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Heartwood-Sapwood-Bark profiles and association studies in *Pterocarpus marsupium* Roxb., a vulnerable antidiabetic forestry species of sub- tropical forest

Perfis de Cerne-alburno-Casca e estudos de associação em *Pterocarpus marsupium* Roxb., uma espécie florestal antidiabética vulnerável de floresta subtropical

Naseer Mohammad[1], Sengodan Saravanan[2], Fatima Shirin[1]

[1]Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India

[2]Institute of Forest Genetics and Tree Breeding, Coimbatore, Tamil Nadu, India

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Abstract

Pterocarpus marsupium Roxb. is a multipurpose forestry species of the sub-tropical region of the Indian subcontinent and its heartwood is known for excellent antidiabetic properties. However, due to unsustainable extraction, its populations are dwindling in natural ranges. In the present investigation, we studied the variations of heartwood and related characters in populations sampled from central India. For this, we sampled populations from different sites falling in mixed and sal forest of the central Indian state of Madhya Pradesh. Adaptive cluster sampling was followed for selection of study sites. Wood core samples were extracted at breast height using a Haglof three-thread increment borer. For each core, we measured bark thickness, sapwood thickness, heartwood diameter (cm), bark (%), sapwood (%), heartwood (%), sapwood area, heartwood area, sapwood area to heartwood area ratio and cross-sectional area. The analysis revealed that bark thickness ranged from 1.0 – 3.6 cm with an average of 2.21 cm; sapwood thickness from 2.0 – 12.0 cm with an average of 6.16 cm; heartwood diameter from 7.29 – 102.19 cm with an average of 36.77 cm. Bark, sapwood and heartwood percentages at breast height ranged from 1.37-31.9%, 1.96-45.97%, 39.23-96.68% with a mean value of 6.34%, 17.80% and 75.86%, respectively. Sapwood area, heartwood area and cross section area at breast height was also estimated and these parameters ranged from 39.76–1043 cm^2, 41.68–8197.6 cm^2 and 161.2–9476.5 cm^2, respectively. Despite its vulnerable status, *P. marsupium* populations recorded high variations for heartwood and related parameters. Correlation and path coefficient analysis revealed that bark (%), sapwood (%) and cross-sectional area are the most significant characters having a bearing on the heartwood percentage and could be utilised for selection, improvement and exploitation of heartwood.

Keywords: Bijasar; Heartwood; Variation; Conservation; Indian kino.

Resumo

Pterocarpus marsupium Roxb. é uma espécie florestal polivalente da região subtropical do subcontinente indiano e seu cerne é conhecido por excelentes propriedades antidiabéticas. No entanto, devido à extração insustentável, suas populações estão diminuindo em áreas naturais. Na presente investigação, estudamos as variações do cerne e caracteres relacionados em populações amostradas na Índia central. Para este estudo, amostramos populações de diferentes locais em floresta mista e floresta de *Shorea robusta* Gaertn do estado

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central da Índia de Madhya Pradesh. A amostragem por conglomerados adaptativos foi seguida para a seleção dos locais de estudo. Baguetas de madeira foram extraídas na altura do peito usando trado de incremento de três fios Haglof. Para cada bagueta de madeira foram mensurados as características de cerne, alburno e casca. A análise revelou que a espessura da casca variou de 1,0 - 3,6 cm com uma média de 2,21 cm; espessura do alburno de 2,0 - 12,0 cm com média de 6,16 cm; diâmetro do cerne da madeira de 7,29 - 102,19 cm com uma média de 36,77 cm. A porcentagem de casca, alburno e cerne na altura do peito variou de 1,37-31,9%, 1,96-45,97%, 39,23-96,68% com um valor médio de 6,34%, 17,80% e 75,86%, respectivamente. A área do alburno, a área do cerne e a área da seção transversal na altura do peito também foram estimadas e variaram de 39,76–1043 cm^2, 41,68–8197,6 cm^2 e 161,2–9476,5 cm^2, respectivamente. A análise de correlação e do coeficiente de trilha revelou que a casca (%), o alburno (%) e a área da seção transversal são os caracteres mais significativos que influenciam a porcentagem do cerne. Apesar do status vulnerável, as populações de *P. marsupium* apresentam alta variação para cerne e parâmetros relacionados. A casca (%), o alburno (%) e a área da seção transversal têm influência significativa na porcentagem do cerne. Portanto, esses caracteres podem ser utilizados para seleção, melhoramento e exploração do cerne.

Palavras-chave: Bijasar; Cerne; Variação; Conservação; Kino indiano.

INTRODUCTION

Pterocarpus marsupium Roxb., commonly called Bijasar, Vijaysar, Indian Kino or Malabar Kino belongs the Fabaceae family. It is a large deciduous, medicinally important forest tree of the sub-tropical region. It is native to India, Bangladesh and Nepal (Devgun et al., 2009). In India, it is widely distributed in the central, western and southern regions, chiefly in dry deciduous tropical forests of Madhya Pradesh, Maharashtra, Chhattisgarh, Odisha, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, West Bengal and Uttar Pradesh (Kirtikar & Basu, 1999). *P. marsupium* has a reputation for its excellent medicinal value, especially its antidiabetic properties and is also known as for quality timber (Mishra et al., 2014).

All parts of *P. marsupium* have been used against various ailments since ages such as leaves for boils, sores, skin diseases and stomach pain; flowers for fever; gum-kino for diarrhea, dysentery, leucorrhoea etc. and bark as astringent & for toothache, bark and resin for the treatment of tumours of the gland, urethral discharges and as abortifacient (Pullaiah, 1999; Pharmacopoeia Commission for Indian Medicine & Homoeopathy, 2001). Phytochemical investigations have established that it contains an array of chemicals including pterosupin, pterostilbene, liquirtigenin, isoliquiritigenin, epicatechin, kinoin, kinotannic acid, kino-red beta-eudesmol, carsupin, marsupol, marsupinol etc., and therefore finds place in the Ayurveda, Unani and Homeopathic systems of medicine (Dhayaney & Sibi, 2019).

However, *P. marsupium* is known worldwide for the antidiabetic properties of its heartwood (Kirtikar & Basu, 1999) and is referred to as 'the miracle cure for diabetes' (Handa et al., 2000; Maurya et al., 2004). Pharmacological investigations have found that its heartwood contains pterostilbene and marsupin (Mathew et al., 1977; Maurya et al., 1984) which are found to be effective against hyperglycemia in comparison with metformin (Manickam et al., 1997).

Natural populations of *P. marsupium* are being reduced in their natural ranges due to over-exploitation (Wilkins, 1991). Poor regeneration of the species also aggravated the situation and thus, it has been included in IUCN Red List of Threatened Species (Barstow, 2017). Therefore, steps to characterise and conserve the natural populations of this valuable species in its natural habitat need to be prioritized.

Hence, the present study was carried out to assess the heartwood, softwood and bark proportions in different populations of *P. marsupium* from central India. Inter-character correlation between heartwood and other associated parameters were also assessed. This will help in targeting the appropriate populations for conservation as well as for the selection of genotypes with higher value of economically important traits.

MATERIAL AND METHODS

For this study, we sampled 133 trees from seven different sites falling in mixed and sal forests of the central Indian state i.e., Madhya Pradesh (Figure 1). Adaptive cluster sampling was followed for selection of sampling sites. Average girth of the sampled trees ranged from

74.25 to 249.44 cm (Table 1). Wood core samples were extracted at breast height using the Haglof three-thread increment borer (Ben Meadows Company, USA) in two perpendicular directions. Following Lehnebach et al. (2017), we measured bark thickness (Bt_1 + Bt_2 in mm converted to cm), sapwood thickness (SWt_1+SWt_2 in mm converted to cm), heartwood diameter (cm), bark percentage (%), sapwood percentage (%), heartwood percentage (%), sapwood area (cm^2), heartwood area (cm^2) sapwood to heartwood area ratio (SWa: HWa), cross-sectional area (cm^2) for each wood core (Figure 2, Table 2).

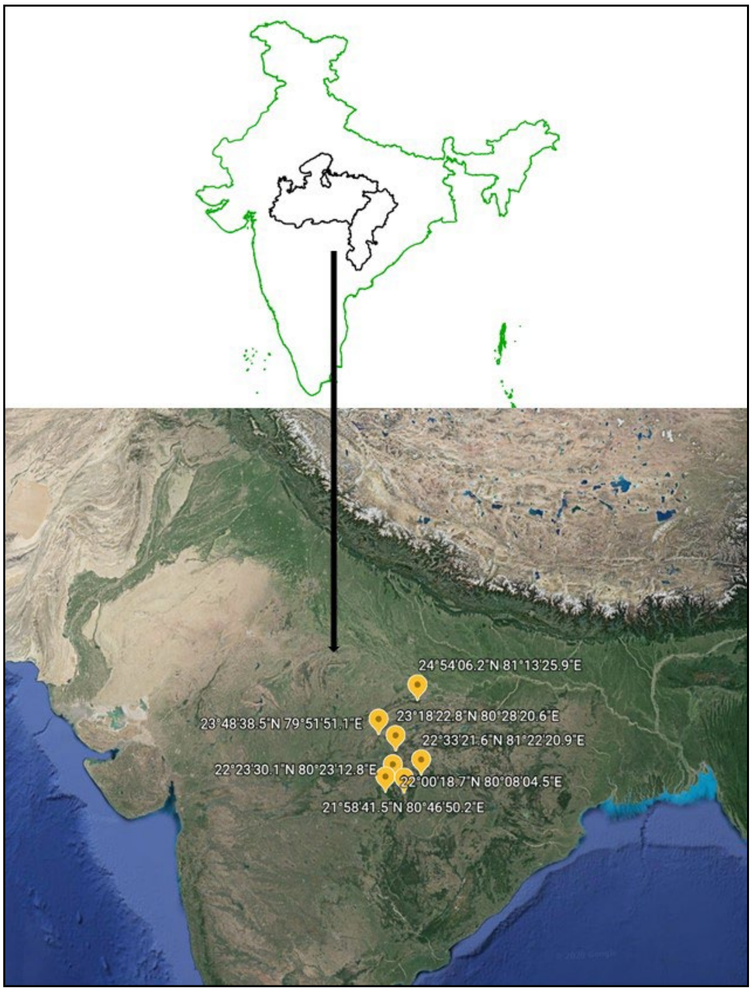

Figure 1. Map displaying sampled locations of *P. marsupium* Roxb. from central India

Table 1. Details of the study sites and sample size selected for heartwood-sapwood-bark profiles and association study.

Sl. no	Study site& Compartment Number	Forest Division	Forest Types (Sub-group)	GPS Coordinates	No of trees sampled	Avg. GBH (cm)
1.	Sara (RF-324)	Mandla	Southern Tropical Dry Deciduous Mixed Forests	22^0 23′ 30.1″ N 80^0 23′ 12.8″ E	18	106.52
2.	Birsa (P-1671)	Balaghat	Northern Tropical Moist Deciduous Forests	21^0 58′ 41.5″ N 80^0 46′ 50.2″ E	17	249.44
3.	Lamta (P-1388)	Balaghat	Northern Tropical Moist Mixed Deciduous Forests	22^0 00' 18.7″ N 80^0 08′ 04.5″ E	20	123.60
4.	Barha (RF-259)	Jabalpur	Southern Tropical Dry Deciduous Teak Forests	23^0 18′ 22.8″ N 80^0 28′ 20.6″ E	12	159.32
5.	Chada (RF-563)	Dindori	Tropical Dry high-level Sal Forest	22^0 33′ 21.6″ N 81^0 22′ 20.9″ E	20	223.25
6.	Bahoriband (P-189)	Katni	Southern Tropical Dry Mixed Deciduous Forests	23^0 48′ 38.5″ N 79^0 51′ 51.1″ E	20	76.00
7.	Semariya (P-166)	Rewa	Northern Dry Mixed Deciduous Forests	24^0 54′ 06.2″ N 81^0 13′ 25.9″ E	26	74.25

Figure 2. Extraction of wood core samples using Haglöf increment borer and recording of wood core data of *P. marsupium*

Table 2. Details of the heartwood, sapwood and bark related parameters estimated for variation and association study.

Sl. No.	Parameters	Abbreviations used	Formulae
1.	Bark thickness (cm)	BKt	$Bt_1 + Bt_2$
2.	Sapwood thickness (cm)	SWt	$SWt_1 + SWt_2$
3.	Heartwood diameter (cm)	HWd	$DBH - (SWt_1 + SWt + Bt_1 + Bt_1)$
4.	Bark Percentage (%	BK (%)	(BKt/DBH) *100
5.	Sapwood (%)	SW (%)	(SWt/DBH) *100
6.	Heartwood (%)	HW (%)	(HWd/DBH) *100
7.	Sapwood Area (cm^2)	SWa	$[DBH/2 - \mu (Bt_{1,} Bt_2)] * \pi - HWa$
8.	Heartwood Area (cm^2)	HWa	$\pi * (HWd/2)^2$
9.	Sapwood area to heartwood area ratio	SWa: HWa	SWa / HWa
10.	CSA (cm^2)	CSA	$\pi * (DBH/2)^2$

Descriptive statistics i.e., mean, standard deviation, standard error, median, range, mean absolute deviation, coefficient of variation and coefficient of dispersion were worked out using SYSTAT Version 13.2 (Systat Software, 2021). The correlation coefficients between all possible pairs of characters were estimated according to the method given by Searle (1961). The significance of correlation coefficients (r) was tested by comparing with 't' value at (n–2) degrees of freedom (Snedecor & Cochran, 1967). The correlation coefficients obtained from the correlation study were further partitioned into direct and indirect effects with the help of path coefficient analysis, as suggested by Wright (1921) and applied in plant breeding by Dewey & Lu (1959). Heartwood percentage was considered as a dependent variable and was assumed to be influenced by the other characters called independent variables. Statistical software Windostat Version 9.2 (Indostat, Hyderabad, India) was used for correlation and path coefficient analysis.

RESULTS AND DISCUSSION

Critical perusal of the data revealed that heartwood diameter (65%), bark percentage (60%), sapwood percentage (60%) and sapwood area (61%) had very high CVs (Table 3). Further, heartwood percentage, heartwood area, SWa:HWa ratio and cross-sectional area at breast height recorded moderate CVs. Estimates of bark thickness and sapwood thickness fall in the high CV category. Since the coefficient of variation shows the extent of variability of data in a sample in relation to the mean of the population, traits having high CVs can be included in the selection criteria of *P. marsupium* (Mohammad et al., 2020).

For better visualization and understanding, population-wise analysis of data was also carried out and presented in Table 4. The analysis revealed that heartwood percentage, heartwood diameter, heartwood area and CSA was found to be highest in the Birsa population followed by the Chada population and therefore had the lowest value for SWa:HWa ratio, which was also observed in Birsa followed by Chada; as SWa:HWa is negatively correlated with HW percentage. Sapwood thickness and sapwood percentage was highest in the Sara population, whereas the lowest were recorded in the Birsa population. Bark thickness was recorded highest in Birsa followed by Sara and Bahoriband population. Bahoriband and Semariya populations which are relatively younger compared to the other five populations recorded lowest values for bark thickness, sapwood thickness, sapwood area heartwood diameter, heartwood area and cross-sectional area.

Table 3. Descriptive statistics of wood core traits of *P. marsupium* Roxb. sampled from Central India

Character	Mean	Standard Deviation	Standard Error	Median	Range	Mean Absolute Deviation	Coefficient of Variation	Coefficient of Dispersion
Bark thickness (cm)	2.21	0.49	0.04	2.00	01-3.6	0.38	0.22	0.16
Sapwood thickness (cm)	6.16	2.02	0.18	6.00	02-12	1.60	0.33	0.26
Heartwood dia (cm)	36.77	24.00	2.13	26.54	7.29-102.19	20.58	0.65	0.75
Bark (%)	6.34	3.79	0.34	5.89	1.37-31.9	2.73	0.60	0.46
Sapwood (%)	17.80	10.62	0.94	15.32	1.96-45.97	8.71	0.60	0.56
Heartwood (%)	75.86	13.29	1.18	78.87	39.23-96.68	11.08	0.18	0.14
Sapwood Area (cm²)	372.59	225.98	20.05	310.88	39.76-1043.82	189.42	0.61	0.60
Heartwood Area (cm²)	1510.02	1798.06	159.55	552.72	41.68-8197.56	1407.51	1.19	2.29
SWa:HWa	0.67	0.67	0.06	0.44	0.04-3.67	0.48	1.00	1.00
CSA (cm²)	2038.57	2055.92	182.43	1016.64	161.23-9476.51	1650.06	1.01	1.48

Where, SWa: HWa - ratio of sapwood area to heartwood area, CSA – cross sectional area, and measurements of wood traits (Sr. no. 8 to 17) are at breast height.

Table 4. Population-wise estimates of the descriptive indices for wood core traits of *P. marsupium* Roxb. sampled from Central India

Variable	Statistic	Population						
		Sara	Birsa	Lamta	Barha	Chada	Bahoriband	Semariya
Bark thickness (cm)	**Mean**	2.30	2.55	2.16	2.05	2.27	1.99	2.13
	SE	0.09	0.14	0.10	0.10	0.08	0.08	0.13
	CV	0.17	0.24	0.20	0.17	0.16	0.19	0.27
Sapwood thickness (cm)	**Mean**	9.03	5.14	5.86	5.86	6.38	5.17	5.7
	SE	0.38	0.39	0.47	0.42	0.27	0.25	0.42
	CV	0.18	0.31	0.36	0.25	0.18	0.22	0.33
Heartwood dia (cm)	**Mean**	22.59	71.74	31.34	42.82	62.44	17.04	15.66
	SE	3.42	4.65	2.42	3.83	2.61	1.09	1.15
	CV	0.64	0.26	0.34	0.31	0.18	0.28	0.33
Bark (%)	**Mean**	7.40	3.57	5.89	4.49	3.27	8.60	10.09
	SE	0.49	0.46	0.48	0.64	0.18	0.56	1.28
	CV	0.28	0.53	0.36	0.49	0.24	0.29	0.57
Sapwood (%)	**Mean**	30.28	7.19	15.55	13.08	9.21	22.17	24.85
	SE	2.56	1.02	1.30	2.25	0.55	1.44	2.13
	CV	0.35	0.58	0.37	0.59	0.26	0.29	0.38
Heartwood (%)	**Mean**	62.30	89.23	78.55	82.42	87.51	69.21	65.05
	SE	2.98	1.46	1.62	2.87	0.69	1.93	2.46
	CV	0.20	0.06	0.09	0.12	0.03	0.12	0.16
Sapwood Area (cm²)	**Mean**	361.16	576.91	324.49	418.47	651.05	158.76	165.08
	SE	27.01	43.59	46.52	45.70	30.13	11.54	15.37
	CV	0.31	0.31	0.64	0.37	0.20	0.32	0.41
Heartwood Area (cm²)	**Mean**	557.32	4313.12	859.01	1566.79	3163.06	246.04	212.65
	SE	196.44	494.61	142.54	234.17	301.94	29.37	31.60
	CV	1.49	0.47	0.74	0.51	0.42	0.53	0.66
SWa:HWa	**Mean**	1.43	0.17	0.46	0.41	0.22	0.81	1.07
	SE	0.19	0.03	0.05	0.13	0.01	0.10	0.18
	CV	0.59	0.81	0.51	1.10	0.32	0.55	0.76
CSA (cm²)	**Mean**	1038.61	5192.69	1313.59	2146.08	4061.38	477.03	456.69
	SE	231.32	515.06	190.25	279.05	325.41	39.02	44.87
	CV	0.94	0.40	0.64	0.45	0.35	0.36	0.43
DBH (cm)	**Mean**	33.90	79.44	39.36	50.73	71.09	24.20	23.64
	SE	3.18	4.35	2.55	3.80	2.49	1.07	1.09
	CV	0.39	0,22	0,29	0,25	0.15	0.19	0.20

Mohammad et al. (2022) investigated the morphological and molecular diversity of *P. marsupium* from the same region and reported a large amount of variation (34-58% CV) for different morphological metric traits. Further, molecular diversity analysis using DNA markers also detected 76.7% of polymorphism. This morphological molecular variation may have formed the basis for large variations recorded in the present investigation for heartwood, sapwood, and bark traits. It is also relevant to note that *P. marsupium* is a predominantly cross pollinating species and this could also have contributed to the high variation for wood traits.

Economically important character in any tree/crop depends on many characters which influence it either jointly or singly and either directly or indirectly through other related characters (Kumar & Gurumurthi,1996). Therefore, selection for economic trait on the basis of *per se* performance alone may not be effective as it gets influenced by component characters associated with it. Heartwood formation is known to be affected by many factors including biochemical, environmental and component characters (Leite et al., 2011; Miranda et al., 2011; Moya, 2001; Moya et al., 2013). Therefore, the correlation between all the studied traits were computed (Table 5). A close examination of the correlation analysis of the studied traits revealed that heartwood percentage is positively correlated with the heartwood diameter, heartwood area, sapwood area and cross-sectional area. Bark traits i.e., thickness and bark percentage exhibited a negative correlation with heartwood percentage. Furthermore, bark thickness and softwood thickness showed positive correlation with each other, while they have significantly negative relationship with heartwood diameter. Cross sectional area at breast height, which is an easily measurable character exhibited strong negative correlation with bark and softwood percentage while showing a positive relation with heartwood diameter and percentage. For a close examination of the relationship of heartwood percentage with other traits, it was plotted against each character (Figure 3). It is irrefutably clear that heartwood percentage has a significantly negative relationship with sapwood percentage, SWa:HWa and bark percentage, whereas CSA, HWd and SWa have a positive relationship.

Table 5. Inter-character correlation between different wood core traits of *P. marsupium* Roxb. sampled from Central India

	Bark thickness (cm)	SW thickness (cm)	HW Dia (cm)	Bark (%)	SW (%)	HW (%)	SW Area (cm^2)	HW Area (cm^2)	SWa:HWa	CSA (cm^2)
Bark thickness (cm)	1.00									
Sapwood thickness (cm)	0.30**	1.00								
Heartwood dia (cm)	0.11^{ns}	-0.21*	1.00							
Bark (%)	0.29**	0.07^{ns}	-0.72**	1.00						
Sapwood (%)	0.01^{ns}	0.61**	-0.79**	0.62**	1.00					
Heartwood (%)	-0.09^{ns}	-0.51**	0.84**	-0.78**	-0.97**	1.00				
Sapwood Area (cm^2)	0.29**	0.31	0.82**	-0.63**	-0.50**	0.58**	1.00			
Heartwood Area (cm^2)	0.08^{ns}	-0.22	0.97**	-0.62**	-0.69**	0.73**	0.75**	1.00		
SWa:HWa (cm^2)	0.05^{ns}	0.57	-0.66**	0.59**	0.95**	-0.93**	-0.43**	-0.54**	1.00	
CSA (cm^2)	0.12^{ns}	-0.16	0.98**	-0.64**	-0.69**	0.73**	0.81**	1.00**	-0.54**	1.00

Where, *significant at 5% level of significance, ** significant at 1% level of significance, ns- non significant

Path coefficient analysis was also carried out taking heartwood percentage as dependent and the rest of the analysed characters as independent variables (Figure 4). Path analysis is a useful tool to break up correlation coefficients into direct and indirect effects (Omokhafe, 2001). Path analysis enhanced the practical utility of correlation coefficient because the observed correlation between the two characters may be due to the influence of other characters (Mohammad et al., 2013a). Among the positively correlated traits, all the traits have a high indirect effect with softwood percentage, whereas their direct effect on the heartwood percentage is minimal. Critical perusal of path diagram also revealed that among the negatively correlated traits, sapwood and bark percentages have a high direct effect on heartwood percentage; while the remaining traits have a negative correlation via SW (%) and Bark (%). Thus, partitioning of correlation in to direct and indirect effect through path analysis revealed that sapwood and bark percentage significantly affect the dependent character i.e., heartwood percentage.

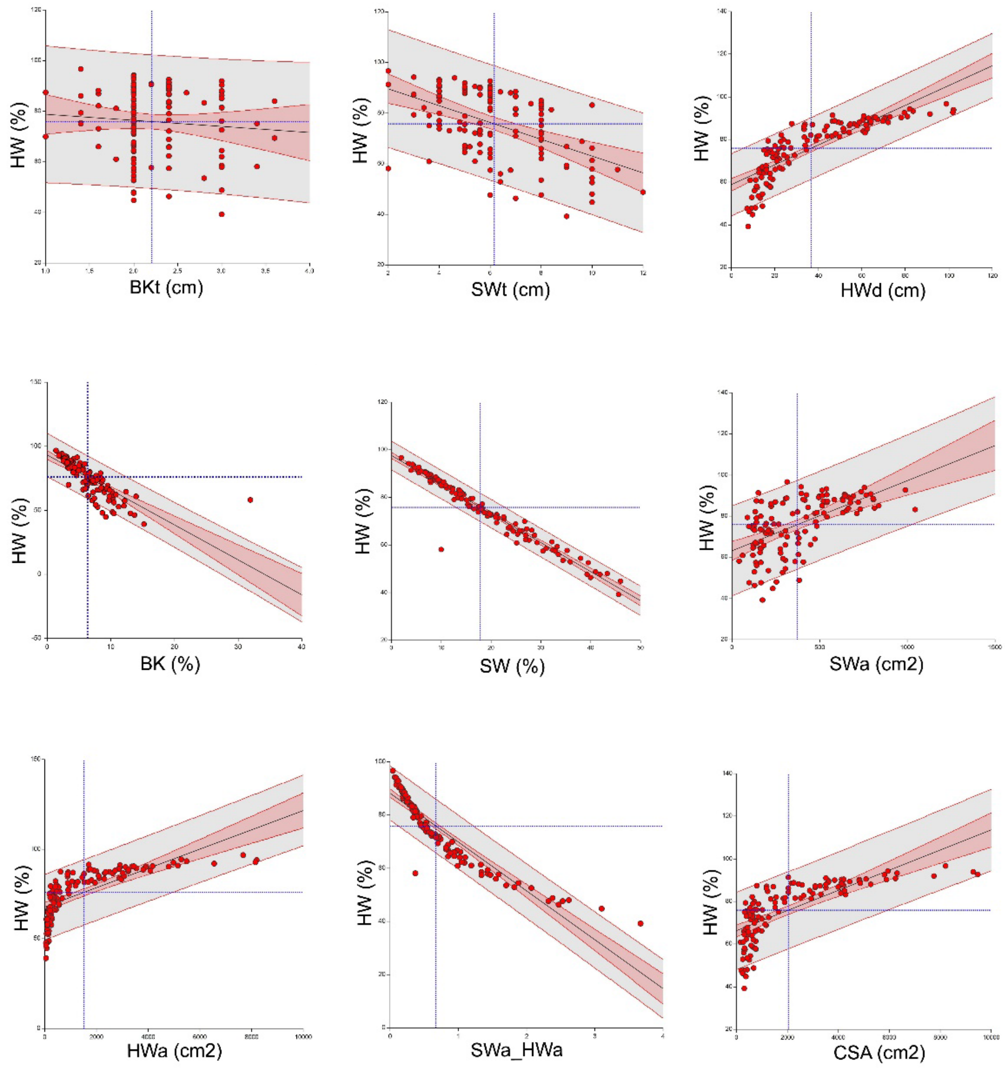

Figure 3. Relationship between HW(%) and Bark thikness (cm), Sapwood thichness (cm), Heartwood dia (cm), bark (%), Sapwood percentage (%), Sapwood area (cm^2), Heatwood area (cm^2), Ratio of SWa:HWa, Cross Sectional Area (cm^2), respectively.

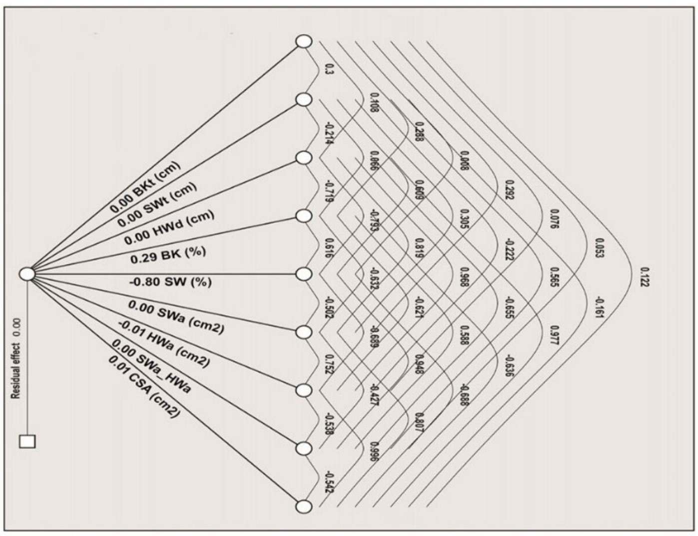

Figure 4. Path coefficinet analysis for heartwood percentage (where, BKt-Bark thikness, SWt-Sapwood thichnes, HWd- Heartwood diameter, BK- bark percentage, SW - Sapwood percentage, SWa - Sapwood area, HWa - Heatwood area, SWa_HWa - SWa:HWa Ratio & CSA - Cross Sectional Area (cm^2)

Therefore, these traits can be used as indicator traits for the comparative assessments of heartwood percentage in a population before exploitation as well as for conservation of genetic resources of *P. marsupium.* Earlier, Rathinathan et al. (1982), Espahbodi et al. (2008) and Chavan et al. (2011), Mohammad et al. (2013b) employed a similar strategy in *Eucalyptus tereticornis, Sorbus torminalis, Casuarina* spp. and *Strychnox nux-vomica* for assessment of inter-character correlation and development of selection criteria.

CONCLUSION

From the results of the present investigation, it is concluded that despite its vulnerable status, *P. marsupium* populations have high variation for heartwood and related parameters. Also; bark percentage, sapwood percentage and cross-sectional area were found to be key traits having significant bearing on the heartwood percentage. Therefore, these characters could be utilized for selection, improvement and exploitation of heartwood.

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REFERENCES

Barstow, M. (2017). *Pterocarpus marsupium*. The IUCN Red List of Threatened Species, e.T34620A67802995. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T34620A67802995.en.

Chavan, R., Viswanath, S., & Shivanna, H. (2011). Correlation and path coefficient analysis in five *Casuarina* species for productivity of biomass. *Karnataka Journal of Agricultural Sciences*, *24*(5), 678-680.

Devgun, M., Nanda, A., &Ansari, S. H. (2009). *Pterocarpus marsupium* Roxb. A comprehensive review.*Pharmacognosy Reviews*, *3*(6), 359-363.

Dewey, O. R., & Lu, K. H. (1959). A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal*, *51*(9), 515-518. http://dx.doi.org/10.2134/agronj1959.00021962005100090002x.

Dhayaney, V., & Sibi, G. (2019). *Pterocarpus marsupium* for the treatment of diabetes and other disorders. *Journal of Complementary Medicine and Alternative Healthcare*, *9*(1), 555754.

Espahbodi, K., Mirzaie-Nodoushan, H., Tabari, M., Akbarinia, M., Dehghan-Shuraki, Y., & Jalali, S. G. (2008). Genetic variation in early growth characteristics of two populations of wild service tree (*Sorbus torminalis* L. Crantz) and their interrelationship. *Silvae Genetica*, *57*(1-6), 340-348. http://dx.doi.org/10.1515/sg-2008-0050.

Handa, S. S., Singh, R., Maurya, R., Satti, N. K., Suri, K. A., & Suri, O. P. (2000). Pterocarposide, an isoaurone C-glucoside from *Pterocarpus marsupium.Tetrahedron Letters*, *41*(10), 1579-1581. http://dx.doi.org/10.1016/S0040-4039(99)02334-5.

Kirtikar, K. R., & Basu, B. D. (1999). *Indian medicinal plants* (Vol. 1). Kolkata: Naya Prakashan.

Kumar, A., & Gurumurthi, K. (1996). Path coefficient studies on morphological traits in *Casuarina equisetifolia. Indian Forester*, *122*(8), 727-730.

Lehnebach, R., Morel, H., Bossu, J., Moguédec, G., Amusant, N., Beauchêne, J., & Nicolini, E. (2017). Heartwood/sapwood profile and the tradeoff between trunk and crown increment in a natural forest: the case study of a tropical tree (*Dicorynia guianensis* Amsh., Fabaceae). *Trees*, *31*(1), 199-214. http://dx.doi.org/10.1007/s00468-016-1473-7.

Leite, H. G., Silva, M. L. M., Binoti, D. H. B., Fardin, L., & Takizawa, F. H. (2011). Estimation of inside-bark diameter and heartwood diameter for *Tectona grandis* Linn. trees using artificial neural networks. *European Journal of Forest Research*, *130*(2), 263-269. http://dx.doi.org/10.1007/s10342-010-0427-7.

Manickam, M., Ramanathan, M., Jahromi, M. A., Chansouria, J. P., & Ray, A. B. (1997). Antihyperglycemic activity of phenolics from *Pterocarpus marsupium. Journal of Natural Products*, *60*(6), 609-610. PMid:9214733.http://dx.doi.org/10.1021/np9607013.

Mathew, J., Rao, A. V. S., & Rao, N. V. S. (1977). Photooxidation of pterostilbene from *Pterocarpus marsupuim* Roxb. *Current Science*, *46*, 337-338.

Maurya, R., Ray, A. B., Duah, F. K., Slatkin, D. J., &Schiff Junior, P. L. (1984). Constituents of *Pterocarpus marsupium. Journal of Natural Products*, *47*(1), 179-181. http://dx.doi.org/10.1021/np50031a029.

Maurya, R., Singh, R., Deepak, M., Handa, S. S., Yadav, P. P., & Mishra, P. K. (2004). Constituents of *Pterocarpus marsupium*: an ayurvedic crude drug. *Phytochemistry*, *65*(7), 915-920. PMid:15081294.http://dx.doi.org/10.1016/j.phytochem.2004.01.021.

Miranda, I., Sousa, V., & Pereira, H. (2011). Wood properties of teak (*Tectona grandis*) from a mature unmanaged stand in East Timor. *Journal of Wood Science*, *57*(3), 171-178. http://dx.doi.org/10.1007/s10086-010-1164-8.

Mishra, Y., Rawat, R., Rana, P. K., Sonkar, M. K., & Mohammad, N. (2014). Effect of seed mass on emergence and seedling development in *Pterocarpus marsupium* Roxb. *Journal of Forestry Research*, *25*(2), 415-418. http://dx.doi.org/10.1007/s11676-014-0469-7.

Mohammad, N., Dahayat, A., Pardhi, Y., & Rajkumar, M. (2022). Morpho-molecular diversity assessment of Indian kino (*Pterocarpus marsupium* Roxb.). *Journal of Applied Research on Medicinal and Aromatic Plants*, *29*, 100373. http://dx.doi.org/10.1016/j.jarmap.2022.100373.

Mohammad, N., Kumar, P., Singh, S., &Tewari, S. (2013a). Character association and path coefficient analysis for productivity traits in basmati rice (*Oryza sativa* L). *Pantnagar Journal of Research*, *11*(3), 332-335.

Mohammad, N., Mishra, Y., & Ansari, S. A. (2013b). Development of selection criteria in bel (*Aegle marmelos*) and kuchla (*Strychnox nux-vomica*) through correlation and path coefficient study. *Bioinfolet*, *10*(1a), 8-11.

Mohammad, N., Sonkar, M., Pardhi, Y., Rana, P. K., & Dahayat, A. (2020). Assessment of morphological variation and association studies in *Litsea glutinosa* (Lour.) C.B. Rob. from central India. *Journal of Sustainable Forestry*, *39*(2), 207-220. http://dx.doi.org/10.1080/10549811.2019.1632720.

Moya, R. (2001). Wood properties of teak (*Tectona grandis*) from Buen Precio Company. *Las maderas de plantaciones forestales* (Vol. 1, pp. 1-8). Cartago, Costa Rica: ITCR.

Moya, R., Marin, J. D., Murillo, O., & Leandro, L. (2013). Wood physical properties, color, decay resistance and stiffness in *Tectona grandis* clones with evidence of genetic control. *Silvae Genetica*, *62*(1-6), 142-152. http://dx.doi.org/10.1515/sg-2013-0019.

Omokhafe, K. O. (2001). Preliminary investigation into tree dryness in *Hevea brasiliensis* by path analysis of tree dryness and latex parameters. *Tropicultura*, *19*, 1-4.

Pharmacopoeia Commission for Indian Medicine & Homoeopathy. (2001). *The ayurvedic pharmacopoeia of India*. Ghaziabad: Pharmacopoeia Commission for Indian Medicine & Homoeopathy.

Pullaiah, T. (1999). *Medicinal plants of Andhra Pradesh*. New Delhi: Regency Publications.

Rathinathan, M., Surendran, C., & Kondas, S. (1982). Inter-relationship of wood yield componenents in *Eucalyptus teriticornis. Indian Forester*, *108*(7), 465-470.

Searle, S. R. (1961). Phenotypic, genotypic and environmental correlations. *Biometrics*, *17*(3), 474-480. http://dx.doi.org/10.2307/2527838.

Snedecor, G. W., & Cochran, W. G. (1967). *Statistical methods* (6th ed.). Ames: Iowa State University Press.

Systat Software. (2021). *Systat Software, Inc., version 13.1*. San José: Systat Software.

Wilkins, C. P. (1991). Conservation of tree crops. In J. H.Dodd (Ed.), *In vitro methods for conservation of plant genetic resources* (pp. 151-237). London: Chapman and Hall. http://dx.doi.org/10.1007/978-94-011-3072-1_8.

Wright, S. (1921). Correlation and causation. *Journal of Agricultural Research*, *20*, 577-589.

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