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Timber Quality of Teak Grown in Home Garden Forestry

K. M. Bhat
P. K. Thulasidas
Division of Forest Utilisation

E. J. Maria Florence
Division of Extension and Training

Kerala Forest Research Institute
(An Institution of Kerala State Council for Science, Technology & Environment)
KFRI Peechi 680 653, Kerala, India

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ABSTRACT OF PROJECT PROPOSAL

1.	Project No.	:	KFRI 368/01
2.	Title	:	Timber Quality of Teak Grown in Home-garden Forestry
3.	Location	:	KFRI, Peechi
4.	Principal Investigator	:	K.M. Bhat (Forest Utilisation)
5.	Co-investigators	:	P.K. Thulasidas (Forest Utilisation) E.J. Maria Florence (Extension & Training)
6.	Duration	:	3 years (July 2001 – June 2004)
7.	Objectives	:	(a) To determine timber property differences particularly figure (colour, grain, texture), dimensional stability, strength, heartwood/sapwood dimensions and durability of farm grown teak as compared to forest plantations (b) To assess the teak timber value from homesteads in terms of poles/posts and grade/recovery of sawn wood and veneer as well as value-added/composite products
8.	Practical Utility	:	(a) Heartwood yield, natural durability and strength properties of teak wood grown in home-garden forestry assessed in relation to forest plantations. (b) Market and decorative value of teak timber from homesteads evaluated in terms of poles/posts/ grade/recovery of sawn wood/veneer and value added composite products in comparison with forest plantations
9.	Funding Agency	:	Kerala Forest Department

Contents

Abstract

Trees grown outside forests especially homesteads play an increasing role in the industrial supply of timber in Kerala. The present study evaluates the timber quality of 35-year-old teak grown in homesteads representing wet and dry localities of Kerala in comparison with that grown in forest plantation of Nilambur (of the same age group), which is widely reputed as Malabar teak.

Grading of 88 logs (of 35-year-old trees) from wet and dry localities reveals that teak timber from homesteads qualifies only for Grade II or III specified in Indian Standard (IS 4895). Grade I timber was not available from either of the two homesteads. The 35-year-old home garden trees from wet site produced timber of average DBH 39.6 cm indicating their potential of producing the log diameter similar to that of Site Quality I (SQ I) prescribed in the All India Yield Table (1970). In contrast, teak from dry site produced smaller dimensional timber of average DBH 24 cm, which qualifies only to SQ II/III with the major share of logs comprising pole sizes. Pole sized logs were less frequent in wet sites than in dry localities. Therefore the sawn wood out turn from wet site was significantly higher than dry and plantation sites. The log form was poor with eccentric growth possessing bends and frequent knots probably due to lack of standard silvicultural regime like spacing/thinning in home garden forestry.

The heartwood proportion at BH level was 71%, 64% and 73% in wet, dry and forest plantation sites respectively. Although stem diameter of the trees differed significantly, the heartwood percentage did not show significant variation with tree size and locality of the planted site. This means that homesteads of wet site areas produce larger diameter logs without adversely affecting the heartwood yield compared to dry localities and plantation sites.

The quantitative measurement of colour, as per the international standard, indicates that wood from wet sites of homesteads is paler with less yellowness and colour saturation. No significant differences were observed between the samples of different localities with regard to brightness and redness. The results suggest that the paler colour of wet site teak wood is one of the causative factors of lower timber price of home garden teak. The total extractive content was significantly lower in wet than in dry site. The paler colour of wet site sample was attributed to lower extractive content. The decorative black streaks of dry site wood sample were probably due to the presence of higher (16%) and more well defined zones of extractive distribution. The heartwood of plantation specimen also often displayed a similar pattern (13%) with uniform golden brown colour.

No significant differences were noticed in wood basic density, moisture content and volumetric shrinkage values among the homesteads of wet and dry localities as well as the forest plantation site in Nilambur. Excepting slightly higher longitudinal compressive stress of dry site home garden teak, no significant variation was encountered in timber stiffness (modulus of elasticity) and bending strength among the samples of homesteads and forest plantation. This implies that teak wood grown in homesteads has almost the same dimensional stability and strength as the plantation grown teak of forest sites.

The accelerated laboratory tests revealed that significant differences existed in natural decay resistance between wet and dry localities. While the two brown rot fungi caused more severe weight loss in wet site samples than in dry and plantations sites, the three white rot fungi did not show significant differences among the sites. In general, *Polyporus palustris* was the most aggressive fungus followed by *Gloeophyllum trabeum*, both belonging to the group of brown rot fungi. The higher susceptibility of wet site home garden teak was attributed to the lower extractive content of the wood.

With a mean value of 2.2 cm, bark was thicker in trees grown in wet locality than in dry (0.8 cm) and plantation (1.1 cm) sites. While thicker bark from wet locality displayed higher moisture content (228%) and lower basic density (263 kg/m^3), thinner bark from dry locality was heaviest with a mean basic density of 640 kg/m^3. Bark from plantation was intermediate with 400 kg m^3 of basic density and 172% of moisture content on dry weight basis.

The study concludes that teak wood grown in homesteads differs from forest plantation grown timber in certain properties such as log form, extent of natural defects, appearance/wood colour and grain as well as natural durability depending on the dry or wet locality although wood density and strength properties are almost similar. These differences in timber quality may influence the price factor of teak wood coming from homesteads especially of wet localities.

1. Introduction

With the changing pattern of industrial roundwood supply, within the frame work of National Forest Policy (1988), trees grown outside forests especially in homesteads and farm land play a significant role to meet the future timber requirements (Plate I). In Kerala, for the year 1993-94, State forests including plantations accounted for only 9% of industrial wood supply, in contrast to 46% by households / home-gardens and 31% by estates. There is however a prevailing notion that farm grown teak is inferior in decorative value, durability and strength properties of the timber to that grown in forest plantations and hence fetches much lower price. Many teak growers often express their serious concern about the timber quality before making further investments on growing high quality teak. The recent preliminary investigations (Bhat 2000; Bhat *et al.* 2001), however, indicate that:

- Fast grown teak timber is not necessarily weaker and less durable than the traditional plantation timber though slightly different in grain and texture.
- Fast growth in relatively young plantations with judicious fertilizer application/genetic inputs can be advantageous in terms of heartwood volume and strength.

The present study aims at evaluating the timber quality of teak grown in home-gardens in comparison with forest plantation. The specific objectives are:

a) to determine timber property differences particularly figure (colour, grain, texture), dimensional stability, strength, heartwood and sapwood dimensions and durability of teak grown in homesteads as compared to forest plantation
b) to assess the teak timber value from homesteads in terms of poles/posts and grade recovery of sawn wood.

2. Materials and Methods

The term 'home-garden forestry' is used in the present study to refer to the practice of growing trees in combination with various crops around the homesteads, as a kind of agroforesty defined by Nair (1989), which is prevalent in Kerala.

2.1 Location of field sampling and selection of trees

A field survey conducted in Kerala revealed that the harvesting age of homestead teak is generally 35 years. Trees were felled in order to compare the 35-year-old homestead teak with that grown in typical forest plantation of Nilambur (Karulai) at the same age group. The field sampling was done from both dry (Nemmara, Palghat Dist) and wet (Muvattupuzha, Ernakulam Dist) localities of Kerala to represent the diverse conditions of moisture/rainfall of home garden forestry which may influence tree growth. The field sampling was done from dry (Nemmara, Palghat District) and wet (Muvattupuzha, Ernakulam District) localities of Kerala in order to compare the 35-year-old homestead teak with that grown in typical forest plantation of Nilambur (Karulai Range) of the same age group. The Nilambur plantation was chosen for comparison in view of the fact that Nilambur teak is widely used in the trade and reputed as *Malabar teak* to represent superior quality timber. The three site conditions and tree characteristics are given in Table 1.

Table 1. Environmental conditions and size of sampled teak trees from wet and dry localities as compared to forest plantation at Nilambur, Kerala

Factor	Wet (Muvattupuzha, Ernakulam)	Dry (Nemmara, Palghat)	Forest plantation (Karulai, Nilambur)
Altitude (m.a.s.l).	20	40	60
North latitude	9^{o} 59'	10^{o} 35'	11^{o} 15'
East longitude	76^{o} 34'	76^{o} 35'	76^{o} 13'
Soil type	Loamy sand	Sandy loam	Silt loam
Annual rainfall – range mm	2500 - 3500	1500 – 2300	2500 – 3000
Temperature range ^{o}C	17 – 34	26 – 37	17 – 37
Relative humidity %	Above 80	70	70
Tree age (years)	35	35	35
Mean tree height (m)	17.0	14.0	21.0
Mean DBH (cm)	39.6	24.0	31.0

2.2 Log characterization and grading

A total of 88 logs collected from 35-year-old trees were graded as per the Indian Standard IS: 4895 (BIS, 1968) covering both wet and dry localities. The logs were graded in house compounds before transporting the logs to the sawmill. The age of the felled trees was also confirmed with the eldest member of the family and the coppiced trees were avoided to keep consistency in classification and grading. Teak logs were classified according to the prevalent practice adopted in the State of Kerala. The properties investigated were log size, straightness of the bole, fluting, ring shake, bend and knots and other visual defects that reduces the market value of teak timber.

2.3 Sawn timber output and recovery

Since full length material was not available from the three locations, only 1m-length basal billet immediately below the breast height (BH) level was used to estimate the sawn timber recovery. However, commercial log volume (in m^3) was estimated for the felled teak trees (5 nos. each) from all the three localities. In the sawmill, flat sawing (tangential sawing) was adopted to achieve maximum recovery. Sawn timber output (in m^3) and recovery (ratio of sawn timber output over log volume) was calculated based on the commercial quarter girth formula.

2.4 Sampling for laboratory investigations

For laboratory investigations, five defect-free dominant teak trees each from the homesteads representing wet and dry localities of Kerala at the harvestable age (35 years) were collected. Five trees from forest plantation at Karulai, Nilambur were also collected from the same age for comparative purpose. Two 5 cm thick transverse discs were removed from each tree at BH level to investigate the physical and anatomical properties. One whole transverse disc was utilized for colour characterization. To estimate the heartwood percentage, the heartwood area and the disc area were calculated by measuring four radii at right angles to one another and four measurements were averaged for each disc.

To determine wood and bark basic density, a diametrical segment was removed from each disc. Two bark samples from opposite radii were also available for the estimation of bark density. The density of wood and bark was measured on oven-dry (O.D) weight to green volume basis. The green volume was measured by water displacement method (Olesen 1971).

For shrinkage of wood (radial, tangential and volumetric shrinkage), 2x2x5 cm size quarter sawn samples from BH level were prepared in both radii from pith to periphery comprising inner, middle and outer portions as per Indian Standard IS: 1708 (1986). A screw gauge was used to measure precisely the shrinkage from green to oven dry condition.

2.5 Mechanical testing

For mechanical testing, the basal billets of 1.0 m length were sawn into scantlings of 3 x 3 cm cross section to prepare test samples from pith to periphery in both radial directions selected randomly just below the BH level. From each radius, defect-free samples with the size of 2x2x30 cm were prepared representing outer, middle and inner positions (excluding pith) for static bending (modulus of rupture – MOR and modulus of elasticity – MOE). The sample size of 2x2x8 cm was also prepared for compression test (maximum compressive stress parallel to grain – MCS) from the same sample sticks used for static bending. Altogether 180 samples were tested (90 each) for static bending and compression parallel to grain. The test was conducted on a 200 kN Universal Testing Machine (Zwick, Germany) following the Indian Standard IS: 1708 (1986). Small pieces were cut from the cleavage portion of the tested samples to determine the wood density in air-dry condition.

2.6 Anatomy

To compare the wood anatomy of home garden teak from wet and dry localities with plantation teak, 15-20μm thick cross sections were taken from the strength-tested samples using a sliding microtome, from pith to periphery comprising inner, middle and outer portions covering the different growth rings in each sample's cross sectional area. Standard microtechnique procedure was followed to prepare sections for microscopic observation. Important anatomical properties studied are ring width, early wood and late wood percentage, vessel diameter, vessel frequency, and proportions of fibres, vessels, parenchyma (ray and axial parenchyma combined) and gelatinous fibres, if any.

2.7 Colour characterization

The 5 cm thick cross sectional disc removed from each tree at BH level was air-dried to 12% moisture content. A radial strip of 3 cm width was cut from inner to outer heartwood in both radii excluding the pith. The two cut samples from the opposite radii were ground in a Wiley mill separately. The powder was passed through No. 40 (420 μm) sieve and retained in No. 60 (250 μm). The colour of these samples was determined by two methods of colour determination; the Munsell system (1905, 1976) and the CIE 1976 (L* a* b*) system within a day or two after sample preparation to avoid colour changes caused by oxidation or light.

Munsell notation of colour difference is considered for visual interpretation as influenced by personal judgment of colour. The wood sample placed under the Colour chart appears through the round openings, allowing an easy comparison with the rectangular colour chips. The colour is then identified by its hue, value and chroma. Hue value ranges from 9.9R to 1.0Y from red to yellow. The scale of value ranges from 0 for pure black to 10 for pure white.

Value indicates lightness/brightness of a colour. Chroma is the departure of a colour from its neutral colour of the same value. Colours of low chroma are sometimes called weak, while those of high chroma are said to be highly saturated, strong or vivid.

The CIE 1976 (L* a* b*) system was used as the colorimetric method for providing more accurate and objective colour determination. The UV spectrophotometer (Shimadzu UV-3100PC) equipped with a reflectance attachment 'Type C' light source representing average day light with a colour temperature of 6500 °K was used for the colour analysis. For measurement, the wood sample was placed at the sample port facing the incident beam to the integrating spheroid in the visible spectrum (380-780 nm) of the UV spectrophotometer. The beam size was approximately 2.0 mm at the entrance port to the integrating spheroid.

2.8 Extractive content

The total extractive content of heartwood at BH level was analysed to ascertain the effect of extractives on natural durability of home garden teak. The ASTM standard D1107-56 for the determination of alcohol – benzene solubility of wood was followed (1984). Whole heartwood sample from pith to periphery in each radial direction was selected and powdered in a wiley mill. The powder was allowed to pass through No 40 (420 µm) sieve and retained on No. 60 (250 µm) sieve. The test specimen consisted of 2 g air-dried sawdust placed in the extraction thimble (30 mm x 100 ml) in the Soxhlet extraction apparatus (capacity 100 ml) and was extracted against 150 ml of ethyl alcohol and benzene (1:2 ratio) in the extraction flask continuously for 8 hours keeping the liquid boiling briskly. This facilitated 4 to 6 siphoning per hour. After evaporating the solvent from the extraction flask, the contents (extractive content) of the flask were dried in an oven at 105 °C for 1hr, cooled in a desiccator and weighed to determine the percentage of extractive content based on moisture-free saw dust.

2.9 Natural decay resistance test

To test the natural decay resistance, the billet (30 cm length) immediately above breast height level was used. The heartwood portion of the billet was sawn into battens of size 2.0 cm for preparing test blocks radially from pith to periphery. From each tree, inner, middle and outer samples from both radii were selected (with 4 replicates) for testing. Test blocks of 2x2x1 cm size were prepared according to the procedure described by Bakshi *et al.* (1967). Altogether, 1800 test blocks (600 each representing wet, dry and forest plantation sites) were prepared so as to accommodate 2 test blocks each in 900 test bottles (500 g capacity). From each tree, three blocks (outer, middle and inner) were used as adjustment blocks (control samples). Highly perishable timber, *Bombax ceiba* Linn. was selected as feeder strip for the test fungi and blocks were prepared from the quarter sawn sample (size 2x2x1 cm). Reference blocks, similar to test blocks in size were also prepared from the same mature tree of *Bombax ceiba*.

The test fungi consisted of cultures of two brown-rot, *Gloeophyllum trabeum* (Pers. ex Fr.) Murr. (FRI 90), *Polyporus palustris* Berk. & Curt. (FRI 422) and three white-rot fungi, *Pycnoporus sanguineus* (Linn. ex Fr.) Murr. (FRI 1135), *Trametes hirsuta* (Wulf. ex Fr.) Lloyd. (FRI 715) and *T. versicolor* (Linn. ex Fr.) Pilät. (FRI 684) obtained from Forest Research Institute, Dehra Dun. The procedure described in ASTM standard (1981) for accelerated laboratory test was followed. The test fungi were subcultured and grown in 2% potato dextrose agar (PDA) in Petri-dishes to prepare adequate inoculum for the 1800 blocks.

Soil block method was used for the decay test. One third of the test bottles were filled with loam soil (pH 5.9) with a water holding capacity of 20 to 40%. In each test bottle, 2 feeder strips were kept and the bottles were sterilized alternatively for 2 days at 121 °C for 30 min. each. An 8 mm diameter PDA disc cut from the margin of the actively growing colony of the fungus was placed aseptically near the feeder strips on the soil. The inoculated bottles were kept in the incubation room at 28 °C and 70% relative humidity. After 2-3 weeks, when the feeder strip was almost covered with the test fungus, the surface sterilized (at 100 °C for 30 min.) test blocks and reference blocks were transferred aseptically and placed on the feeder strips. Adjustment blocks were kept on the un-inoculated feeder strips.

After eight week's exposure to the test fungi two reference blocks were taken out, the mycelium removed, oven dried and weighed to determine the percentage weight loss. This was continued every week until 60 percent weight loss was reached in the reference blocks. At that stage, test blocks and adjustment blocks were taken out and their oven dry weight determined. If the adjustment blocks had suffered any weight loss due to any other causes, necessary corrections were made in the oven dry weight of test blocks. The weight loss in test blocks due to decay was calculated and the decay resistance graded.

2.10 Statistical analysis

A One-way ANOVA followed by Duncan's multiple range test ($\alpha = 0.05$) was used to test the significance of diameter at breast height (DBH), heartwood percentage, wood basic density, moisture content, extractive content percentage, sawn timber recovery rates and colour differences between the home garden and plantation grown teak. Multivariate analysis of variance (MANOVA) was carried out to study the effect of localities on variation in strength properties. Pearson Correlation Coefficient (2-tailed) was also done to study the inter-relationships among the various parameters.

3. Results and Discussion

3.1 Log characterization and grading

Grading of 88 logs (of 35-year-old trees) from wet and dry localities revealed that teak timber from homesteads qualifies only for Grade II or III specified in Indian Standard (IS 4895, 1968). Grade I timber was not available from either of the two homesteads (Table 2). The 35-year-old home garden teak from wet site produced timber of average DBH 39.6 cm which has the potential of producing the log diameter similar to that of Site Quality I (SQ I) prescribed in the All India Yield Table (1970). In contrast, teak from dry site produced smaller dimensional timber of average DBH 24 cm, which qualifies only to SQ II/III with major share of the logs comprising pole classes. Pole sized logs were less frequent in wet site than in dry sites (Table 3). The log form was poor and major part of the logs were eccentric with tension wood and possessed bends and frequent knots probably due to lack of standard silvicultural management practices in home garden forestry.

Table 2. Classification and grading of teak timber from homesteads

Teak timber classes	Girth limits (cm)	Length (m)	Number of logs in each Grade*			Number of logs graded in the homesteads	
			A	B	C	Wet	Dry
1	>150	>3	-	-	-	-	-
II	>100 – 149	>3	3	3	2	5	3
III	>76-99	>3	7	8	4	4	15
IV	60-75	>3	6	10	7	3	20
Total						12	38

Table 3. Classification and grading of teak poles from homesteads

Pole classes	Girth limits (cm)	Length (m)				Number of poles in each Grade*				Number of poles graded in the homesteads	
		A	B	C	D	A	B	C	D	Wet	Dry
1	(65-75)	>12	9-12	6-9	3-6	-	-	1	2	-	3
II	(53-64)	>12	9-12	6-9	3-6	1	1	3	2	-	7
III	(41-52)			>6		-	-	5	-	-	5
IV	(28-40)				>6	-	-	-	12	-	12
V	15-27)				<6	-	-	-	11	5	6
Total										5	33

**Grade A - Cumulative value of permissible visual defects up to 2.5 units*
Grade B - Cumulative value of permissible visual defects up to 5 units
Grade C & D - Cumulative value of permissible visual defects 7.5 units and above

3.2 Colour

The mean colour values determined through Munsell and L* a* b* specification systems are presented in Table 4. The Munsell notation for wet site sample was comparable with dry and plantation specimens with regard to hue (Table 4 and Fig. 1a). However, chroma value of the former was less than that of dry and plantation specimens (Fig. 1c). The sample colour is red tending more towards yellow-red in the Munsell system. Similar tendency was reported in 32 Japanese hardwoods and 60 Malaysian timbers (Minemura *et al.* 1995, 1998). As characterized by Vetter *et al.* (1990), colour of the samples was yellow to yellowish brown among the 98 Amazonian timbers. The variability in luminance *(i.e.,* darkness or lightness) is the primary cause of heartwood colour variability (Phelps *et al.* 1983). The dry and plantation samples exhibit higher 'value' for the lightness index (Fig. 1b).

Table 4. Comparison of mean colour values with standard deviations (in parenthesis) as determined by Munsell and L* a* b* specification system for 35-year-old teak from home garden and forest plantation (*n* = 5)

Location	Munsell system			L* a* b* specification system		
	Hue	Value	Chroma	L* (Lightness/ brightness)	a* (Redness)	b* (Yellowness)
Wet	8.86YR [a] (0.207)	5.06 [a] (0.36)	3.48 [b] (0.19)	52.338 [a] (3.46)	6.35 [a] (0.44)	21.13 [b] (0.91)
Dry	9.18YR [a] (0.4)	5.24 [a] (0.3)	3.82 [a] (0.25)	54.038 [a] (2.94)	6.37 [a] (0.60)	23.4 [a] (1.34)
Plantation	8.78YR [a] (0.32)	5.48 [a] (0.3)	3.9 [a] (0.2)	56.396 [a] (2.87)	6.848 [a] (0.88)	23.44 [a] (0.94)

The mean values for each parameter with 'a' are statistically non-significant at P >0.05

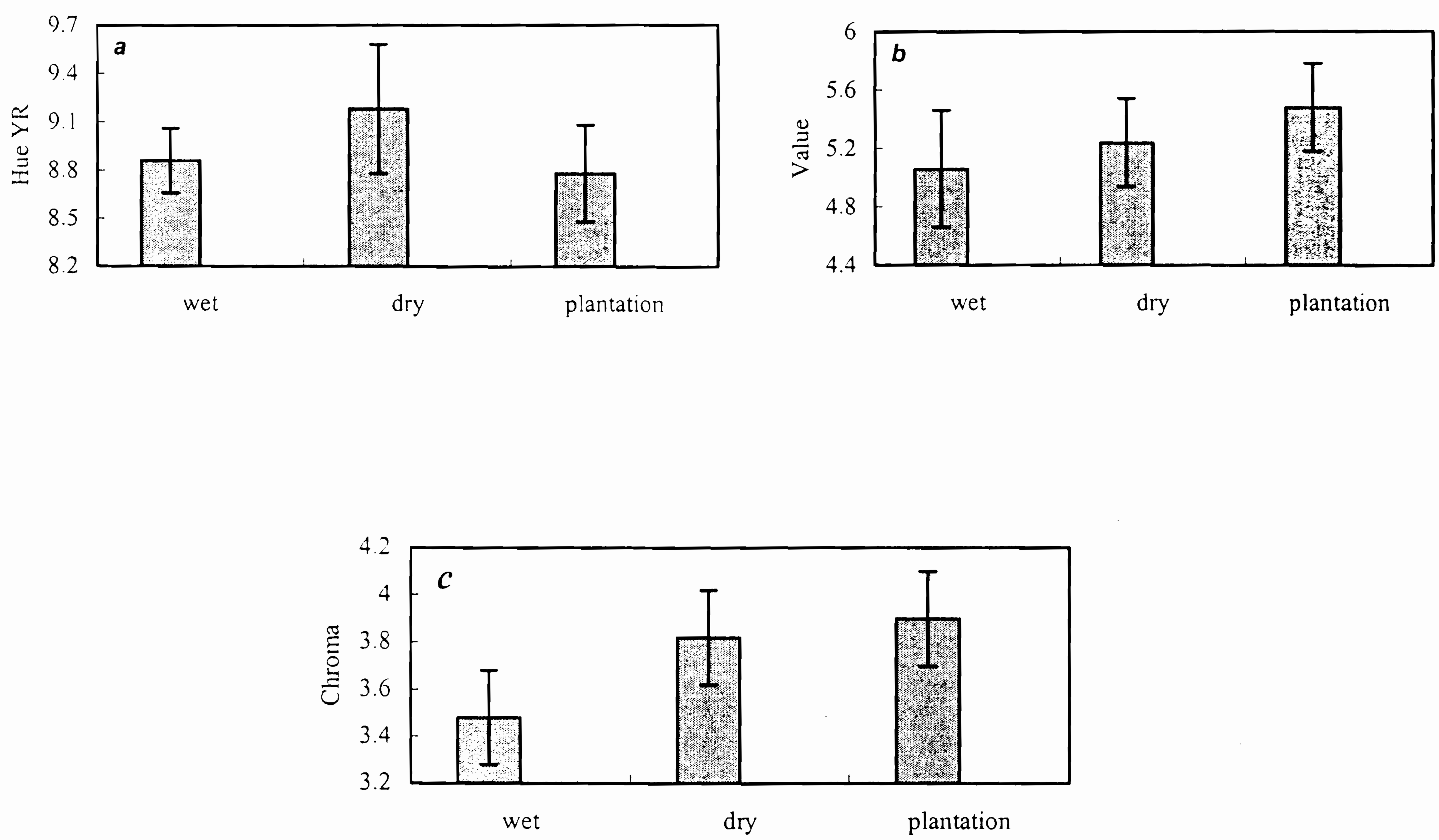

Fig. 1a – c. Munsell hue, value and chroma in relation to wet, dry sites of home garden teak and forest plantation

The chromaticness index a* (redness) and b* (yellowness) together contribute to the chroma or saturation of colour in L*a*b* system. The percentage luminance, lightness/brightness index is represented by the symbol L*. The three factors L* a* b* are highly saturated in plantation specimen of teak from Nilambur (Figs. 2a-c), which is reputed for its colour in the trade as Malabar teak. This is in agreement with the findings of Wilkins and Stamp (1990) in eucalypts that more saturated wood colour is found in silviculturally treated trees although site quality has been reported to influence wood colour (Sullivan 1967a, 1967b; Rink 1987; Barajas-Morales 1985). In *Juglans nigra* Nelson *et al.* (1969) found that luminance was generally greater on a site of better quality as reported here for forest plantation coming under site quality SQ I or II. Incidentally, the dry site of home garden forestry also exhibited a similar pattern of greater luminance. The redness index a* of the wet site sample was comparable to that of dry and plantation. But yellowness value b* was less, hence low luminance index L* of wet site sample (Fig. 2c). The wet site sample being paler (less yellow) also differed significantly ($P < 0.05$) from the dry site and plantation specimens of more yellowish colour (Plate I). The same trend was observed in the visual comparison using the Munsell system (Table 4, Figs. 1a-c).

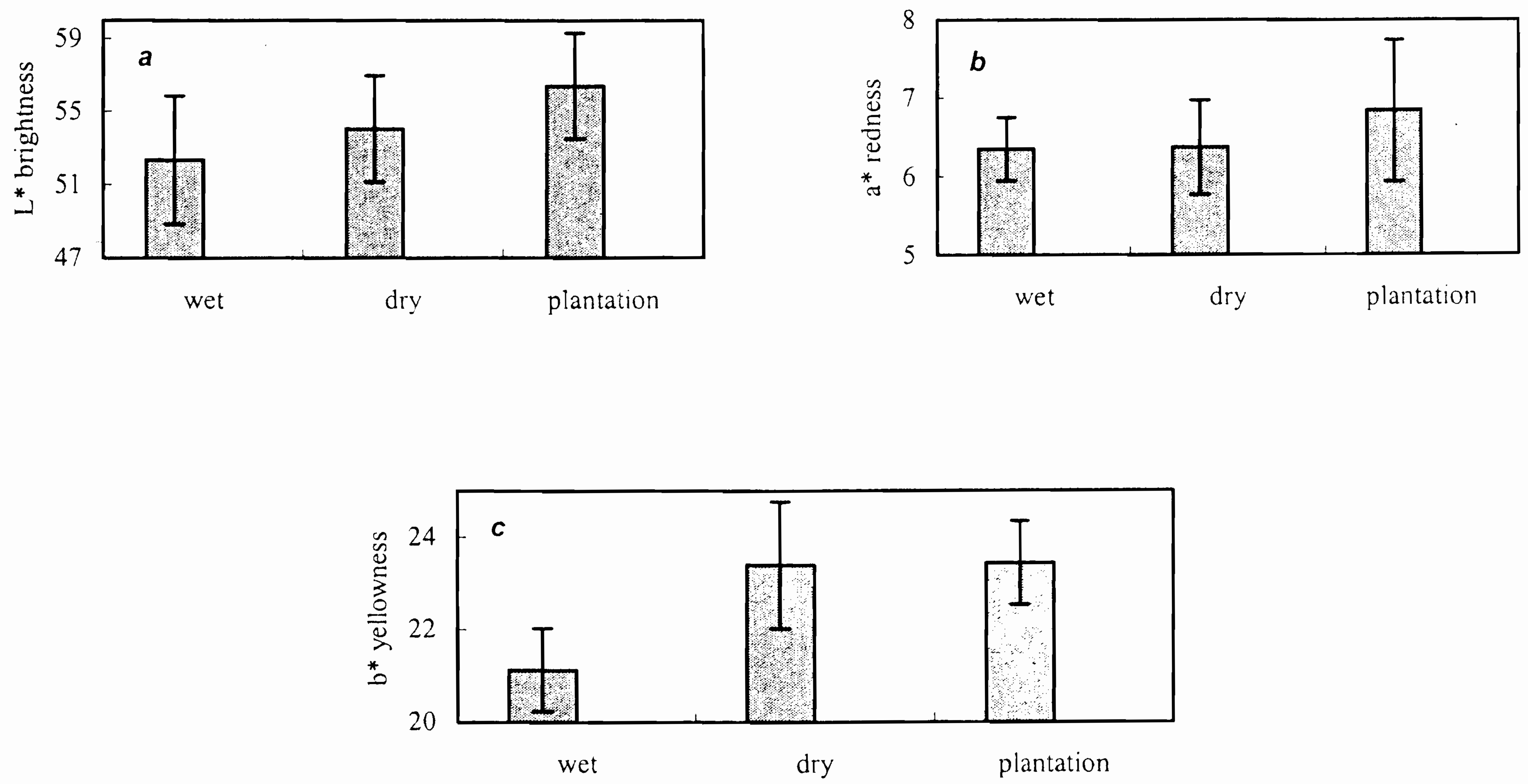

Fig. 2a – c. Lightness index (L*) and chromaticness a* and b* (CIE L* a* b* system) in relation to wet, dry sites of home garden teak and forest plantation

Heartwood from drier areas was darker in colour. Similar trend was reported in eucalypts which produced lighter coloured heartwood in faster grown trees of high rainfall areas (Hillis 1978). The paler colour (less yellowness b*) of the wet site sample was correlated with the faster growth as seen from the wet site (Table 1). The dry locality teak wood displayed characteristic darker heartwood with decorative black streaks (Plate I), probably due to denser distribution patterns of slower growth and higher amount of extractives as related to the site/edaphic factors (Bhat 2003; Thulasidas and Bhat 2003). This is in agreement with the observations by Hillis (1971) and Gierlinger *et al.* (2004) on differences in wood colour primarily due to variations in the quantity and nature of extractive content. Similarly, Hiller *et al.* (1972) found a positive correlation between percent luminance (lightness /brightness), and extractive content in black walnut (*Juglans nigra* L).

3.3 Heartwood proportion

Heartwood proportion of stem volume also determines the timber value in the market as it is the naturally durable part of the timber for which teak has world-wide reputation. The heartwood proportion, as measured at breast height, was 71%, 64% and 73% from wet, dry and forest plantation site respectively. Although stem diameter of the trees differed significantly, the heartwood percentage did not show significant variation with tree size and locality (Table 5 & Fig. 3) as it was reported to vary more with tree age (Bhat 2000). This means that homesteads of wet site areas produce larger diameter logs without adversely affecting the heartwood yield compared to dry and plantation site.

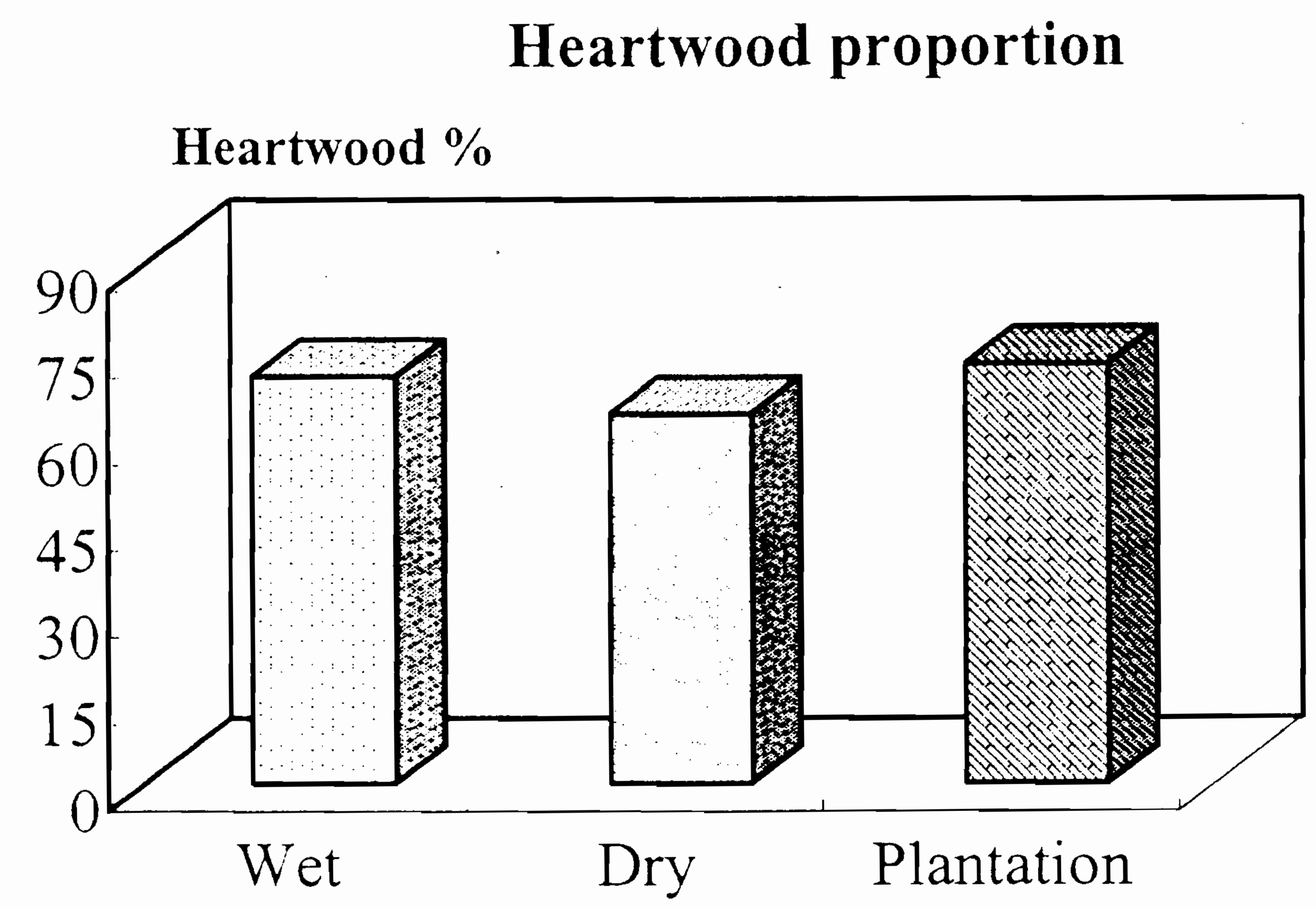

Fig. 3. Mean heartwood percentage of teakwood at BH level from wet, dry and plantation localities

3.4 Bark properties

With a mean value of 2.2 cm thickness, bark was thicker in trees grown in wet locality than in dry (0.8 cm) and plantation (1.1 cm) sites (Table 5). While thicker bark from wet locality displayed higher moisture content (228%) and lower basic density (263 kg/m^3), thinner bark from dry locality was heaviest having a mean basic density of 640 kg/m^3 with 60% moisture content. Bark from plantation was intermediate with 400 kg/m^3 of basic density and 172% of moisture content on dry weight basis.

3.5 Physical and mechanical properties of wood

No significant differences were noticed in wood basic density, moisture content and volumetric shrinkage values, as measured by standard methods, among the homesteads of wet and dry localities as well as the plantation site in Nilambur (Table 5). This implies that teak grown in homesteads has almost the same dimensional stability as the plantation grown teak of forest sites. Excepting slightly higher longitudinal compressive stress of dry site home garden teak, no significant variation was encountered in timber stiffness (modulus of elasticity) and bending strength among the samples compared.

Wood basic density values of home garden teak from wet and dry localities and plantation did not show any significant difference ($P>0.05$) (Fig. 4). The density values recorded here were similar to those reported elsewhere. The volumetric shrinkage of teakwood from wet and dry localities shows no significant variation ($P>0.05$), however, the plantation specimen recorded a slightly higher value (Table 5).

Table 5. Mean values and range of various physical properties of home garden and plantation teak (*n*=5)

Parameter	Wet		Dry		Plantation		Bar diagram
	Mean	SD	Mean	SD	Mean	SD	
DBH (cm)	39.6	3.8	24.0	2.1	31.0	0.9	W D P
Heartwood %	71	7.4	64	8.1	73	3.9	W $\overline{\text{D P}}$
Bark thickness (cm)	2.2	0.5	0.8	0.1	1.1	0.3	W $\overline{\text{D P}}$
Bark moisture content (%)	290	28.4	60	19.4	172	26.8	$\overline{\text{W D P}}$
Bark density (kg/m^3)	263	0.2	640	0.9	400	0.5	W D P
Wood basic density (kg/m^3)	600	0.5	645	0.1	597	0.02	$\overline{\text{W D P}}$
Wood moisture content (%)	91	15.2	68	13.2	90	3.9	$\overline{\text{W P}}$ D
Volumetric shrinkage (%)	9.2	1.2	8.3	2.2	11.8	2.1	$\overline{\text{W D}}$ P

Bars connecting the localities display non-significant differences at 5% probability level. W – wet, D – dry, P- plantation

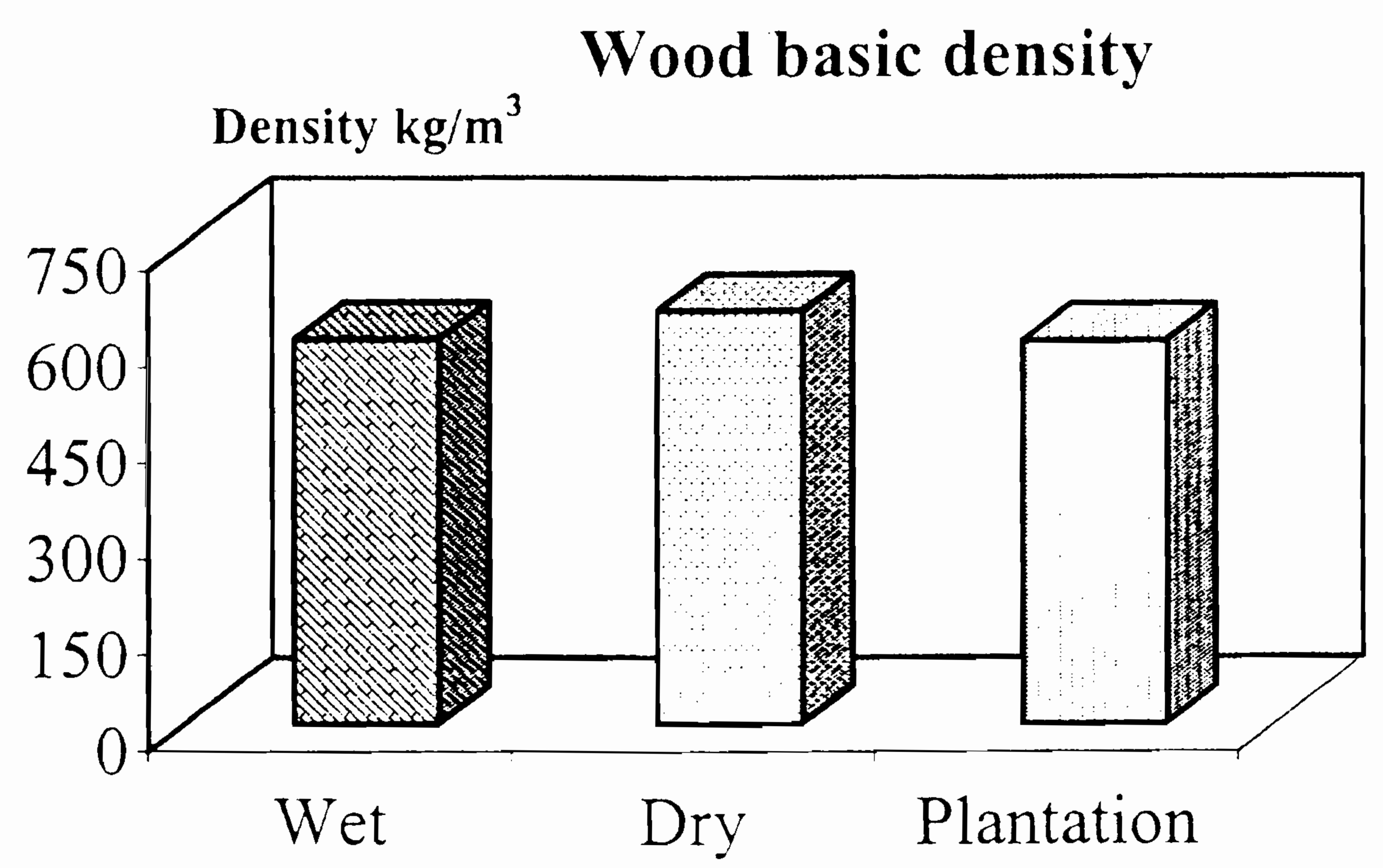

Fig. 4. Mean basic density of teakwood at BH level from wet, dry and plantation localities

3.6 Strength properties

The results of the static bending and compression tests are presented in the Table 6. The test result indicated no significant variation in Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) with respect to wet, dry and plantation sites except for the higher values obtained for Maximum Compressive Stress (MCS) parallel to grain from dry site. This may be due to the higher air-dry density values obtained for dry site (Fig. 8). The moisture content of the samples tested was around 12%. As expected strength values decreased radially from outer to inner in all the trees studied with the decrease of density (Table 6).

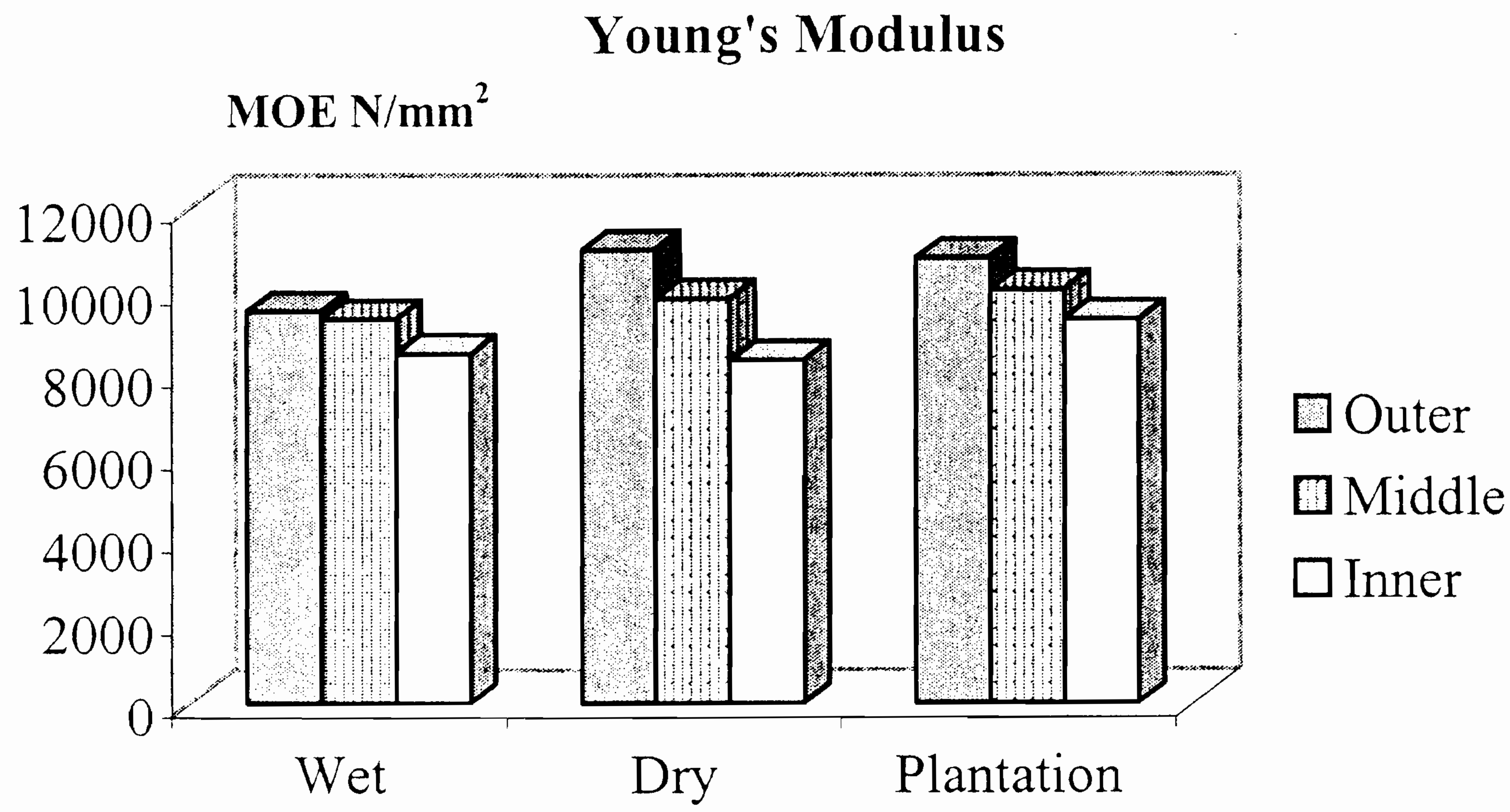

Fig. 5. Mean MOE of 35-year-old home garden teak compared to plantation teak (values indicate outer, middle and inner positions of the tree radius)

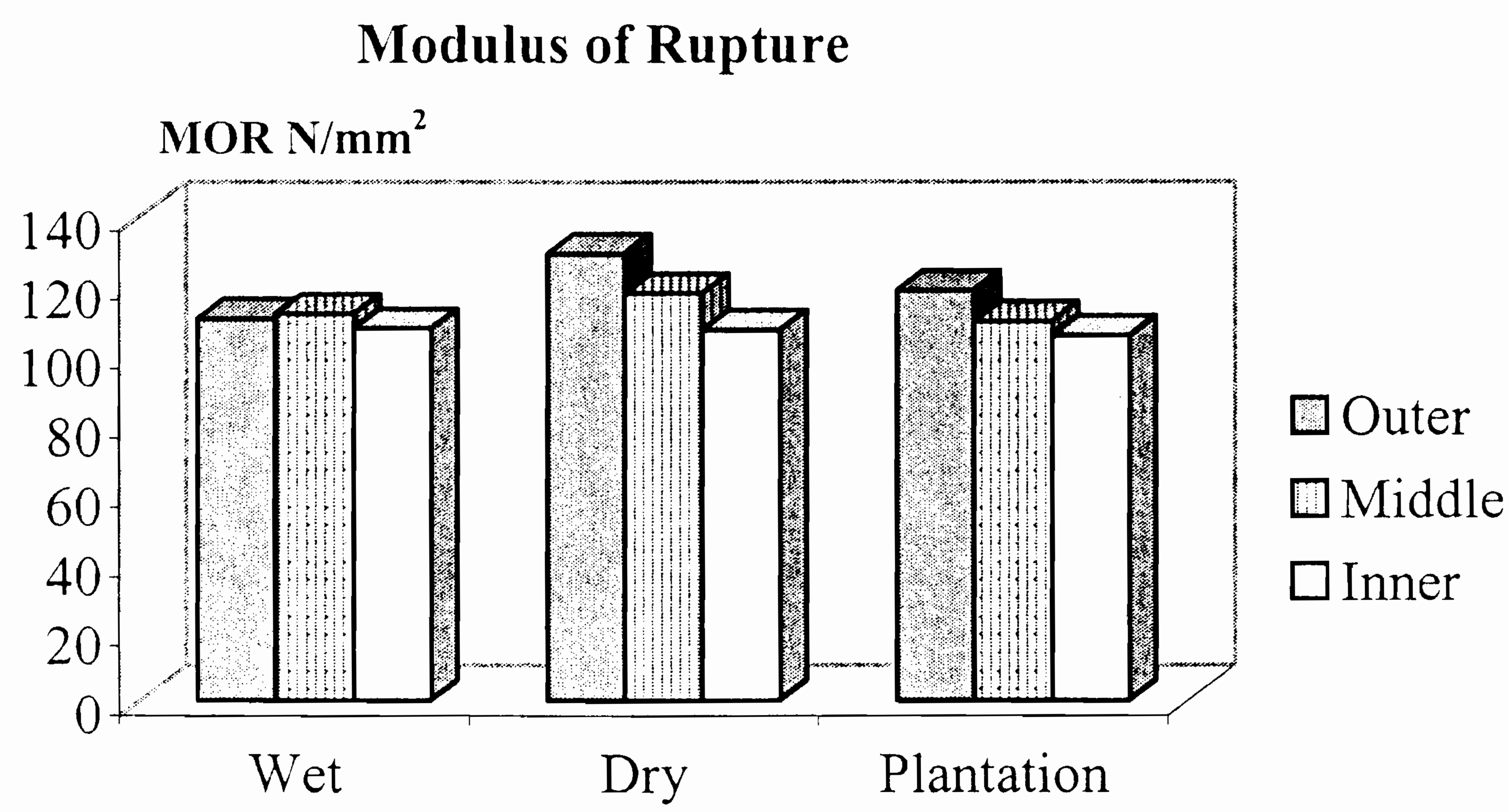

Fig. 6. Mean MOR of 35-year-old home garden teak compared to plantation teak (values indicate outer, middle and inner positions of the tree radius)

Table 6. Comparison of mean air-dry density and strength values (modulus of elasticity (MOE), modulus of rupture (MOR) and maximum compressive stress (MCS) parallel to grain (with SD in parenthesis) of 35-year-old home garden teak with the same aged Plantation teak from Nilambur

Parameter	Wet	Dry	Plantation	Bar diagram
Air-dry density	606	693	635	
Kg/m^3	(0.05)	(0.05)	(0.02)	$\overline{W\,D\,P}$
CV%	8.0	7.2	3.2	
MOE	9102.28	9709.90	10045.21	
N/mm^2	(1847.7)	(1107.5)	(1203.8)	$\overline{W\,D\,P}$
CV%	20.3	11.4	12.0	
MOR	109.89	118.01	111.20	
N/mm^2	(17.97)	(10.5)	(5.5)	$\overline{W\,D\,P}$
CV%	16.4	8.9	5.0	
MCS	52.07	60.60	55.56	
N/mm^2	(6.6)	(4.08)	(2.7)	$\overline{W\,P}\,D$
CV%	12.6	6.7	4.9	

Bars connecting the localities display non-significant differences at 5% probability level. W – wet, D – dry, P-plantation; *n* =30

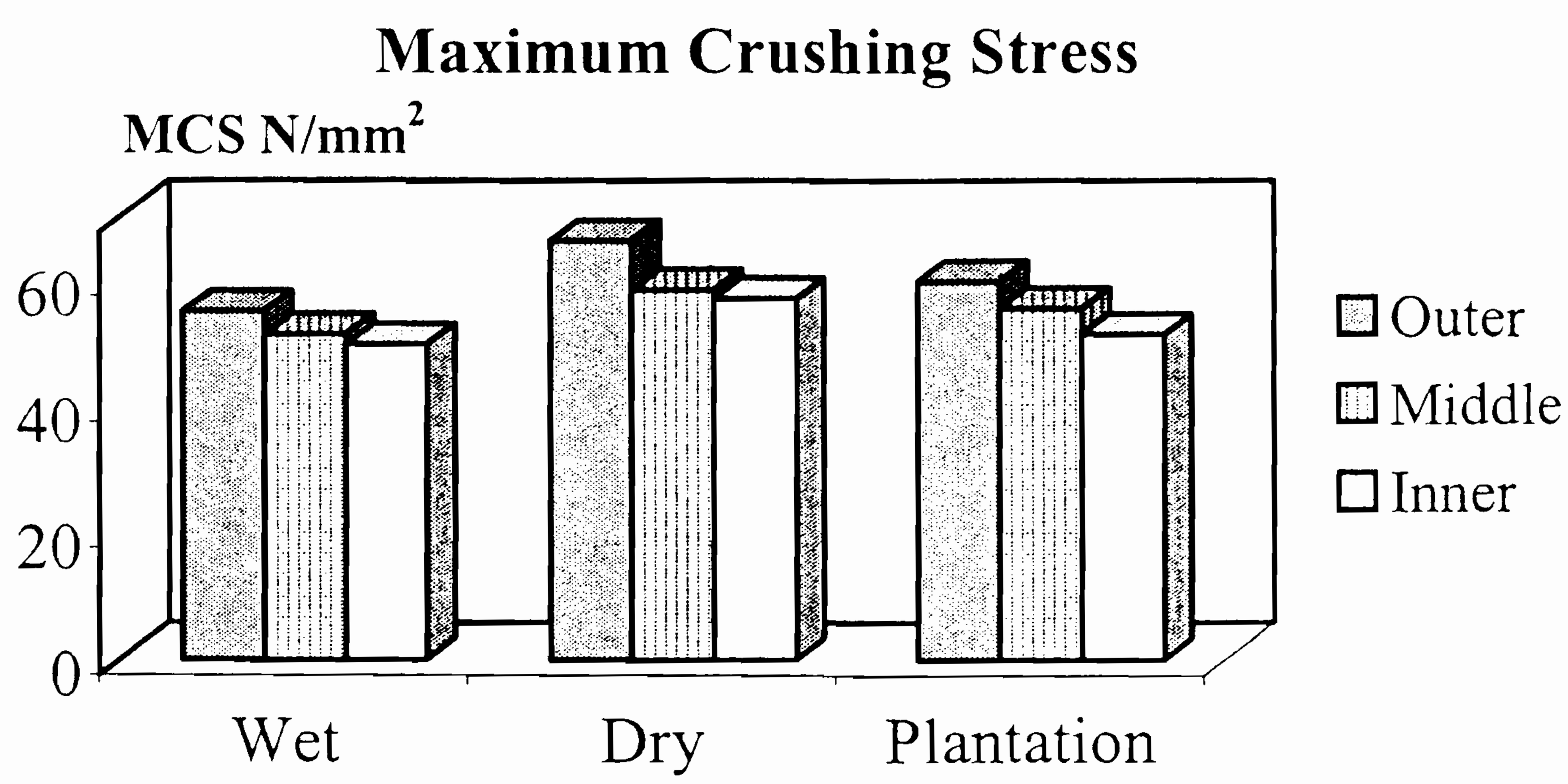

Fig. 7. Mean MCS of 35 year-old home garden teakwood compared to plantation grown teak (values indicate outer, middle and inner positions of the tree radius)

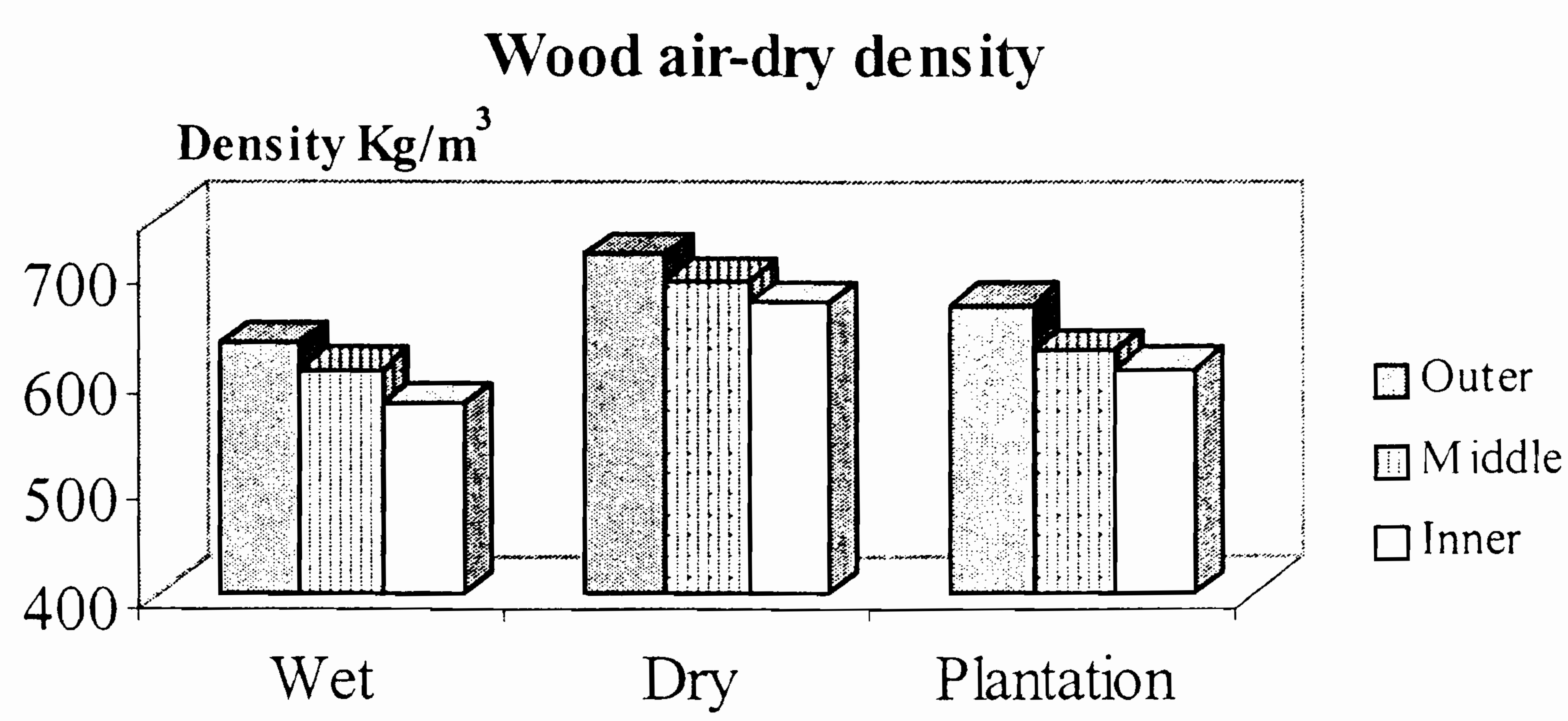

Fig. 8. Mean air-dry density of strength tested home garden teakwood compared to plantation teak (values indicate outer, middle and inner positions of the tree radius)

Table 7. Summary of the results of multivariate analysis (MANOVA) of strength properties of teak from home garden forestry compared to plantation teak

Source of variation	d.f.	F-value				
		MOR	MOE	Density	MCS	Density
Between location	2	0.62^{ns}	0.56^{ns}	2.017^{ns}	4.08*	5.59*
Between radial level	2	8.27**	11.95**	9.86**	16.09**	14.51**
Radial level by location	4	1.76^{ns}	1.0^{ns}	1.64^{ns}	0.67^{ns}	0.24^{ns}

*** Significant at 1% probability level, * Significant at 5% probability level,* ^{ns}*- non-significant*

It is clear from Tables 6 and 7 that 35-year-old teak trees felled from homesteads are in no way inferior in strength properties. Furthermore, the higher MCS values obtained from dry site sample showed the superiority of the home garden teak for any type of structural use.

3.7 Anatomical properties

The 35-year-old home garden teak from wet site displayed significantly wider rings, lower vessel percentage and vessel frequency while the differences in vessel diameter, fibre percentage and parenchyma percentage were not statistically significant (Table 8) (Plate I). More lignified walls were observed from dry site sample and the wall thickness of plantation teak was more or less uniform. The gelatinous fibres constituted 8.8 and 7% in both wet and dry localities while in plantation teak these fibres were not observed probably due to lesser eccentric growth and tension wood in silviculturally treated plantation teak.

Table 8. Comparison of anatomical properties of home garden teak and plantation grown teak

Property	Wet		Dry		Plantation		Bar diagram
	Mean	SD	Mean	SD	Mean	SD	
Ring width, mm	14.3	2.7	6.3	4.2	5.1	1.8	W D P
Vessel diameter, µm	196.2	15.4	193.4	1.9	184.4	9.3	W D P
Vessel frequency /mm^2	1.1	0.1	1.7	0.1	1.7	0.1	W D P
Fibre %	50.7	4.1	45.3	12.3	53.9	1.9	W D P
Vessel %	13.1	1.8	19.2	1.6	17.6	0.7	W D P
Parenchyma%	34.0	5.0	35.6	11.4	28.6	2.5	W D P
Gelatinous fibres %	8.8	-	7.0	-	-	-	W D

Bars connecting the localities display non-significant differences at 5% probability level. W - wet, D - dry, P- plantation

3.8 Extractive content

The results of the total extractive content as determined by ethanol-benzene solubility of wood are presented in Table 9. The ANOVA showed significant differences in total extractive content between wet and dry sites with the lowest extractive content from wet site. In contrast, dry site showed higher values for total extractive content though the difference from plantation specimen was non-significant (Table 9). The paler colour of wet site sample was correlated with lower extractive content 12% whereas the decorative black streaks of dry site sample were probably due to the presence of higher amount of extractives (16%). The heartwood of plantation specimen also showed a similar pattern (13%) with uniform golden brown colour.

Table 9. Mean values (with SD in parenthesis) of total extractive content of home garden teak from wet and dry localities and forest plantation teak (n=5)

Parameter	Solvent	Wet Mean	Wet CV%	Dry Mean	Dry CV%	Plantation Mean	Plantation CV%	Bar diagram
Total extractive content %	ethanol-benzene (1:2 ratio)	12.4 (2.2)	17.9	15.98 (1.4)	8.6	13.3 (2.8)	21.0	$\overline{W\ P}\ D$

The amount of heartwood extractives in teak provides a good indication of the natural durability (Sandermann and Simatupang 1966; Simatupang *et al.* 1996; Yamamoto *et al.* 1998) and dimensional stability.

3.9 Durability

The percentage weight losses in the test blocks provide a measure of the relative decay resistance of the home garden teak to selected five fungi. The mean weight loss data of the test blocks exposed to the selected decay fungi are given in Table 10. The ANOVA revealed significant differences in the percentage of weight loss caused by brown rot fungi (Table 11). While the two brown rot fungi caused severe weight loss in wet site sample than dry and plantation sites, the three white rot fungi did not show any significant variation in weight loss among the three sites and the mean weight loss was less than 10%.

Teak timber generally falls under Class I (Highly Resistant Timbers) of the general classification system (Bakshi *et al.* 1967; ASTM 1981). The weight loss in wet site samples due to the attack of two brown rot fungi, viz. *Gloeophyllum trabeum* (Pers. ex Fr.) Murr. and *Polyporus palustris* Berk. & Curt. to the extent of 15% and 42% respectively brings down the timber to the category of Class II (Resistant Timbers) and Class III (Moderately Resistant Timbers). Although the dry and plantation specimens belonged to almost the same durability classes, they were relatively more resistant with lesser weight losses (Table 10). White rotters did not cause any damage to the timber as the percentage weight loss was in the range of 1.64-2.92 which is less than the threshold value of 10% for the durability Class I (Table 10) as reported by Bhat and Florence (2003) for 5-year-old juvenile teak from high input plantations.

Table 10. Mean values of weight loss percentage of 35-year-old home garden teak from wet and dry sites compared to forest plantation

Location	Weight loss %				
	Brown rot		White rot		
	Gloeophyllum trabeum	*Polyporus palustris*	*Pycnoporus sanguineus*	*Trametes hirsuta*	*T. versicolor*
Wet	15.08	41.97	1.86	2.66	2.00
Dry	5.18	19.68	1.74	2.92	1.74
Plantation	3.92	31.61	2.02	2.12	1.64
Bar diagram	$W\ \overline{D\ P}$	W D P	$\overline{W\ D\ P}$	$\overline{W\ D\ P}$	$\overline{W\ D\ P}$

Bar connecting the localities display non-significant differences at 5% probability level, W - wet; D - dry; P-plantation

The present findings of relatively high susceptibility of wet site home garden teak to brown rot fungi is attributed to lower extractive content (12%) than dry site (Table 9). The natural durability of teak is perhaps dependent also on the amount of individual compound (tectoquinone) present in the total extractive content (Haupt *et al.* 2003).

Table 11. ANOVA of decay resistance test (% weight loss) of 35-year-old home garden teak from wet, dry sites compared to plantation teak subjected to five decay fungi

Source of Variation	d.f.	Sum of squares	Mean square	F-value
		Gloeophyllum trabeum		
Between location	2	373.876	186.938	4.01*
Within location	12	558.859	46.580	
		Polyporus palustris		
Between location	2	1243.834	621.917	17.13**
Within location	12	435.612	36.301	
		Trametes hirsuta		
Between location	2	1.663	0.831	0.04*
Within location	12	2.349	0.196	
		T. versicolor		
Between location	2	0.346	0.173	0.44^{ns}
Within location	12	4.689	0.391	
		Pycnoporus sanguineus		
Between location	2	0.197	0.00986	0.39^{ns}
Within location	12	2.996	0.250	

*** Significant at 1% probability level; * Significant at 5% probability level;* ^{ns} *non-significant*

4. Conclusions

Based on the results presented, the study draws the following conclusions:

1. Timber grown in homesteads of wet sites has generally larger diameter logs and that from dry localities has smaller dimensional logs with more pole sizes than forest plantation of similar age group. Obviously, the sawn wood out turn from wet site logs was significantly higher. However, due to lack of standard silvicultural practices such as initial spacing/pruning/thinning, log form is different in home garden teak with more severe defects like bends and knots which may lower the timber value.
2. While the darker colour of heartwood with black streaks from dry site home garden is more or less similar to that of forest plantation sample, timber sample from wet site displays paler colour which may adversely affect the price of the timber.
3. Timber from homesteads of wet sites is more susceptible to brown rot fungi although no significant differences exist with respect to white rot fungi among the home garden and plantation grown timbers.
4. Higher natural durability of teak wood from drier locality home gardens is reflected in higher extractive contents with darker colour than wet site teak which has faster growth.
5. Teak wood of home garden forestry is not inferior to that of forest plantation in its strength properties and heartwood proportion of the stem volume.
6. Bark properties varied significantly with thicker bark of lower density and higher moisture content in homesteads especially of wet site.

5. Acknowledgments

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6. Literature Cited

American Society for Testing Materials (ASTM). 1984. Standard test method for alcohol-benzene solubility of wood. ASTM D-1107-84, Annual Book of ASTM Standards, Part 22, Philadelphia, 2 pp.

American Society for Testing Materials (ASTM). 1981. Standard method of accelerated laboratory test of natural decay resistance of woods, ASTM D- 2017-71 (Re approved 1978), Annual Book of ASTM Standards, part 22, Philadelphia, pp. 639-645.

Bakshi, B.K., Puri, Y.N. and Singh, S. 1967. Natural decay resistance of Indian Timbers. I. Introduction and method. II. Decay resistance of Sal (*Shorea robusta* Gaertn.) and Teak (*Tectona grandis* L.f.). *Indian Forester* 93: 305-328.

Barajas-Morales, J. 1985. Wood structural differences between trees of two tropical forests in Mexico. *IAWA Bulletin* 6, 355-364.

Bhat, K.M., Priya, P.B. and Rugmini, P. 2001. Characterisation of juvenile wood in teak. *Wood Science & Technology* 34: 517-532.

Bhat, K.M. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. *Bios et Forests des Tropiques* 263(1): 6-16.

Bhat, K.M. 2003. Quality concerns of sustainable teak wood chain. *In:* Proceedings (unedited) of the International Conference on "Quality Timber Products of Teak from Sustainable Forest Management". 2-5 December 2003, Kerala Forest Research Institute, Peechi, India. pp.130-141.

Bhat, K.M. and Florence, E.J.M. 2003. Natural decay resistance of juvenile teak wood grown in high input plantations. *Holzforschung*, 57 (5): 453-455.

Bureau of Indian Standards. 1986. Indian Standard Methods for testing small clear specimens of timber. IS: 1708 (Pts, 2, 3, 4, 5, 8).

Bureau of Indian Standards. 1968. Grading rules for Teak logs, IS: 4895: 1-11.

Commission Internationale de I clairage (CIE). 1976. Publication No.15.2, *Colorimetry*.

FRI & Colleges. 1970. Growth and Yield Statistics of Common Indian Timbers (Plains Region) Vol. 2. Forest Research Institute and Colleges, Dehra Dun.

Gierlinger, N., Jacques, D., Grabner, M., Wimmer, R., Schwanninger, M., Rozenberg, P. and Pâques, L.E. 2004. Colour of larch heartwood and relationships to extractives and brown-rot decay resistance. *Tress-Structure and Function*, 18 (1), 102-108.

Haupt, M., Richter, H.G., Leithoff, H., Meier, D., Puls, J. and Faix, O. 2003. Natural durability of plantation grown teak (*Tectona grandis* L. f.) from Panama in relation to heartwood extractives. *In:* Nair, K.K.N., Bhat, K.V., Muralidharan, E.M. (Eds.), Proceedings (Abstract) of the International Conference on "Quality Timber Products of Teak from Sustainable Forest Management". 2-5 December 2003, Kerala Forest Research Institute, Peechi, India. pp.85.

Hiller, C.H., Freese, F. and Smith, D.M. 1972. Relationship in black walnut heartwood between color and other physical and anatomical properties. *Wood Fiber* 4, 38-42.

Hillis, W.E. 1971. Distribution, properties and formation of some wood extractives. *Wood Science & Technology* 5, 272-289.

Hillis, W.E. 1978. Wood quality and utilization. *In:* Hillis, W.E., Brown, A.G. (Eds.), Euclayptus for wood production. CSIRO, Australia. pp. 259-289.

Minemura, N., Lim, S.C. and Hong, L. T. 1998. Colour characteristics of Malaysian timbers. *Journal of Tropical Forest Products* 4 (1): 90-92.

Minemura, N., Umehara, K. and Satoh, M. 1995. Color improvement (1). Report of the Hokkaido Forest Products Research Institute, 84, 14-20.

Munsell Color Company. 1976. Munsell Book of Color, Baltimore, USA.

Munsell, A.H. 1905. A Color Notation. Boston, USA

Nair, P.K. K. R. 1989. *Agroforestry Systems in the Tropics*. Kulwer Academic Publ.664p.

Nelson, N.D., Maeglin, R.R. and Wahlgren, H.E. 1969. Relationship of black walnut wood color to soil properties and site. *Wood Fiber* 1, 29-37.

Olesen, P.O. 1971. The water displacement method. *Forest Tree Improvement* 3: 3-23.

Phelps, J.E., McGinnes, E.A., Garnett, Jr. H.E. and Cox, G.S. 1983. Growth- quality evaluation of black walnut wood. Part II – Color analysis of veneer produced on different sites. *Wood and Fiber Science* 15, 177-185.

Puri, Y.N. 1962. Natural decay resistance of Indian timbers. III. Heartwood extractives of Sal (*Shorea robusta* Gaertn.) and Teak (*Tectona grandis* L. f.). *Indian Forester* 93 (7): 447-454.

Rink, G. 1987. Heartwood color and quantity variation in a young black walnut progeny test. *Wood and Fiber Science* 19, 93-100.

Rudman, P., and Da Costa, E.W.B. 1959. Variation in extractive content and decay resistance in the heartwood of *Tectona grandis*. *Journal of the Institute of Wood Science* 3: 33-42.

Sandermann, W. and Simatupang, M.H. 1966. On the chemistry and biochemistry of teakwood (*Tectona grandis* L. f.). *Holz als Roh- und Werkstoff* 24: 190-204.

Simatupang, M.H., Rosamah, E. and Yamamoto, K. 1996. Importance of teakwood extractives to wood properties and tree breeding. *In:* Proceedings of the "Conference on Forestry and Forest Products Research". November, 1996. Vol. 2: 235-246.

Sullivan, J.D. 1967a. Color characterization of wood: color parameters of individual species. *Forests Products Journal* 17, 25-29.

Sullivan, J.D. 1967b. Color characterization of wood: spectrophotometry and wood color. *Forests Products Journal* 17, 43-48.

Thulasidas, P.K. and Bhat, K.M. 2003. Timber value of teak from homesteads: some observations from Kerala, India. *In:* Nair, K.K.N., Bhat, K.V., Muralidharan, E.M. (Eds.), Proceedings (Abstract) of the International Conference on "Quality Timber Products of Teak from Sustainable Forest Management". 2-5 December 2003, Kerala Forest Research Institute, Peechi, India, pp. 83.

Vetter, R.E., Coradin, V.R., Martino, E.C. and Camargos, J.A.A. 1990. Wood colour - A comparison between determination methods. *IAWA Bulletin* 11 (4): 429-439.

Wilkins, A.P. and Stamp, C.M. 1990. Relationship between wood color, silvicultural treatment and rate of growth in *Eucalyptus grandis* Hill (Maiden). *Wood Science & Technology* 24, 297-304.

Yamamoto, Y., Simatupang, M.H. and Hashim, R. 1998. Caoutchouc in teak wood (*Tectona grandis* L.f.): formation, location, influence on sunlight irradiation, hydrophobicity and decay resistance. *Holz als Roh- und Werkstoff* 56:201-209.

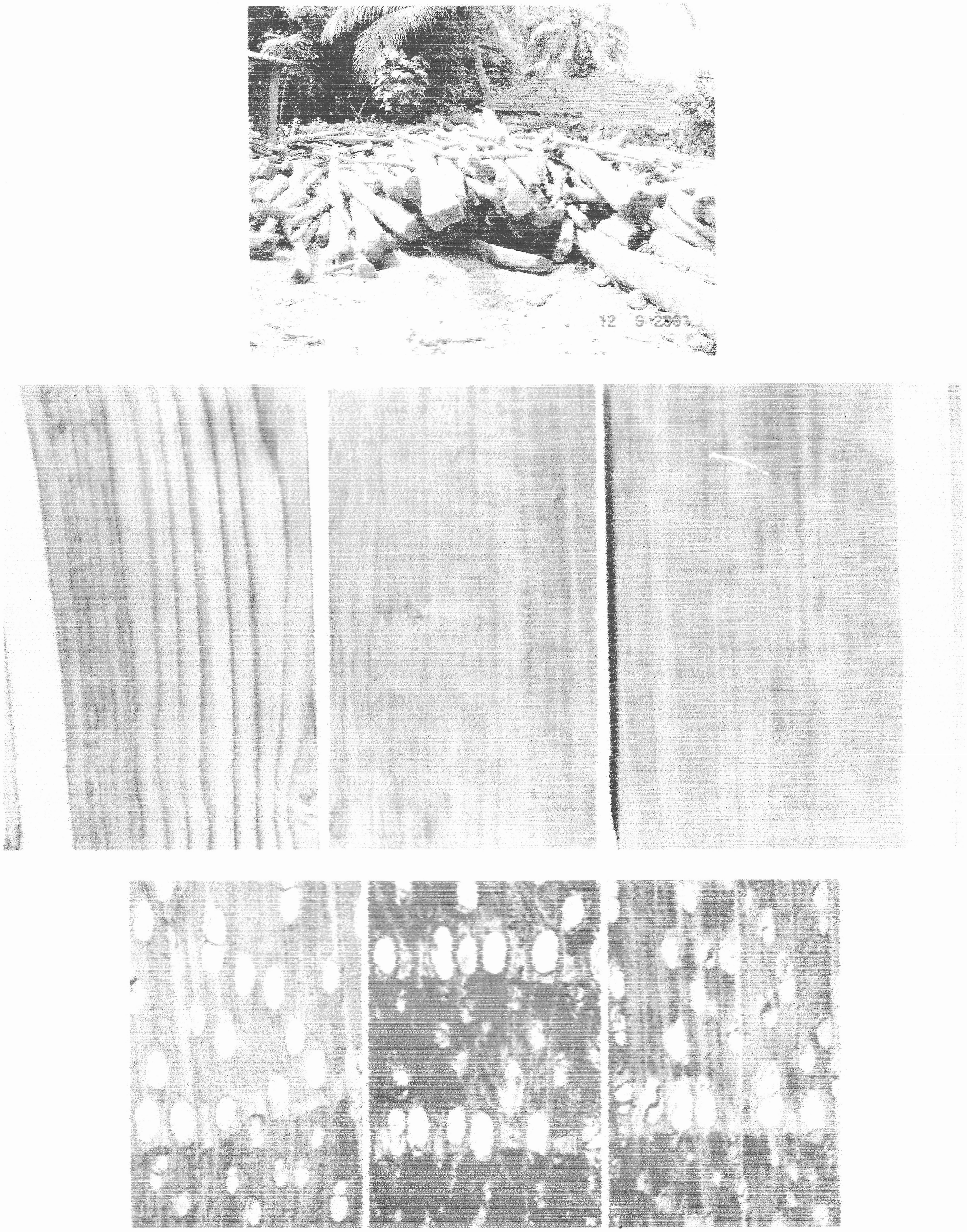

Plate I.

Top row: Teak wood supply from homesteads

Middle row: Wood colour of homestead teak as compared to forest plantation. Note the golden brown colour with black streaks in dry site (left), paler heartwood in wet site (middle) and uniform golden brown colour of forest plantation teak (right)

Bottom row: Transverse sections of home garden teak (wet and dry sites) compared with plantation grown teak (x80); Note the faster growth with wider ring from wet site (left) and forest plantation teak (right), narrow ring and denser tissue in dry site (middle)