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Wood variation in physico-mechanical properties of *Dalbergia sissoo* Roxb. *ex* DC. from local markets of Himachal Pradesh

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Abstract

Attempt was made to evaluate the wood variation in *Dalbergia sissoo* (shisham) from the local markets of Himachal Pradesh. The highest moisture content (20.17%) was observed in the wood samples of Nalagarh site. Highest specific gravity of 0.644 was observed in Dattowal and lowest (0.748) in Nalagarh site. Significant variation in mechanical properties was observed for all the studied parameters. The maximum bending strength was recorded in Baroh and Sundernagar site (0.006 kN/mm^2) and maximum tensile strength (0.094 kN/mm^2) was noticed in the wood samples from Baroh site. The maximum compressive strength parallel to grain (0.069 kN/mm^2) was observed in Kangu site and maximum compressive strength perpendicular to grain (0.038 kN/mm^2) was found in Baroh site. The maximum modulus of elasticity parallel to grain (0.231 kN/mm^2) was recorded in Ghumarwin and maximum modulus of elasticity perpendicular to grain (1.653 kN/mm^2) was noticed in wood samples of Galore site. The greater modulus of elasticity due to tension and bending was found in the wood samples of the sites Baroh (2.876 kN/mm^2) and Kangu (10.369 kN/mm^2) respectively. The maximum bending modulus of rupture was observed in the wood samples from the sites of Sundernagar (0.116 kN/mm^2) and for teak was found to be 0.323 kN/mm^2. The maximum elongation for shisham wood samples for bending was found in Nalagarh site (0.039 mm) and for tension in the site of Sarahan (0.033 mm). The mechanical properties of shisham wood were compared with standard teak wood samples and it was found that the wood samples of shisham were superior in some mechanical properties.

Keywords: Bending, Elasticity, Moisture, Specific gravity.

Introduction

Wood has remained as an important substance throughout history because of its unique properties and has been used as a most versatile constructional material for thousands of years (Rowell, 2013). Wood is essentially composed of cellulose, hemicelluloses, lignin and extractives. Each of these components contributes to fibre properties, which ultimately have an impact on wood properties. Two major chemical components in wood, lignin (18-35%) and carbohydrate (65-75%) are complex, polymeric materials along with minor amount of extraneous materials, mostly in the form of organic extractives and inorganic material (ash). Overall, wood has an elemental composition of about 50 per cent carbon, 6 per cent hydrogen, 44 per cent oxygen, and trace amounts of several metal ions.

Wood is highly anisotropic in its properties *i.e.,* it has different properties in different directions. This is due to its cellular structure and physical organization of the cellulose chain molecules within the cell walls (Schniewind, 1989). It is a natural, renewable cellular resource of botanical origin with unique structural and chemical characteristics that render desirable end uses for variety of purposes

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with excellent strength-to-weight properties (Hingston et al., 2001).

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 dbh under favourable conditions. This 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 900 m, but occasionally ascending to 1500 m. This species is a strong light demander and right from the seedling stage it requires full overhead light for successful regeneration and establishment. It is, therefore, found in riverine environments. It has long been grown in combination with agricultural crops, field boundaries around the fruit orchard, as wind breaks and shelter belts and as scattered trees in 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 and are somewhat even better than teak. The heartwood of shisham is extremely durable both in exposed and under cover conditions as compared to sapwood. The heartwood is golden to dark brown whereas sapwood is white to pale brownish white. The wood has straight grain, though it can sometimes be interlocked. Texture is medium to coarse with a good natural lustre. The wood has a distinct scent which is the characteristic of most of woods in the *Dalbergia* genus, though the scent is somewhat milder compared to other species. Sissoo timber is easy to work, machines well and takes an excellent polish and is highly valued in India, where its price is at par with teak (Luna, 2005). The tree itself tends to grow in a crooked fashion, clear sections of lumber are seldom seen. Sissoo wood has good working characteristics and responds well to nearly all machining operations, glues and finishes well. It is also commonly planted in Southern Indian cities as a street tree and is one of the most preferred species for doors and windows in Northern India. The wood is suitable for handles of striking, scooping, cutting and shaping tools. Although eminently suitable for railway sleepers, due to its usefulness in constructional and cabinet purposes, it is rarely used for this purpose. Shisham, like teak and rosewood, ranks amongst the finest of India's cabinet and furniture woods due to its attractive brown colour, desirable figure, good grain etc. The use of woody material is increasing continuously, thus resulting in consumption of larger quantities by different timber processing industries. Due to this increased demand, the pressure on forests has increased, resulting in shortage of wood and other woody products (Rahman et al., 2005). Like teak and sal, shisham wood can be used as timber and for other purposes.

At present, there has only few studies on the physical and mechanical properties of shisham wood, although some clonal comparative studies have been conducted at Dehradun in Uttarakand and Solan in Himachal Pradesh. As physical and mechanical properties are important parameters for the practical application of wood for different purposes, the present study aims to understand the species, its complete and effective utilization. In this back drop a study was carried out with twin objectives of investigating the variation in physical and mechanical properties of shisham wood.

Materials and Methods

The present study on the characterization of physical and mechanical properties of shisham wood was carried out in three sub experiments.

Experimental Material

Wood samples of *Dalbergia sissoo* were collected randomly from ten different market sites of Himachal Pradesh. Details of sites with their coordinates from the market sites have been given in Table No.1

Experiment 1: Identification and authentication of *Dalbergia sissoo* wood

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

Sl. 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		

The following physical properties were recorded for the identification and authentication of the wooden samples taken from the market:

i) Colour
ii) Odour
iii) Texture

i) Colour

Colour of the wood is due to the presence or infiltration of chemical products and is a variable feature of some diagnostic value. Colour was observed in each wood sample using Royal Horticultural Society chart (RHS, 2015). Wooden samples were matched with different colours in the chart and the colour codes were recorded for each sample.

ii) Odour

The odour of the wood is due to one or more volatile chemicals, generally at a very low concentration, that humans or other animals perceive by the sense of olfaction. Odours are also commonly called scents, which can refer to both pleasant and unpleasant odours.

iii) Texture

Wood texture describes the relative size as well as the amount of variation in size of the wood cells. It depends upon the size of the cells, and its distribution, and proportion of the various types of cells. Texture of *Tectona grandis* ranges from medium to coarse and was determined based upon the range of tangential diameters of vessels under four main classes (Peng et al., 1988) as given below:

Texture		Mean tangential diameter of vessels
(a) Very fine	:	<100 µm
(b) Fine	:	100-200 µm
(c) Medium	:	200-300 µm
(d) Coarse	:	>300 µm

In order to measure the vessel diameter, the cross section of the wood sample was observed by using ocular micrometer of 15x fitted in the eyepiece of microscope with 4x magnification objective lens which was standardized with the help of stage micrometer.

Experiment 2: To study the physical properties of *Dalbergia sissoo* wood

Species	:	*Dalbergia sissoo*
No. of sites	:	10
Control (*Tectona grandis*)	:	1
Replications	:	3
Design	:	CRD

Observations recorded:

i) Moisture content (%)
ii) Maximum moisture content (%)
iii) Specific gravity

i) Moisture content (%)

Fresh weight of the standard samples was recorded just after they were cut from logs of Shisham wood procured from different sites. After initial weighing, the samples were oven dried at 102±1^{0}C till constant weight. This weight of samples was recorded as oven dried weight (g).

The moisture per cent of the samples was calculated by using the formula given by Desch and Dinwoodie (1996).

$$\text{Moisture content (\%)} = \frac{Mi - Mo}{Mo} \times 100$$

Where,

M_i = Initial weight of sample (g)

M_o = Oven dried weight of sample (g)

ii) Maximum moisture content (MMC %)

Maximum moisture content (MMC) of wood samples was determined as per procedure prescribed by Indian Standard IS: 1708 (BIS, 1986). The wood samples were submerged in distilled water for 7 days to ensure complete saturation. The saturated samples were taken out and weighed. These samples were then dried first in air and then at 105±2^{o}C till constant weight. The maximum moisture content (%) was calculated using the formula:

$$\text{Maximum moisture content (MMC \%)} = \frac{Mm - Mo}{Mo} \times 100$$

Where, M_m = Saturated weight of sample (g)

M_o = Oven dried weight of sample (g)

iii) Specific gravity

Specific gravity of the samples was determined by the maximum moisture content method (Smith, 1954). Wood samples were prepared from the disc which was cut from the base of log for each sample. These samples were submerged in distilled water till saturation. The weight of the samples at this point was recorded as weight at maximum moisture content level. These samples were then oven dried at 102±1^{0}C until constant weight was attained.

The specific gravity was calculated as per the formula given below:

$$\text{Specific gravity} = \frac{1}{\frac{Mm - Mo}{Mo} + \frac{1}{GS}}$$

Where,

Mm = Fresh/ Green weight of the sample having maximum moisture

Mo = Oven dried constant weight of the sample

GS = Average density of wood substances, a constant, having value 1.53

Experiment 3: To study mechanical properties of *Dalbergia sissoo* wood

Species	: *Dalbergia sissoo*
No. of sites	: 10
Control (*Tectona grandis*)	: 1
Replications	: 3
Design	: CRD

Observations recorded:

i. Tensile strength (kN/mm^2)
ii. Bending strength (kN/mm^2)
iii. Compression strength parallel to grain (kN/mm^2)
iv. Compression strength perpendicular to grain (kN/mm^2)
v. Compression Modulus of elasticity (kN/mm^2)
vi. Bending Modulus of rupture (kN/mm^2)
vii. Bending Modulus of elasticity (kN/mm^2)
viii. Tensile Modulus of elasticity (kN/mm^2)

The standard size of the specimen for conducting this test was 300 mm x 10 mm x 10 mm. The computer generated data and graph from Universal Testing Machine (UTN-10) was obtained to derive the values of maximum load, maximum displacement and breaking pattern for all the samples. Utmost care was taken so that each specimen faced similar type of test measures.

i) Tensile strength (kN/mm^2)

The standard size of the specimen taken was 300 mm x 10 mm x 10 mm which was tested for bending strength on Universal Testing Machine (UTN-10) and data were recorded. Utmost care was taken so that each specimen faced similar type of test measures.

ii) Bending strength (kN/mm^2)

The standard size of the specimen taken was 300 mm x 20 mm x 20 mm which was tested for bending strength on Universal Testing Machine (UTN-10) and data were recorded. Utmost care was taken so that each specimen faced similar type of test measures.

iii) Compression strength parallel to grain (kN/mm^2)

This test was conducted in the direction parallel to the grain using Universal Testing Machine (UTN-10). The standard size of specimens for the compression test was 50 mm x 20 mm x 20 mm along the grain. All samples faced similar type of test measures.

iv) Compression strength perpendicular to grain (kN/mm^2)

The size of the specimen taken was 50 mm x 20mm x 20 mm across or perpendicular to the direction of grain and the data were recorded on Universal Testing Machine (UTN-10). Proper care was taken so that each specimen faced similar type of test measures.

v) Compression Modulus of elasticity (kN/mm^2)

The compressive strength data and graphs perpendicular to grain were used for the determination of modulus of elasticity. It was calculated as:

$$\text{Modulus of elasticity} = \frac{PL}{\Delta A}$$

Where,

P = Load at limit of proportionality in Newton (N)

L = Gauge length of the specimen in mm

Δ = Displacement at limit of proportionality in mm

A = Cross- sectional area in mm^2

a) Modulus of elasticity parallel to grain (kN/mm^2)

The compressive strength data and graphs parallel to grain were used for the determination of modulus of elasticity.

b) Modulus of elasticity perpendicular to grain (kN/mm^2)

The compressive strength data and graphs perpendicular to grain were used for the determination of modulus of elasticity

vi) Bending modulus of rupture (kN/mm^2)

The size of the specimen taken was 30x20x20 mm and the data were recorded on Universal Testing Machine (UTN-10). Care was taken so that each specimen faced similar type of test measures.

$$MOR = \frac{3PL}{2bh^2}$$

Where,

P = Maximum load (kN)

L = Length of test piece (mm)

b = Breadth of test piece (mm)

h = Thickness of test piece (mm)

vii) Bending modulus of elasticity (kN/mm^2)

The static bending strength data and graph were used for the determination of bending modulus of elasticity. It was calculated using load and displacement at limit of proportionality as follows:

$$\text{Modulus of elasticity} = \frac{PL^3}{4\Delta bh^3}$$

Where,

P = Load at limit of proportionality in Newton (N)

L = Gauge length of the specimen in mm

Δ = Displacement at limit of proportionality in mm

b = Breadth of the specimen in mm

h = Height/depth of the specimen in mm

viii) Tensile modulus of elasticity (kN/mm^2)

The static bending strength data and graph were used for the determination of bending modulus of elasticity. It was calculated using load and displacement at limit of proportionality as follows:

$$\text{Modulus of elasticity} = \frac{PL}{\Delta A}$$

Table 2. Variation in colour, texture and odour of *Dalbergia sissoo* wood from different market locations in Himachal Pradesh.

Sl. No.	Sites	Colour	Texture	Odour
1	Andreta (Kangra)	Moderate brown 200[D]	Medium	Sweet
2	Baroh (Kangra)	Moderate brown 200[D]	Coarse	Sweet
3	Galore (Hamirpur)	Moderate brown 200[D]	Coarse	Sweet
4	Kangu (Hamirpur)	Moderate brown 200[D]	Medium	Sweet
5	Nalagarh (Solan)	Moderate brown 200[C]	Medium	Sweet
6	Chowkiwala (Solan)	Moderate brown 165[A]	Coarse	Sweet
7	Dattowal (Solan)	Moderate brown 165[A]	Medium	Sweet
8	Ghumarwin (Bilaspur)	Moderate brown 200[D]	Coarse	Sweet
9	Sundernagar (Mandi)	Moderate brown 200[C]	Medium	Sweet
10	Sarahan (Sirmaur)	Moderate brown 200[D]	Medium	Sweet

Where,

P = Load at limit of proportionality in Newton (N)

L = Gauge length of the specimen in mm

Δ = Displacement at limit of proportionality in mm

A = Cross- sectional area in mm^2

Results and Discussion

Experiment 1: Identification and authentication of *Dalbergia sissoo* wood

Colour of the wood samples of Shisham collected from different market sites was matched with RHS Colour Chart {Fan 4, sixth edition (2015)} for identification purpose (Table 2). Wooden samples procured from Chowkiwala and Dattowal were found similar in colour when matched with Greyed Orange Group sheet number 165 (moderate brown [A] colour). Samples from Nalagarh and Sundernagar were found to be moderate brown [C] when matched with moderate brown colour from Brown Group with sheet number 200 whereas, rest of the wood samples were moderate brown [D] from same group and sheet number. The texture of the shisham wood varied from coarse to medium on the basis of tangential diameter of the vessels. The odour of all the shisham wood samples collected from different market sites was sweet (Table 2).

Experiment 2: Physical properties of shisham

The presence of moisture in wood makes it dimensionally unstable and it also indicates the degree of porosity in wood. The data related to moisture content of wood of Shisham collected from different sites are presented in Table 3. The

Table 3. Variation in the moisture content and maximum moisture content and specific gravity of *Dalbergia sissoo* wood from various market locations in Himachal Pradesh

Sl. No.	Site	Moisture content (%)	Maximum Moisture Content (%)	Specific gravity
1	Andreta (Kangra)	13.97 (3.87)	61.75	0.560
2	Baroh (Kangra)	13.16 (3.76)	48.93	0.604
3	Galore (Hamirpur)	13.32 (3.78)	48.07	0.604
4	Kangu (Hamirpur)	13.16 (3.76)	57.26	0.561
5	Nalagarh (Solan)	20.17 (4.60)	68.33	0.517
6	Chowkiwala (Solan)	12.82 (3.72)	60.46	0.576
7	Dattowal (Solan)	12.33 (3.65)	46.99	0.644
8	Ghumarwin (Bilaspur)	10.80 (3.44)	59.32	0.559
9	Sundernagar (Mandi)	11.30 (3.51)	55.27	0.580
10	Sarahan (Sirmaur)	12.73 (3.71)	63.46	0.546
	Mean	13.37	56.98	0.575
	SE (d)	NS	NS	0.006
	$CD_{0.05}$	NS	NS	0.012

maximum moisture content of 20.17 per cent was observed in wood samples collected from Nalagarh site and the minimum moisture content (10.80 %) was found in sample procured from Ghumarwin site. The higher maximum moisture content was observed in wood samples procured from Nalagarh site which was 68.33 per cent and the lower maximum moisture content was noticed in the wood sample from Dattowal site *i.e.,* 46.99 per cent. Specific gravity is the parameter which determines the strength of wood and gives the idea of the weight, density and porosity of wood. The data obtained on specific gravity are presented in Table 3, which revealed significant variation among Shisham wood samples collected from different sites. The maximum specific gravity (0.644) was recorded in wood from Dattowal site and the minimum specific gravity of 0.517 was observed in wood samples from Nalagarh site.

Experiment 3: Mechanical properties of shisham

The ability of any material to resist the stretching forces is its tensile strength. Wood when used for construction and other purposes ought to face these forces. Hence, this parameter reveals the ability of wood to work under such stresses. A critical analysis of the data recorded for tensile strength is presented in Table 4. Data obtained showed significant variation among samples collected from different sites. The maximum tensile strength was noticed in wood samples collected from Baroh site (0.094 kN/mm^2) which was statistically at par with samples of Galore site (0.078 kN/mm^2). The minimum tensile strength (0.030 kN/mm^2) was observed in the samples procured from site of Ghumarwin and this was statistically at par with the samples from Dattowal (0.039 kN/mm^2) and Andreta (0.032 kN/mm^2) sites.

Bending strength of wood determines its capacity to be used as beams, pillars etc**.** The data pertaining to bending strength of Shisham wood samples collected from different sites are shown in Table 4. There was no significant variation among the samples collected from different sites. The

Table 4. Variation in Tensile and Bending strength of *Dalbergia sissoo* wood from various market sources in Himachal Pradesh.

Sl. No.	Site	Tensile Strength (kN/mm^2)	Bending Strength (kN/mm^2)
1	Andreta (Kangra)	0.032	0.004
2	Baroh (Kangra)	0.094	0.006
3	Galore (Hamirpur)	0.078	0.004
4	Kangu (Hamirpur)	0.066	0.005
5	Nalagarh (Solan)	0.068	0.005
6	Chowkiwala (Solan)	0.047	0.004
7	Dattowal (Solan)	0.039	0.005
8	Ghumarwin (Bilaspur)	0.030	0.004
9	Sundernagar (Mandi)	0.055	0.006
10	Sarahan (Sirmaur)	0.076	0.004
	Mean	0.058	0.005
11	Control (Teak)	0.076	0.015
	SE (d)	0.008	NS
	$CD_{0.05}$	0.016	NS

maximum bending strength (0.006 kN/mm^2) was noticed in wood samples from Baroh and Sundernagar while the minimum tensile strength (0.004 kN/mm^2) was observed in the sites, Chowkiwala, Andreta, Galore, Ghumarwin and Sarahan. In standard teak wood samples, a bending strength value of 0.015 kN/mm^2 was noticed.

Compressive strength of wood is a vital property in timber as it subjected to compressive forces during its utilization. The data on compression strength perpendicular to grain showed significant variation among samples of Shisham wood collected from different sites as shown in Table 5. The maximum compressive strength perpendicular to grain of .038 kN/mm^2 was noticed in wood samples from Andreta site and the minimum compressive strength perpendicular to grain was recorded in samples of the Sundernagar site (0.022 kN/mm^2). In teak, compressive strength of 0.034 kN/mm^2 was observed, which was superior to all the Shisham wood samples collected from different market sites. The compression perpendicular to grain is a stress applied parallel to the length of the wood cells and is important for its application in sports goods. Compressive strength parallel to grain revealed significant variation among different Shisham wood

Table 5: Variation in compression strength perpendicular and parallel to grain (kN/mm^2) of shisham wood from various market sources in Himachal Pradesh.

Sl. No.	Site	Compression perpendicular to grain (kN/mm^2)	Compressionparallel to grain(kN/mm^2)
1	Andreta (Kangra)	0.038	0.064
2	Baroh (Kangra)	0.031	0.069
3	Galore (Hamirpur)	0.033	0.062
4	Kangu (Hamirpur)	0.029	0.062
5	Nalagarh (Solan)	0.029	0.056
6	Chowkiwala (Solan)	0.023	0.061
7	Dattowal (Solan)	0.025	0.053
8	Ghumarwin (Bilaspur)	0.023	0.063
9	Sundernagar (Mandi)	0.022	0.065
10	Sarahan (Sirmaur)	0.032	0.046
	Mean	0.028	0.060
11	Control (Teak)	0.034	0.067
	SE (d)	0.002	0.003
	$CD_{0.05}$	0.003	0.006

collected from the respective sites (Table 5). The data showed the highest compressive strength parallel to grain in wood samples from Baroh site (0.069 kN/mm^2), which was statistically at par with the sites of Andreta (0.064 kN/mm^2), Ghumarwin (0.063 kN/mm^2) and Sundernagar (0.065 kN/mm^2) while the lowest compressive strength perpendicular to grain (0.046 kN/mm^2) was noticed in Sarahan site. Teak showed compressive strength of 0.067 kN/mm^2.

Elasticity of the wood is its level of retention of original size and shape. Hence, determination of wood elasticity has great significance in finding its suitability for specific uses. The data on modulus of elasticity (MOE) perpendicular to grain are presented in Table 6. The maximum value for modulus of elasticity perpendicular to grain among samples of Shisham wood collected from the sites was observed for Ghumarwin site *i.e.*, 1.653 kN/mm^2 while the minimum (0.827 kN/mm^2) modulus of elasticity (MOE) was noticed in wood samples from Sarahan site. The modulus of elasticity in teak wood samples was found to be 0.717 kN/mm^2. Table 6 revealed significant variations in the values of modulus of elasticity (MOE) parallel to grain.

Table 6. Variation in Compression Modulus of Elasticity perpendicular and parallel to grain (kN/mm^2) of shisham wood from various market sources in Himachal Pradesh.

Sl. No.	Site	MOE perpendicular to grain(kN/mm^2)	MOE parallel to grain (kN/mm^2)
1	Andreta (Kangra)	1.247	0.107
2	Baroh (Kangra)	1.346	0.142
3	Galore (Hamirpur)	0.861	0.140
4	Kangu (Hamirpur)	0.933	0.100
5	Nalagarh (Solan)	1.199	0.231
6	Chowkiwala (Solan)	0.950	0.145
7	Dattowal (Solan)	0.838	0.196
8	Ghumarwin (Bilaspur)	1.653	0.163
9	Sundernagar (Mandi)	0.948	0.152
10	Sarahan (Sirmaur)	0.827	0.097
	Mean	1.080	0.147
11	Control (Teak)	0.717	0.082
	SE (d)	0.090	0.016
	$CD_{0.05}$	0.188	0.032

Among all the wood samples collected from different sites, the maximum modulus of elasticity parallel to grain was recorded for Nalagarh site (0.231 kN/mm^2) while the minimum modulus of elasticity (MOE) was noticed for Sarahan site (0.097 kN/mm^2). The modulus of elasticity in teak wood samples was recorded as 0.082 kN/mm^2.

Modulus of Rupture (MOR) is a measure of a wood specimen strength towards rupture. It can be used to determine overall strength of wood species; unlike the modulus of elasticity, which measures the deflection of wood. Significant variation was observed in modulus of rupture among different species from different sites which could be attributed to variable cellular composition of woods. The data on modulus of rupture (MOR) are presented in Table 7. The maximum value of modulus of rupture among Shisham wood samples collected from the different sites was observed for Sundernagar site (0.116 kN/mm^2) while the minimum value for modulus of rupture was noticed for Sarahan site (0.081 kN/mm^2). The maximum bending modulus of rupture (0.242 kN/mm^2) was observed in teak wood samples collected from Solan market. Variation in elongation (%) in wood samples of Shisham wood collected from different sites may be due to the difference in alignment of the cells. The total elongation also depends upon the length of the gauge and also upon the species. The data on elongation of Shisham wood collected from the different sites are presented in Table 7. The maximum value for elongation in bending test (3.867 %) was noticed in the site of Nalagarh and the minimum value was observed in Sarahan site (2.167 %). The maximum value for elongation in tension test was recorded in the Sarahan site (3.300 %) which was statistically at par with the sites of Baroh (3.000 %), Kangu (2.833 %), Nalagarh (2.867 %) and Galore (2.933 %) while the minimum value was noticed for Andreta site (1.433 %).

The data pertaining to bending modulus of elasticity of Shisham wood collected from the different sites are presented in Table 8. The maximum value for bending modulus of elasticity was observed for the Kangu site (10.369 kN/mm^2) while the minimum value was noticed for Nalagarh site (6.935 kN/mm^2). The maximum value was observed in the samples of teak *i.e.,* 15.264 kN/mm^2. The data pertaining to tension modulus of elasticity of Shisham wood samples collected from the different sites are presented in Table 8. The maximum value for tensile modulus of elasticity among Shisham wood samples was observed for Baroh site (2.876 kN/mm^2) while the minimum value was noticed for Ghumarwin site (1.853 kN/mm^2). The maximum value was observed in the samples of teak (2.990 kN/mm^2).

Table 7. Variation in Bending Modulus of Rupture (kN/mm^2), elongation (%) in tension and bending (kN/mm^2) of shisham wood from various market sources in Himachal Pradesh.

Sl. No.	Site	Modulus of Rupture static bending test(kN/mm^2)	Elongation Static Bending test (%)	Elongation Tension test (%)
1	Andreta (Kangra)	0.089	2.333	1.433
2	Baroh (Kangra)	0.113	3.100	3.000
3	Galore (Hamirpur)	0.098	2.367	2.933
4	Kangu (Hamirpur)	0.104	2.800	2.833
5	Nalagarh (Solan)	0.097	3.867	2.867
6	Chowkiwala (Solan)	0.084	2.267	1.820
7	Dattowal (Solan)	0.099	2.800	1.600
8	Ghumarwin (Bilaspur)	0.088	2.767	1.533
9	Sundernagar (Mandi)	0.116	3.177	2.333
10	Sarahan (Sirmaur)	0.081	2.167	3.300
	Mean	0.097	2.764	2.365
11	Control(Teak)	0.242	3.087	2.443
	SE (d)	0.011	0.004	0.003
	$CD_{0.05}$	0.024	0.008	0.006

Table 8. Variation in Tensile and Bending Modulus of Elasticity (kN/mm^2) of shisham wood from various market sources in Himachal Pradesh.

Sl. No.	Site	Bending MOE (kN/mm^2)	Tensile MOE (kN/mm^2)
1	Andreta (Kangra)	8.591	2.052
2	Baroh (Kangra)	8.921	2.876
3	Galore (Hamirpur)	9.283	2.536
4	Kangu (Hamirpur)	10.369	2.246
5	Nalagarh (Solan)	6.935	2.329
6	Chowkiwala (Solan)	7.188	2.365
7	Dattowal (Solan)	8.716	2.229
8	Ghumarwin (Bilaspur)	7.891	1.853
9	Sundernagar (Mandi)	9.199	2.328
10	Sarahan (Sirmaur)	9.297	2.222
	Mean	8.639	2.304
11	Control (Teak)	15.264	2.990
	SE (d)	NS	0.202
	$CD_{0.05}$	NS	0.421

Chowkiwala and Dattowal wood samples were found to match in colour with Greyed Orange Group of sheet number 165 *i.e.*, moderate brown [A] colour. The texture of the Shisham wood samples from the sites of Andreta, Kangu, Nalagarh, Dattowal, Sundernagar and Sarahan were of medium type and coarse type wood samples were collected from the sites of Baroh, Chowkiwala, Galore and Ghumarwin. The maximum specific gravity was observed for the wood procured from Dattowal site (0.644). The maximum tensile strength was recorded for the wood taken from Baroh site whereas maximum bending strength was for Baroh and Sundernagar sites. The maximum compressive strength parallel to grain was noticed for Andreta site and maximum compressive strength perpendicular to grain was for Baroh site. The maximum modulus of elasticity parallel to grain was observed for Ghumarwin site and modulus of elasticity perpendicular to grain was recorded for Nalagarh site. The maximum modulus of elasticity in bending was observed for Baroh site and modulus of elasticity in tension was recorded for Kangu site. The maximum elongation in bending was observed for Nalagarh site and maximum elongation in tension noticed for Sarahan site. So based on the above obtained results, it could be concluded that the shisham wood from the sites of Dattowal, Baroh and Ghumarwin showed better performance and could be recommended for use in different applications.

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