		
			1	2	3
Tukey HSD	Peshawar	10	66778.84		
	Swabi	10	82690.25	82690.25	
	DI Khan	10		104227.17	
	Kohat	10			156781.64
	Sig.		.320	.105	1.000
Alpha = .05					

3.2.3 Compression strength parallel to grain (kg/cm^2)

The means for groups in homogenous subsets of Compression strength parallel to grain were displayed in Table 11 in an order, Dera Ismail Khan > Kohat > Swabi > Peshawar. The compression strength value of 489.25 was higher in Dera Ismail Khan Site while values of 422.75, 391.8 and 345.5 were lowest in that of Kohat, Swabi and Peshawar sites respectively. There were no significant differences found for Shisham (*Dalbergia sissoo*) wood samples among the groups Peshawar & Swabi, Kohat & Swabi and Dera Ismail Khan & Kohat sites as reflected in Table 11 while wood samples from Swabi & Peshawar sites showed significant difference at 0.05 significance level from wood samples of Dera Ismail Khan site. It meant that Shisham (*Dalbergia sissoo*) wood from Peshawar site differed significantly from Kohat and Dera Ismail Khan Sites.

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Table 11: Means for groups in Homogeneous subsets of Compression Parallel to Grain

	Site	N	Subset		
			1	2	3
Tukey HSD	Peshawar	10	345.50		
	Swabi	10	391.80	391.80	
	Kohat	10		422.75	422.75
	DI Khan	10			489.25
	Sig.		.272	.612	.056
Alpha = .05					

3.2.4 Compression strength perpendicular to grain (kg/cm^2)

Table 12 given below illustrated the means for groups in homogenous subsets of Compression perpendicular to grain property and the order recorded as, Dera Ismail Khan > Kohat > Peshawar > Swabi. The highest values 146.87 and 145.48 of compression strength were observed in Dera Ismail Khan and Kohat sites respectively while the lowest values 132.49 and 98.87 recorded in wood of Peshawar and Swabi sites respectively. Results also showed that Shisham (*Dalbergia sissoo*) wood from Swabi site had significant difference at alpha 0.05 in its compression perpendicular to grain property to all other sites while there was no significant difference found among the Shisham (*Dalbergia sissoo*) wood from Peshawar, Kohat and Dera Ismail Khan group and were found identical.

Table 12: Means for groups in Homogeneous subsets of Compression Perpendicular to Grain

	Site	N	Subset	
			1	2
Tukey HSD	Swabi	10	98.87	
	Peshawar	10		132.50
	Kohat	10		145.48
	DI Khan	10		146.88
	Sig.		1.000	.163
Alpha = .05				

3.2.5 Tensile strength (kg/cm^2)

The means for groups in homogenous subsets were displayed in the Table 13 with respect to sites in order, Dera Ismail Khan > Peshawar > Swabi > Kohat. The highest value of 45.78 for tensile strength was recorded in Dera Ismail Khan Site while the lowest values 28.45, 25.35 and 22.10 were observed in Peshawar, Swabi and Kohat sites respectively. Results also showed that Shisham (*Dalbergia sissoo*) wood samples from Kohat, Swabi and Peshawar sites were found identical and no significant difference while the wood sample from Dera Ismail Khan Site was significantly differed from all other sites.

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Table 13: Means for groups in Homogeneous subsets of Tensile Strength

	Site	N	Subset	
			1	2
Tukey HSD	Kohat	10	22.10	
	Swabi	10	25.35	
	Peshawar	10	28.45	
	DI Khan	10		45.78
	Sig.		.136	1.000
Alpha = .05				

3.2.6 Impact bending (m-kg/cm^2)

The Table 14 given below identified means for group in homogenous subsets of Impact bending and varied in the order, Dera Ismail Khan > Peshawar > Kohat > Swabi. Result indicated that Impact bending value of 6.05 for Shisham (*Dalbergia sissoo*) wood of Dera Ismail Khan Site was higher than that of Peshawar, Kohat and Swabi sites recorded as 2.80, 1.04 and 0.58 respectively. As shown by calculated impact bending, wood samples collected from Dera Ismail Khan Site have very better tendency to absorb sudden shocks. Results also showed that was no significant difference found in the group Swabi & Kohat wood samples while there was a significant difference at 0.05 significance level Peshawar and Dera Ismail Khan wooden samples. Similarly, a significant difference occurred between wood samples of Peshawar and Dera Ismail Khan Sites.

Table14: Means for groups in Homogeneous subsets of Impact Bending

	Site	N	Subset		
			1	2	3
Tukey HSD	Swabi	10	0.58		
	Kohat	10	1.04		
	Peshawar	10		2.80	
	DI Khan	10			6.05
	Sig.		.853	1.000	1.000
Alpha = .05					

3.2.7 Cleavage (kg/cm)

The means for groups in homogenous subsets of Cleavage were listed in Table 15 and the following order were observed for the property, Dera Ismail Khan > Peshawar > Swabi > Kohat. Highest cleavage value of 40.80 was recorded in Dera Ismail Khan Site while the lowest values 35.50, 30.15 and 27.60 were observed in Peshawar, Swabi and Kohat sites respectively which means that the wood has better nail and screw holding power. It results indicated that there were no significant differences found among Shisham (*Dalbergia sissoo*) wood samples from Kohat & Swabi, Peshawar & Swabi and Dera Ismail Khan & Peshawar group. However, a significant difference was found at alpha 0.05 among Peshawar, Kohat and Dera Ismail Khan wooden samples between the group Swabi & Dera Ismail Khan wood samples.

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Table 15: Means for groups in Homogeneous subsets of Cleavage

	Site	N	Subset		
			1	2	3
Tukey HSD	Kohat	10	27.60		
	Swabi	10	30.15	30.15	
	Peshawar	10		35.50	35.50
	DI Khan	10			40.80
	Sig.		.597	.058	.061
Alpha = .05					

3.2.8 Hardness (kg)

With respected to sites, the following order, Dera Ismail Khan > Kohat > Peshawar > Swabi was observed as depicted in Table 16. It can be realized that the top value of 1084 for hardness of wood samples were recorded in Dera Ismail Khan site and the lowest values and 796, 675 and 649 were recorded in Kohat, Peshawar and Swabi sites respectively. Results also showed that Shisham (*Dalbergia sissoo*) wood from Swabi significantly differed from Kohat and Dera Ismail Khan wood samples, wood samples from Peshawar had significant difference with Dera Ismail Khan wood samples while there was found significant difference between the Shisham (*Dalbergia sissoo*) wood samples from Kohat and Dera Ismail Khan sites.

Table 16: Means for groups in Homogeneous subsets of Side Hardness

	Site	N	Subset		
			1	2	3
Tukey HSD	Swabi	10	649.00		
	Peshawar	10	675.00	675.00	
	Kohat	10		796.50	
	DI Khan	10			1084.00
	Sig.		.953	.086	1.000
Alpha = .05					

Moreover, as reflected in the Table 17 highest figure of 1088 was observed for End hardness in Dera Ismail Khan Site while the lowest figures and 796, 752 and 708 were recorded in Kohat, Swabi and Peshawar sites respectively. This indicates that the wood sample from Dera Ismail Khan has good dentation properties when used over knives or other sharp machines. The means for groups in homogenous subsets of End hardness of Shisham (*Dalbergia sissoo*) wood indicated statistical significant difference at 0.05 level of significance. A significant difference was found between Shisham (*Dalbergia sissoo*) wood from Kohat and Dera Ismail Khan while the wood samples from Swabi and Peshawar had no significant difference and uniform.

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Table 17: Means for groups in Homogeneous subsets of End Hardness

	Site	N	Subset		
			1	2	3
Tukey HSD	Peshawar	10	708.00		
	Swabi	10	752.00		
	Kohat	10		839.00	
	DI Khan	10			1088.00
	Sig.		.476	1.000	1.000
Alpha = .05.					

3.3 Discussion

In comparison with traditional timbers such as *Cedrus deodara Roxb, Acacia nilotica* and *Dalbergia sissoo* Roxb. Awan *et al*., 2012 investigated the strength properties of farming *Eucalyptus camaldulensis* and recorded variable values for various species. Results of Awan *et al*., 2012 have shown that *Acacia nilotica* has a lower crushing strength parallel to grain than *Dalbergia sissoo* wood. Considering modulus of elasticity (MoE), modulus of rupture (MoR) and crushing strength parallel to the grain *Dalbergia sissoo* was superior to *Eucalyptus camaldulensis*. It was found that *Tamarix aphylla* has a high resistance to splitting when compared with *Dalbergia sissoo* wood while all the remaining properties are inferior to *Dalbergia sissoo* wood. The mean standards of 0.738g/cm3 for wood density, static bending-MoR of 1152kg/cm2, maximum compressive strength parallel to grain of 101 kg/cm2 and perpendicular to grain of 68 kg/cm2, maximum tensile strength 682kg/cm2, impact bending 601 kg/cm and nail holding capacity of 173 kg/cm in Shisham (*Dalbergia sissoo*) wooden samples were recorded.

Similar results have been published by Mahmood *et al*., 2016 by investigated some anatomical, physical and mechanical properties of salt tolerant tree species grown in Punjab, Pakistan. Paper reports on the wood characteristics of selected species of salt-tolerant tree species to be tested as a replacement for regular standard *Dalbergia sissoo* wood. With regard to various wood quality parameters, the evaluated tree species differed greatly. For Shisham wood the maximum values observed for strength properties of Shisham (*Dalbergia sissoo*) wood was 1122 ± 47.8 kg/cm2 for modulus of rupture (MoR), 85790 ± 1098 kg/cm2 for modulus of elasticity (MoE), 560 ± 15.3 kg/cm2 for maximum compression parallel to grain, 36 ± 3.71 kg/cm2 for tensile strength perpendicular to grain, 650 ± 13.6 kg for side grain hardness, 800 ± 21 kg for end grain hardness, 22 ± 1.11 kg/cm for cleavage and 1.79 ± 0.20 per 4/cm2 kg/m for impact bending.

In 2017, Sunny studied the variation in physical and mechanical properties of Shisham (*Dalbergia sissoo*) wood obtained from various sites in India. A maximum moisture content of 68.326 was noted in the wooden samples collected from Nalagarh and the minimum moisture content of 46.995 was observed in samples obtained from the Dattowal site. The data on specific gravity recorded by Sunny, 2017 showed substantial differences between the wooden samples of Shisham collected from various sites. At Dattowal site, the maximum moisture specific gravity 0.644 was noted and a minimum

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specific gravity of 0.517 was found in wooden samples collected from Nalagarh site. A crucial data analysis of the data noted for tensile strength showed substantial differences between wooden samples. The highest tensile strength was noted in Baroh site wooden samples 0.094kN/mm2 which was statistically equal to the Galore site 0.078kN/mm2 wooden samples. The minimum tensile strength was found from the site Ghumarwin 0.030kN/mm2 and was statistically equal to the wooden samples of Andreta 0.032kN/mm2 and Dattowal 0.039kN/mm2 site. He stated that there were no major differences between the Shisham wooden samples collected for bending strength property from various sites. Maximum bending strength 0.006kN/mm2 was observed in wooden samples from Baroh and Sundernagar, while minimum tensile strength 0.004kN/mm2 was observed at the Galore, Saraham, Chowkiwala, Ghumarwin and Andreta sites. The compression strength perpendicular to grain was found to be substantially different and the highest compressive strength perpendicular to grain of 0.038kN/mm2 was observed from Andreta site, while the lower compressive strength perpendicular to grain in the Sundernagar site of 0.022kN/mm2. The compression strength parallel with grain data showed considerable variation and was statistically equal for the wooden samples procured from Sundernagar site 0.065kN/mm2, Baroh site 0.069kN/mm2, Ghumarwin 0.063kN/mm2 and Andreta 0.064kN/mm2 site whereas, the lowest compressive strength of 0.046kN/mm2 was observed in Sarahan site as per results. Sunny, 2017 recorded the maximum value of modulus of elasticity (MoE) between wooden samples of Shisham wood obtained from various sites for Ghumarwin site i.e 1.655kN/mm2 while in wooden samples from Sarahan site the minimum value of 0.827kN/mm2 was noticed for modulus of elasticity. He also observed significant variations in modulus of rupture (MoR) property and the maximum modulus of rupture (MoR) value of Shisham wooden samples obtained from various sites was 0.116kN/mm2 for Sundernagar site, while the lowest value was observed for Sarahan site 0.081kN/mm2. He also testified that out of total 105 combinations of simple coefficients of correlation obtained amongst physical and mechanical parameters, 3 were found to be positive and important whereas, 7 were testified as negatively correlated and significant.

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Figure 2: QQ Plots Showing Data Normality of all Properties with Respect to Sites

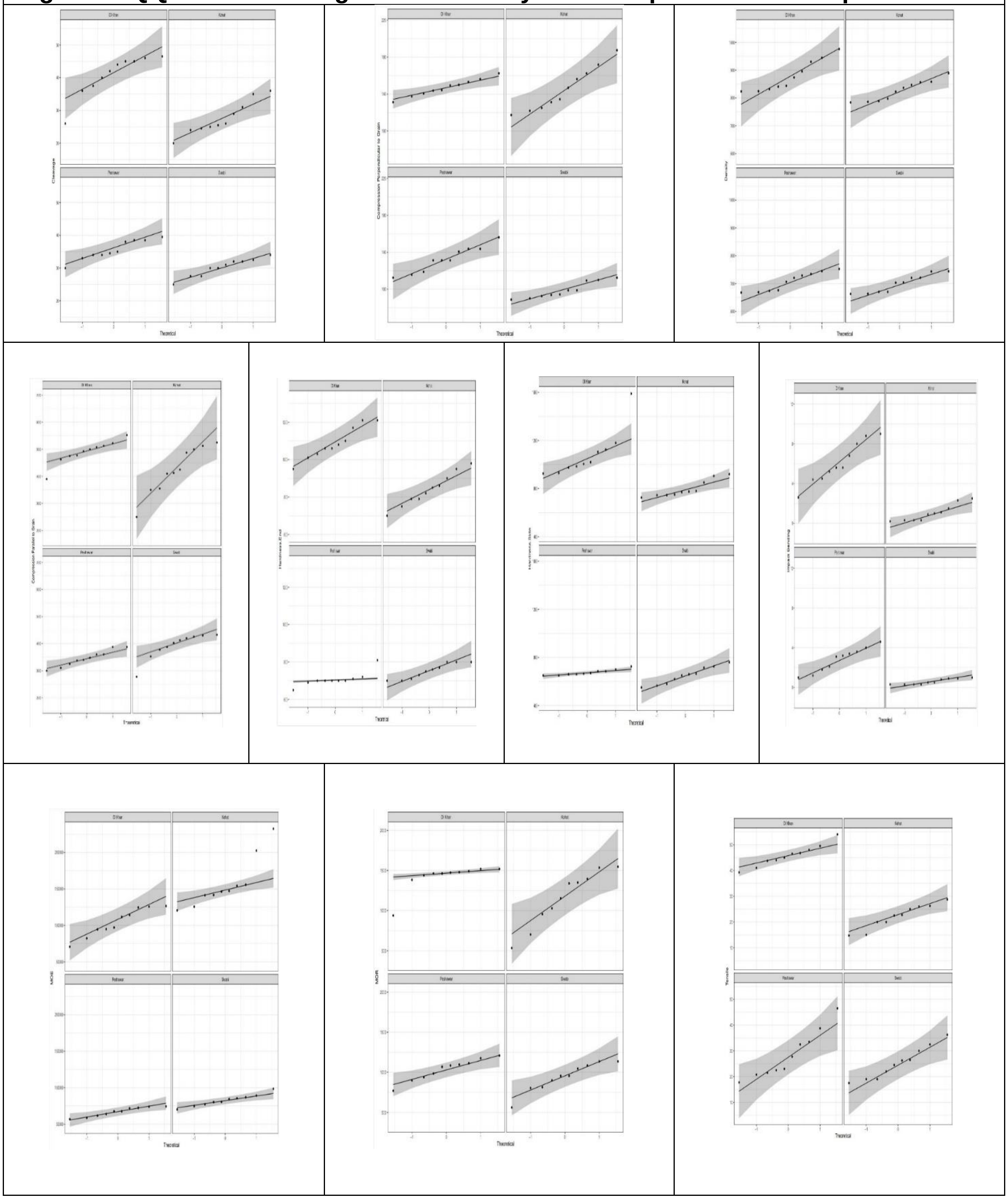

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Figure 3: Mean Plots of Each Property with Respect to Sites

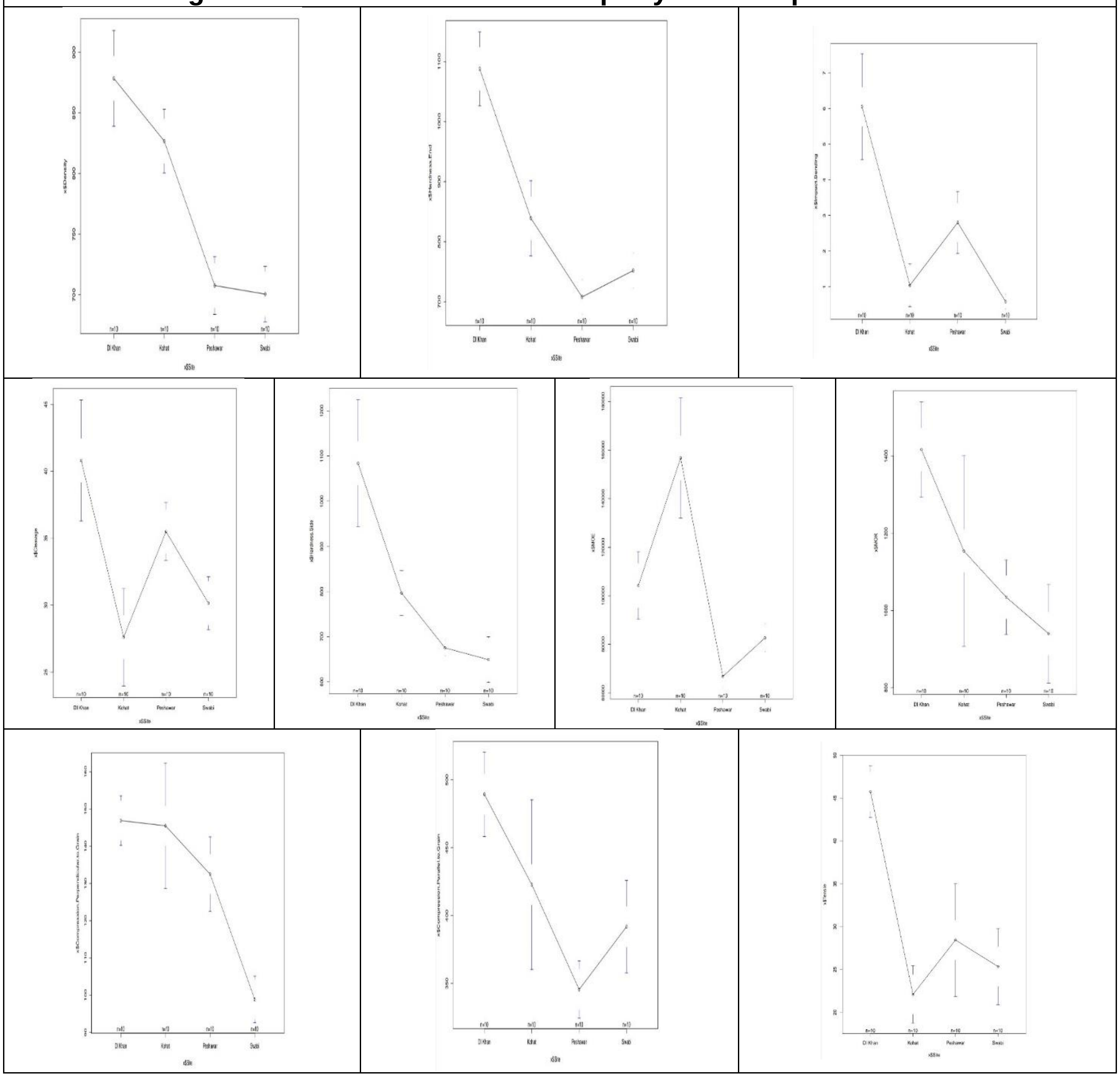
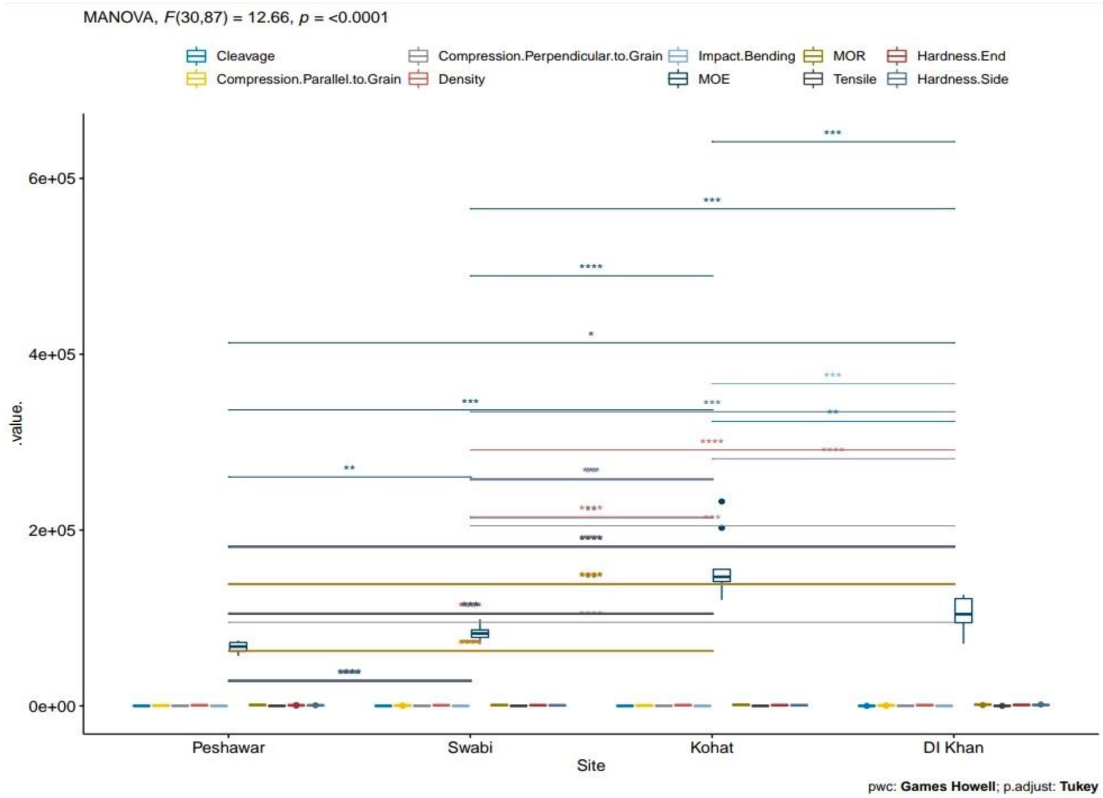


Figure 4: Graphical Representation of MANOVA and Pair-wise Comparisons of all Dependent Variables



4. CONCLUSION

Based on results, it can be concluded that:

- There is statistically significant difference in strength properties of Shisham (*Dalbergia sissoo*) wood collected from three different forest types. Most of the pairwise comparisons of properties among sites are significant.
- The findings indicate that the Shisham (*Dalbergia sissoo*) collected from Dera Ismail Khan Site i.e Tropical Thorn Forest is found to be better in strength properties when compared with the same species grown in Tropical Dry Deciduous Forests and Sub-Tropical Broad Leaved i.e., Kohat, Peshawar and Swabi sites.
- There is statistically positive significant correlation between the density and strength properties of wood. As density increases the strength properties also increases.

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5. RECOMMENDATIONS

- Overall, Shisham (*Dalbergia sissoo*)wood from Dera Ismail Khan i.e. Tropical Thorn Forest is recommended for potential utilization to supply in wood based industries particularly furniture industries of Pakistan with valuable hardwood timber due to its better strength properties preferably over the Shisham (*Dalbergia sissoo*) from other two forest types of KP Pakistan and where the stiffness property (MoE) is of prime concern, Shisham wood from Kohat i.e Tropical Dry Deciduous Forests will be the best choice from amongst the studied areas.
- Tropical Thorn Forest (Dera Ismail Khan) is recommended for the Shisham (*Dalbergia sissoo*) wood production due to high and better strength properties.
- Wood density is recommended as a wood quality indicator for assessing the preliminary quality and other wood properties.

Conflict of interest

The authors have declared no conflict of interest in publication of this article.

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