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INCLINATION OF LATICIFERS AND PHLOIC RAYS IN TEN CLONES OF *HEVEA BRASILIENSIS*

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A detailed investigation on various structural traits of bark and their influence on the inclination and orientation of laticifers in *Hevea brasiliensis* was attempted in ten clones, *viz.*, Tjir 1, Gl 1, GT 1, PB 86, PB 28/59, PB 235, RRIM 600, RRIM 703, RRII 105 and RRII 300 at the age of 17-21 years. The inclination of laticifers in seedling progenies of two Wickham x Amazon cross combinations (RRII 105 x MT 1005 and RRIM 600 x AC 495) and bud grafted plants of RRII 105 and RRIM 600 was also studied at the age of 4 years to understand the pattern of inclination during the immature growth phase.

The present investigation revealed significant clonal variation in the angle of inclination of laticifers and phloic rays. The clones RRIM 703, Gl 1, RRII 300, Tjir 1, PB 235 and GT 1 showed laticifers inclined towards the right and the clone PB 86 towards the left direction. Three clones, PB 28/59, RRIM 600 and RRII 105, showed the laticifer inclination towards both left and right directions. The young budded plants of RRII 105 showed rightward inclination whereas the laticifers of the clone RRIM 600 showed both rightward and leftward inclination. The seedling progenies of both cross combinations showed rightward inclination. Correlation and regression analyses conclusively proved that various anatomical characters showed positive or negative associations with laticifer inclination. The inclination of phloic rays was identified as the most important factor which shows positive influence on inclination of laticifers. The inclination of laticifers in *H. brasiliensis* can be considered as a clone - specific character and has great significance on the direction and angle of tapping cut to be adopted for optimisation of potential yield of different clones.

Key words: Bark anatomy, *Hevea brasiliensis*, Laticifer inclination, Phloic rays.

INTRODUCTION

Hevea brasiliensis is the major source of natural rubber (NR), extracted from the latex formed in the specialised tissues called laticifers or latex vessels (Dickerson, 1964; Southorn, 1966). Latex vessels are distributed among the secondary phloem tissue (bark) as articulated anastomose network. Anatomically bark of *H. brasiliensis* consists of an inner soft bark continuous to cambium and outer hard bark peripheral to soft bark marked with abundance of stone cells. Latex is extracted by tapping cut, done at a specific angle on the bark based on the orientation and inclination of laticiferous system (Gomez, 1982). A half spiral cut on the bark of tree trunk from upper left to lower right at an angle of 25° in seedlings and 30° for budded trees is generally adopted (Vijayakumar *et al.*, 2000).

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The most important consideration during the early evolution of tapping was the angle of inclination of laticifers and slope of tapping cut. Petch (1911) made the first observation about the orientation of wood elements in 25 trees, of which the orientation was vertical in seven trees and towards the right in 18 trees and hence recommended left inclined cut. Later, De Jong (1916) observed that the angle of inclination of laticifers in 93 trees had an average of 3.7° to the right and calculated the extra yield for various angles of cut. Mass (1925) and Dijkman (1951) also reported extra latex yield on tapping in relation to the inclination of latex vessels.

Gomez and Chen (1967) studied the angle of inclination of laticifers in 28 clones of *H. brasiliensis* and reported the inclination towards the right from 2.1 to 7.1°. However, in certain trees belonging to clones *viz.*, RRIM 600, BD 5 and RRIM 618 a leftward inclination ranging from 3.22 to 3.84° was observed. In this context the advantages and disadvantages of steepening the slope of tapping cut were discussed. A 45° tapping slope was recommended for budded trees through which 2-3% increase in yield was obtained. The major disadvantage of this system of tapping is the higher rate of bark consumption. Hence, a thorough knowledge on the inclination of laticifers in different *H. brasiliensis* clones is necessary to adopt perfect systems of tapping. This would help to categorize different clones with specific pattern of laticifer inclination and orientation. The present study attempts to observe the inclination of laticifers in different clones of *H. brasiliensis* with reference to the influence and inter-relationship of various bark structural traits on the alignment and orientation of laticifers and phloic elements in the mature and immature growth phases.

MATERIALS AND METHODS

Ten clones of *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg. were selected from the germplasm garden planted in the Central Experiment Station of Rubber Research Institute of India (RRII) in randomized block design (RBD) with three replicates and three trees per plot. The clones *viz.*, Tjir1, Gl 1, GT 1, PB 28/59, PB 86, PB 235, RRIM 600, RRIM 703, RRII 105 and RRII 300 were at the age of 17 to 21 years and under regular tapping. Seedling progenies of two Wickham x Amazon cross combinations (RRII 105 x MT 1005 and RRIM 600 x AC 495) and bud grafted plants of two clones *viz.,* RRII 105 and RRIM 600, at the age of 4 years, were also selected to observe the inclination pattern of laticifers in the juvenile growth phase (Table 1).

Virgin bark samples were collected from nine trees from each clone at 150 cm height in the case of mature trees and 20-30 cm height from the ground in the case of juvenile plants. The method of bark sampling was adopted as per Gomez and Chen (1967) with certain modifications as described in Figure1.

A vertical line was drawn on the tree trunk along the longitudinal axis of the tree and the bark samples of 2 x 2 cm and 2 x 3 cm were collected parallel to the vertical line. A longitudinal mark was made on the sampled bark by cutting on the right top corner to maintain the orientation of the bark on the tree. The samples collected were fixed in formalin-acetic-alcohol (FAA) and sections of 30 – 60 µm thickness were taken in tangential longitudinal (TLS) plane, using

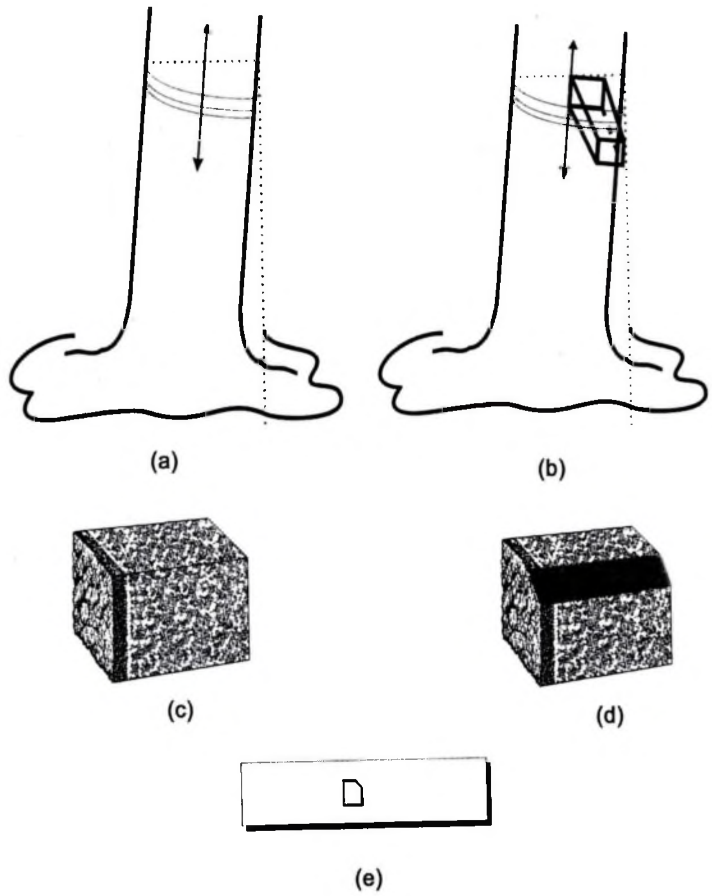

Fig. 1. Method of bark sampling and mounting of sections. (a) vertical line drawn on tree trunk along the longitudinal axis. (b) bark sampler placed parallel along the vertical line. (c) collected bark sample (d) a cut made on the corner of the bark sample. (e) Mounting of sections on the slides maintaining the orientation of the tissue.

Reichert Jung sledge microtome, stained with Oil Red O (Omman and Reghu, 2003) and the micro slides prepared maintaining the actual orientation of the tissues as on the tree.

The bark sections were observed under Leitz Aristoplan research microscope attached to Leica Q 5000 IW image analysis system. The images of the sections documented in the image analysis system were used to measure the inclination of laticifers and phloic rays by means of Leica Q Win V. 2.1 image analysis software. The parameters studied were (i) angle of inclination of laticifers in both soft bark and inner hard bark and (ii) angle of inclination of phloic rays in soft and inner hard bark. The data obtained were subjected to statistical analyses *viz.*, analysis of variance and regression (Gomez and Gomez, 1983; Panse and Sukhatme, 1985).

Table 1. **Details of materials selected**

Clones	Age (years)	Origin/Parentage
Tjir I	21	Primary clone evolved by Tjirandji Estate, Indonesia
Gl 1	21	Primary clone evolved by Glenshiel Estate, Malaysia
PB 86	21	Primary clone evolved by Prang Besar Estate, Malaysia
GT 1	21	Primary clone evolved by Gondang Tapen Estate, Indonesia
PB 28/59	21	Primary clone evolved by Prang Besar Estate, Malaysia
RRII 105	19	Hybrid clone (Tjir x GI 1) evolved by Rubber Research Institute of India
RRIM 600	19	Hybrid clone (Tjir 1 x PB 86) evolved by Rubber Research Institute of Malaysia
RRIM 703	19	Hybrid clone (RRIM 600 x RRIM 500) evolved by Rubber Research Institute of Malaysia
PB 235	21	Hybrid clone (PB 5/51 x PB 5/78) evolved by Prang Besar Estate
RRII 300	17	Hybrid clone (Tjir x PR 107) evolved by Rubber Research Institute of India
Seedlings (Wickham x Amazon)		
Seedling Progeny	4	Hybrid progeny (RRII 105 x MT 1005)
Seedling Progeny	4	Hybrid progeny (RRIM 600 x AC 495)
Budded plants		
RRII 105	4	Hybrid clone (Tjir x GI 1)
RRIM 600	4	Hybrid clone (Tjir 1 x PB 86)

RESULTS AND DISCUSSION

The orientation and distribution pattern of laticifers and other phloic elements in the bark are given Figure 2. The latex vessels present in the soft bark immediately above the cambial zone and the inner hard bark just above the soft bark (SB) are functional. In the inner hard bark (IHB), although few stone cells are distributed at random, their presence do not interrupt the continuity of the laticifers. The hard bark region situated immediately above the inner hard bark is occupied with large number of stone cells, thus disrupting the laticifers and rendering them non-functional and this region is called outer hard bark (OHB) region. These observations indicated that the laticifers present in the soft bark and inner hard bark only were contributing to latex yield.

Angle of inclination of laticifers in soft bark

The laticifers showed varying degrees of inclination (Table 2) in the SB region ranging from 3.36 to 8.42° towards the right in six clones *viz.*, RRIM 703, GT 1, RRII 300, Tjir 1, PB 235 and Gl 1. The angle of inclination was maximum (8.42°) for RRIM 703 (Fig.3a) and minimum (3.36°) for Gl 1 (Fig.3b). The rightward inclination of laticifers observed in other clones was 5.75° for GT 1 (Fig.3c), 5.13° for RRII 300 (Fig.3d), 4.27° for Tjir 1 (Fig.3e) and 3.58° for PB 235. The inclination of laticifers for four clones *viz.*, PB 86, RRII 105, PB 28/59 and RRIM 600 were either towards right, left or in both the directions. Moreover, within these clones the individual trees showed varying degrees of laticifer inclination to right and left. For instance seven trees of PB 86

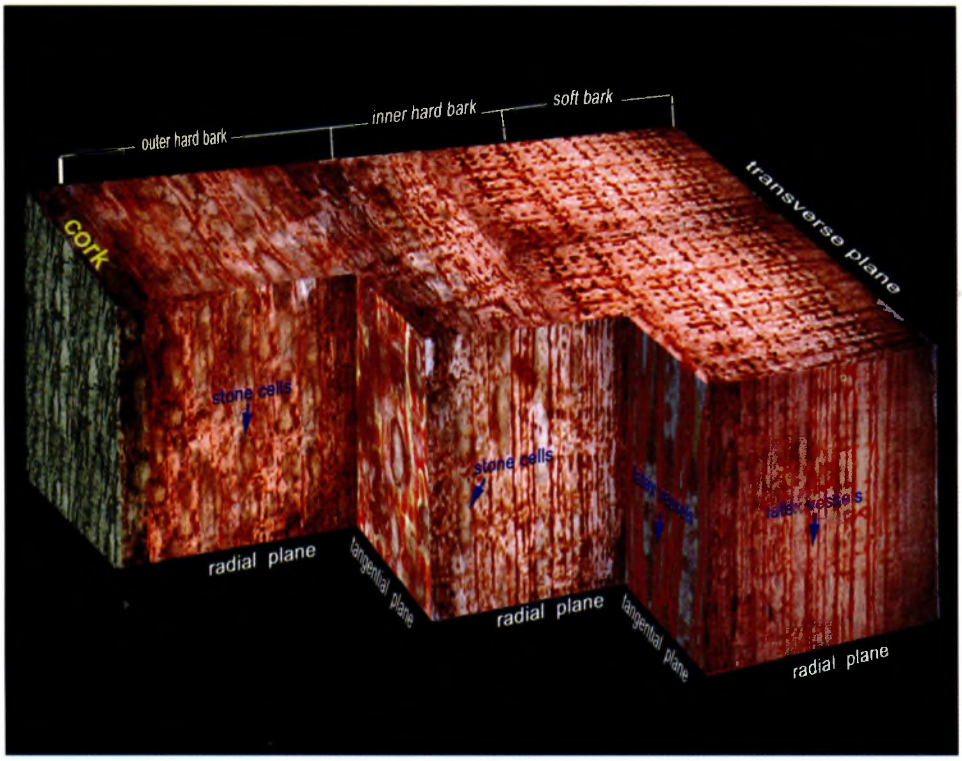

Fig. 2. Three dimensional picture of bark of *H. brasiliensis*

showed leftward inclination with a mean angle of 4.27°; one tree with rightward inclination (4.33°) and another tree with both leftward (1.15°) and rightward (1.08°) inclination. In RRII 105 the laticifers were both left (2.10°) and right (3.24°) for eight trees (Fig.3f) and towards right only for one tree at an angle of 8.06°. Six trees of PB 28/59 showed both left (1.61°) and rightward (4.01°) laticifer inclination (Fig.3g) and three trees were exclusively with rightward inclination (4.21°). Five trees of the clone RRIM 600 had laticifers inclined towards both left and right (Fig.3h); three trees were with leftward and one tree with rightward inclination.

Angle of inclination of laticifers in the inner hard bark

With respect to the inclination of laticifers in the IHB region (Table 3), six clones *viz.*, RRIM 703, GT 1, RRII 300, Tjir 1, PB 235 and Gl 1 were found to have laticifers inclined exclusively towards the right with a maximum degree of 8.73° for RRIM 703 and minimum of 3.52° for PB 235 (Fig. 4 a). For GT 1 the inclination was 7.01° followed by RRII 300 (5.50°), Gl 1 (4.63°) and Tjir 1 (4.51°). Tree to tree variation for this trait was low for RRIM 703 and GT 1, medium for Tjir 1 and high for RRII 300 and Gl 1.

Table 2. **Angle of inclination of latex vessels in soft bark**

Clone	No. of trees	Latex vessel inclination	Mean (degrees)	CV (%)
RRIM 703	9	right	8.42	33
GT 1	9	right	5.75	35
RRII 300	9	right	5.13	57
Tjir I	9	right	4.27	37
PB 235	9	right	3.58	80
Gl 1	9	right	3.36	43
PB 86	1	left &	1.15	
		right	1.08	
	1	right	4.33	
	7	left	4.27	
RRII 105	8	left &	2.10	
		right	3.24	
	1	right	8.06	
	Nil	left		
PB 28/59	6	left &	1.61	
		right	4.01	
	3	right	4.21	
	Nil	left		
RRIM 600	5	left &	1.44	
		right	1.49	
	1	right	2.60	
	3	left	2.51	
Juvenile seedling (RRII 105xMT 1005)	4	right	3.84	
Juvenile seedling (RRIM 600xAC 495)	4	right	2.55	
Juvenile budded plants(RRII 105)	4	right	5.01	
Juvenile budded plants(RRIM 600)	3	right	3.30	
	1	right	2.14	

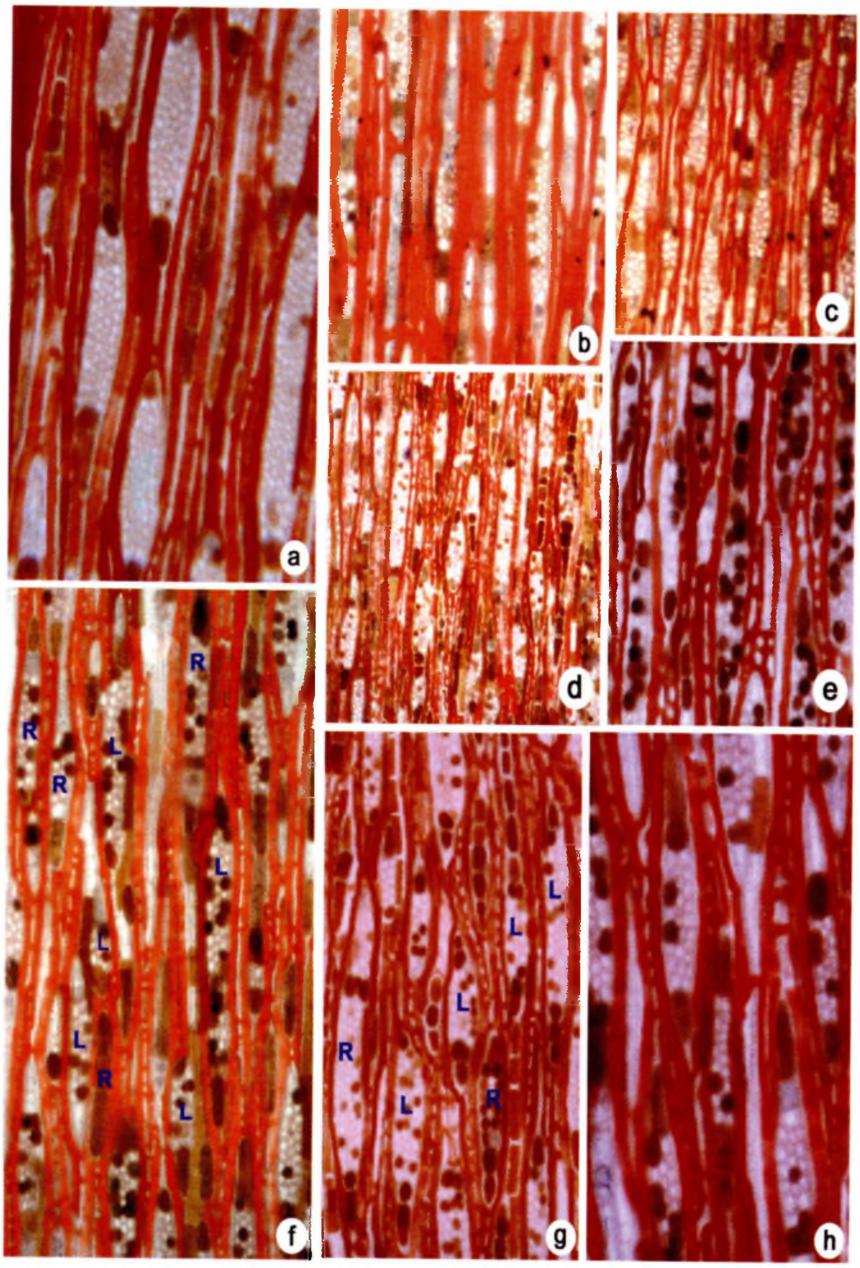

Fig. 3. TLS of bark sho·.ing inclination of laticifers in soft bark. (a) RRIM 703 rightward inclination. (b) Gl 1 rightward inclination. (c) GT 1 rightward inclination. (d) RRII 300 rightward inclination. (e) Tjir 1 rightward inclination. (f) RRII 105 leftward and rightward inclination. (g) PB 28/59 both leftward and rightward inclination. (h) RRIM 600 leftward inclination. a - X125; b,e,f,g,h - X75; c-X50: d- X30)

Table 3. **Angle of inclination of latex vessels in the inner hard bark**

Clone	No. of trees	Latex vessel inclination	Mean (degrees)	CV (%)
RRIM 703	9	right	8.73	29
GT 1	9	right	7.01	19
RRII 300	9	right	5.50	26
Tjir I	9	right	4.51	35
PB 235	9	right	3.52	42
Gl 1	9	right	4.63	55
PB 86	1	left &	0.80	
		right	1.30	
	1	right	3.20	
	7	left	4.42	
RRII 105	7	left &	2.42	
		right	2.68	
	2	right	7.15	
	Nil	left		
PB 28/59	5	left &	1.92	
		right	2.84	
	4	left	6.24	
	Nil	left		
RRIM 600	3	left &	2.05	
		right	0.85	
	3	right	3.20	
	3	left	3.13	

Four clones (PB 86, RRII 105, PB 28/59 and RRIM 600) exhibited the inclination towards the left, right or both directions. In PB 86 (Fig. 4 b) seven trees showed laticifers inclined exclusively towards the left with a mean degree of 4.42°. However, one tree showed rightward inclination (3.20°) and another tree had laticifers inclined towards both left (0.08°) and right (1.30°). Both left and rightward laticifer inclination was noticed in seven trees of the clone RRII 105 with a mean value of 2.42° left and 2.68° right. However, two trees of this clone showed rightward inclination with the mean value 7.15°. In PB 28/59, four trees rightward inclination with the mean value 6.24° and five trees with inclination towards both left and right direction (Fig. 4c). The clone RRIM 600 exhibited inclination of laticifers towards both directions. Three trees showed inclination of laticifers towards left and three towards right and the laticifers of three trees were inclined towards both directions.

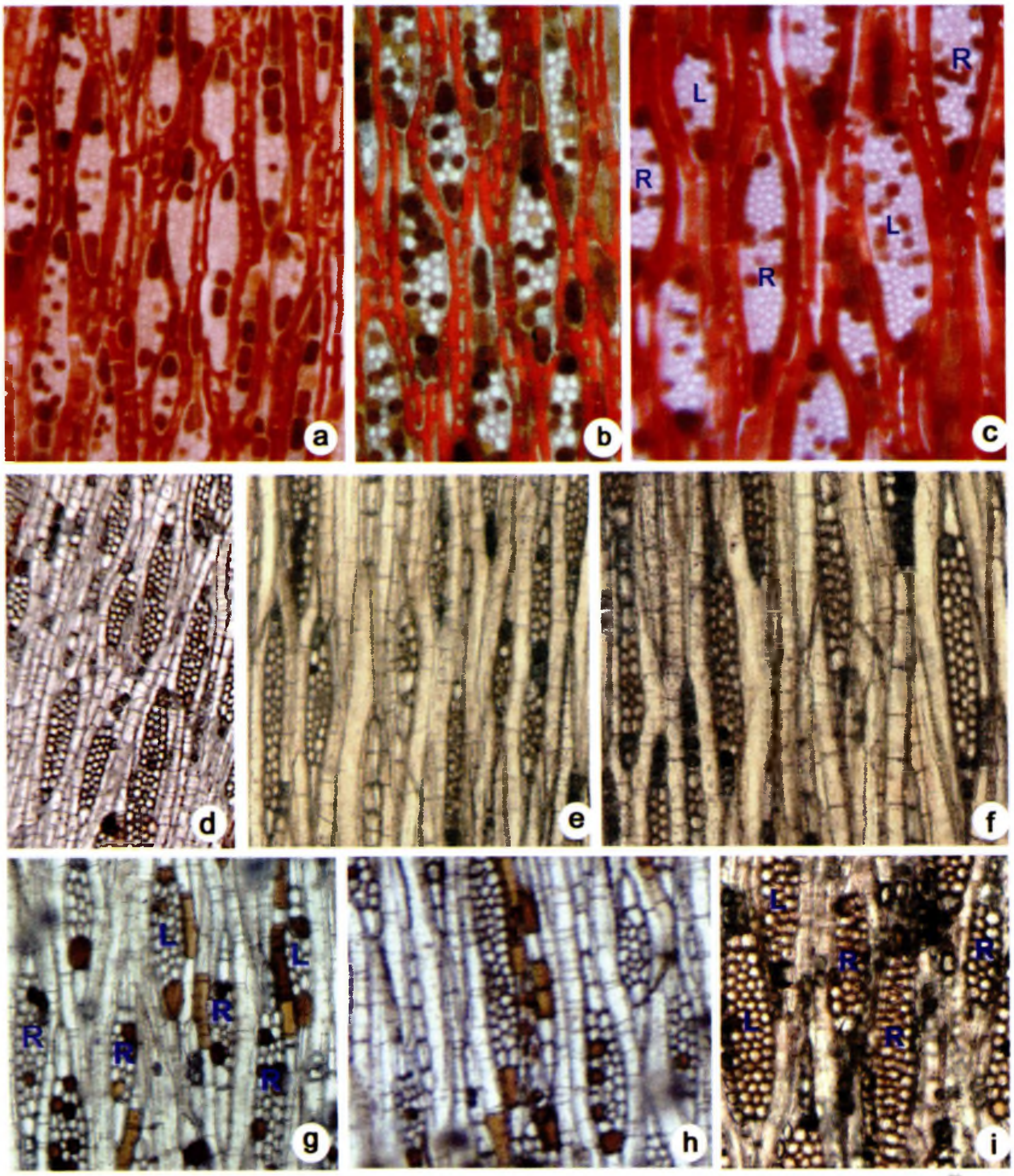

Fig. 4. TLS of bark. a-c inclination of laticifers in inner hard bark region. (a) PB 235 rightward or inclination. (b) PB 86 leftward inclination. (c) PB 28/59 both right and leftward inclination; **d-i** inclination of phloic rays. (d) RRIM 703 rightward inclination. (e) Gl 1 rightward inclination in SB. (f) PB 86 leftward inclination in SB. (g) RRII 105 left and rightward inclination in SB. (h) RRIM 600 leftward inclination in SB. (i) RRII 105 left and rightward inclination in IHB. a-i-X75

Table 4. **Angle of inclination of phloic rays in soft bark**

Clones	No. of trees	Inclination of phloic rays	Mean (degrees)	CV (%)
RRIM 703	9	right	7.13	30
GT 1	9	right	6.88	25
RRII 300	9	right	5.27	58
Tjir I	9	right	3.50	42
PB 235	9	right	3.59	70
Gl 1	9	right	3.09	56
PB 86	1	left &	2.21	
		right	1.18	
	1	right	7.30	
	7	left	5.21	
RRII 105	7	left &	2.02	
		right	2.68	
	2	right	5.45	
	Nil	left		
PB 28/59	4	left &	1.73	
		right	1.28	
	5	right	5.81	
	Nil	left		
RRIM 600				
	5	left &	1.33	
		right	1.31	
	1	right	2.42	
	3	left	1.61	
Juvenile seedling (RRII 105xMT 1005)	4	right	3.15	
Juvenile seedling (RRIM 600xAC 495)	4	right	2.69	
Juvenile budded plants(RRII 105)	4	right	5.62	
Juvenile budded plants(RRIM 600)	3	right	3.60	
	1	left	1.75	

Angle of inclination of phloic rays in soft bark

The phloic rays of six clones (RRIM 703, GT 1, RRII 300, Tjir 1, PB 235 and Gl 1) showed inclination exclusively towards the right (Table 4). Among these, RRIM 703 (Fig. 4d) recorded the maximum rightward inclination (7.13°) followed by GT 1 (6.88°), RRII 300 (5.27°), PB 235 (3.59°), Tjir 1(3.50°) and the minimum was for Gl 1 (3.09°) (Fig. 4e). The intraclonal variation for this trait was high in the clones PB 235, RRII 300 and Gl 1.

The phloic rays were inclined towards left, right or both directions in four clones (PB 86, RRII 105, PB 28/59 and RRIM 600). PB 86 showed leftward inclination of rays (Fig. 4f) in seven trees with a mean value of 5.21°. In this clone the phloic ray inclination was noticed in one tree with right (7.30°) and another with both left (2.21°) and right (1.18°). In RRII 105, seven trees had rays inclined towards both directions (Fig. 4g). Two trees showed rightward inclination of rays at 5.45°. In clone PB 28/59, four trees showed leftward and rightward inclination with mean value of 1.73° and 1.28°, respectively. The other five trees recorded rightward inclination of phloic rays. In three trees of RRIM 600, it was noticed that the rays were inclined towards the left (Fig. 4h) with a mean inclination of 1.61° in which five trees showed leftward and rightward inclination and one tree with rightward inclination.

Angle of inclination of phloic rays in the inner hard bark

Table 5 depicts the angle of inclination of phloic rays in IHB zone. Among the clones studied, six of them showed inclination of rays towards the right (RRIM 703, GT 1, RRII 300, PB 235, Tjir 1 and Gl 1) and four clones (PB 86, RRII 105, PB 28/59 and RRIM 600) had rays inclined towards left, right or towards both directions.

The angle of inclination of rays towards the right was the highest for RRIM 703 (8.95°) and the lowest for Gl 1 (3.40°). Other clones like GT 1, RRII 300, PB 235 and Tjir 1 recorded rightward inclination with mean values 6.64°, 5.78°, 3.89° and 3.57°, respectively. Tree to tree variation for this character was the highest for RRII 300 and Gl 1, medium for Tjir 1 and PB 235 and the lowest for RRIM 703 and GT 1.

Seven trees of PB 86 exhibited only leftward inclination of phloic rays with an average angle of 4.24°. One tree showed rightward inclination (3.25°) and another one showed both rightward (1.08°) and leftward (2.00°) inclination of rays. Whereas in RRII 105, six trees exhibited both leftward (3.20°) and rightward (3.59°) inclination (Fig. 4i) and three of them showed only rightward (4.13°) inclination. In PB 28/59, four trees had both leftward and rightward inclination with mean values of 1.55° and 3.18°, respectively. Other five trees with rightward inclination had an average slope of 6.38°. The clone RRIM 600 showed a mixed pattern of ray inclination of both left (2.00°) and right (0.85°) for three trees. Three trees of this clone showed only rightward (3.20°) inclination and another three trees had leftward (3.00°) inclination.

Factors affecting latex vessel inclination

Correlation of characters with latex vessel inclination

The laticifer inclination towards the right direction was positively correlated with phloic

Table 5. **Angle of inclination of phloic rays in the inner hard bark**

Clone	No. of trees	Inclination of phloic rays	Mean (degrees)	CV (%)
RRIM 703	9	right	8.95	29
GT 1	9	right	6.64	27
RRII 300	9	right	5.78	57
Tjir I	9	right	3.57	33
PB 235	9	right	3.89	39
Gl 1	9	right	3.40	58
PB 86	1	left &	2.00	
		right	1.08	
	1	right	3.25	
	7	left	4.24	
RRII 105	6	left &	3.20	
		right	3.59	
	3	right	4.13	
	Nil	left		
PB 28/59	4	left &	1.55	
		right	3.18	
	5	right	6.38	
	Nil	left		
RRIM 600	3	left &	2.00	
		right	0.85	
	3	right	3.20	
	3	left	3.00	

rays inclined to the right in both SB and IHB (Table 6). Characters which showed negative correlation were diameter of laticifers, distance between latex vessel rows in SB and area occupied by stone cells in IHB and outer hard bark (OHB).

Leftward inclination of latex vessels in SB showed highly significant correlation with the leftward inclination of phloic rays in the SB zone, whereas the thickness of IHB and stone cell area in this zone were negatively correlated (Table 7). Inclination of latex vessels in IHB was associated positively with leftward inclination of latex vessels in IHB but the number of stone cell rows in IHB and OHB regions showed negative correlation.

Certain trees exhibited both leftward and rightward inclination of latex vessels within the bark of same tree. Different factors were also found associated with each other on latex vessels inclination towards the right and left in SB and IHB regions of the bark (Table 8). The leftward inclination of latex vessels in these regions showed significant positive correlation with leftward inclination of phloic rays and negative correlation with the number of laticifer rows. The rightward inclination of latex vessels in SB showed highly significant positive correlation with four traits *viz.*, the rightward inclination of phloic rays in SB and IHB, the rightward inclination of laticifers in IHB, outer hard bark thickness and tree girth.

Table 6. **Correlation of laticifer inclination with other characters in soft bark and inner hard bark (in trees with rightward inclination)**

		Character	Inclination of laticifers to right in SB	Inclination of laticifers to right IHB
Soft bark		**Inclination of laticifers to right**	1.000	0.699 **
	Rays contiguous to LV in SB	ray width	0.205	0.140
		ray height	-0.088	-0.083
		height/width ratio	-0.199	-0.130
	Rays in LV free zone in SB	total ray frequency	-0.169	-0.239
		frequency of multiseriate rays	0.066	-0.170
		frequency of biseriate rays	0.048	0.163
		frequency of uniseriate rays	-0.245	-0.125
Inner hard bark		**Inclination of rays to right**	0.862 **	0.688 **
	Rays contiguous to LV in IHB	ray width	-0.111	-0.231
		ray height	-0.139	-0.182
		height/width ratio	-0.049	0.045
		total ray frequency	0.001	0.016
		frequency of multiseriate rays	0.157	0.010
		frequency of biseriate rays	0.269	0.215
		frequency of uniseriate rays	-0.267	-0.183
		Inclination of LVs to right	0.699 **	1.000
	Rays in LV free zone in IHB	ray width	-0.039	-0.050
		ray height	-0.246	-0.117
		height/width ratio	-0.120	0.027
		total ray frequency	0.177	0.171
		frequency of multiseriate rays	0.217	0.104
		frequency of biseriate rays	-0.043	0.207
		frequency of uniseriate rays	-0.063	0.021
	All other parameters	**Inclination of rays to right**	0.778 **	0.850 **
		ray width	-0.057	-0.071
		ray height	-0.326	-0.185
		height/width ratio	-0.123	0.007
		total ray frequency	0.026	0.071
		frequency of multiseriate rays	-0.002	0.000
		frequency of biseriate rays	a	a
		frequency of uniseriate rays	0.092	0.238
		STL	-0.293	0.001
		STD	-0.084	-0.187
		LV dia.	-0.384 *	-0.430 *
		FIC	-0.018	0.078

.....*continued*

TLV Den	-0.053	0.143
LVD CR	0.089	0.230
LVD NCR	-0.230	-0.084
DC 1 LVR	-0.142	0.334
SBT	-0.137	-0.239
NLVR SB	0.033	-0.101
DR SB	-0.320 *	-0.099
IHBT	0.205	0.018
NLVR IHB	0.297	0.134
DR IHB	-0.389 *	-0.339 *
NSR IHB	-0.040	-0.144
OHBT	0.298	0.003
TBT	0.277	0.262
SCA IHB	-0.487 *	-0.377 *
SCAO HB	-0.519 *	-0.365 *
Girth	0.084	-0.227
Slope	0.239	0.152
LAI	-0.026 -	0.287

* Significant at $p \leq 0.05$ ** Significant at $p \leq 0.01$ [a] variable is absent

STL -sieve tube length; STD-sieve tube diameter; LV Dia- latex vessel diameter; FIC- frequency of interconnections /unit area; TLV Den -total vessel density; LVD CR -latex vessel density contiguous to rays; LVD NCR- latex vessel density non contiguous to rays; DC 1LVR -distance from cambium to 1^{st} latex vessel row, SBT- soft bark thickness; NLVR SB- number of latex vessel rows in soft bark; DR SB- distance between adjacent rows in SB; IHB- thickness of inner hard bark; NLVR IHB- number of latex vessel rows in inner hard bark; DR IHB-distance between adjacent rows in inner hard bark; NSR IHB- number of stone cell rows in inner hard bark; OHBT-thickness of outer hard bark; TBT- total bark thickness; SCA IHB- stone cell area in inner hard bark; SCA OHB- stone cell area in outer hard bark; Girth- girth of the tree; Slope- leaning angle of trees; LAI- laticifer area index

Other characters exhibiting significant negative correlation were density of latex vessels non-contiguous to rays and area occupied by stone cells in OHB. The rightward inclination of latex vessels in IHB also depicted highly significant positive correlation with four traits *viz.*, rightward inclination of phloic rays in SB and IHB and also with tree girth. Two other characters like total density of laticifers and density of laticifers non-contiguous to rays showed negative correlation.

Regression analysis

Regression analysis was done separately for trees with rightward, leftward and right to leftward inclination of latex vessels to identify the most important character responsible for the laticifer inclination in SB and IHB. The results indicated that the effect of various independent variables were positively and negatively associated with the laticifer inclination (dependent variable).

Trees with laticifers inclined to right

Different characters associated with rightward inclination of rays are presented in Table 9. The inclination of phloic rays in soft bark had highly significant positive effect on inclination of latex vessels in SB, whereas the sieve tube diameter

Table 7. **Correlation of laticifer inclination with other characters in soft bark and inner hard bark (in trees with leftward inclination)**

		Character	Inclination of laticifers to left in SB	Inclination of laticifers to left in IHB
Soft bark	Rays contiguous to LV in SB	**Inclination of LV to left**	1.000	0.597
		ray width	-0.075	0.344
		ray height	-0.505	-0.441
		height/width ratio	-0.380	-0.580
	Rays in LV free zone in SB	total ray frequency	0.279	0.117
		frequency of multiseriate rays	0.018	0.027
		frequency of biseriate rays	-0.521	-0.125
		frequency of uniseriate rays	0.284	0.242
		Inclination of rays to left	0.910 **	0.562
	Rays contiguous to LV in IHB	ray width	0.021	0.341
		ray height	-0.031	0.445
		height/width ratio	-0.028	-0.009
		total ray frequency	0.578	-0.048
		frequency of multiseriate rays	0.362	-0.082
		frequency of biseriate rays	-0.521	-0.214
		frequency of uniseriate rays	0.350	0.377
Inner hard bark	Rays in LV free zone in IHB	**Inclination of lvs to left**	0.597	1.000
		ray width	-0.165	0.320
		ray height	-0.231	-0.151
		height/width ratio	-0.569	-0.540
		total ray frequency	-0.137	-0.487
		frequency of multiseriate rays	-0.137	-0.487
		frequency of biseriate rays	a	a
		frequency of uniseriate rays	a	a
		Inclination of rays to left	0.888 **	0.761 *
		ray width	0.446	-0.145
		ray height	-0.228	0.033
		height/width ratio	-0.642	0.158
		total ray frequency	-0.441	0.133
		frequency of multiseriate rays	-0.205	0.480
		frequency of biseriate rays---	a	a
		frequency of uniseriate rays	-0.521	-0.421
		STL	-0.293	0.001
		STD	-0.084	-0.187

.....continued

All other parameters	LV dia.	0.389	0.300
	FIC	-0.140	-0.667
	TLV Den	-0.237	-0.353
	LVD CR	-0.216	-0.408
	LVD NCR	-0.138	0.370
	DC 1 LVR	-0.142	0.334
	SBT	0.279	-0.196
	NLVR SB	0.535	0.182
	DR SB	-0.578	-0.560
	IHBT	-0.815 *	-0.628
	NLVR IHB	-0.624	-0.347
	DR IHB	-0.111	-0.174
	NSR IHB	-0.510	-0.724 *
	OHBT	0.298	0.003
	TBT	-0.166	-0.511
	SCA IHB	-0.713 *	-0.107
	SCAO HB	-0.286	0.007
	Girth	-0.188	-0.121
	Slope	0.623	0.119
	LAI	-0.159	-0.086

* Significant at $p \leq 0.05$ ** Significant at $p \leq 0.01$ [a] variable is absent

STL -sieve tube length; STD-sieve tube diameter; LV Dia- latex vessel diameter; FIC- frequency of interconnections /unit area; TLV Den -total vessel density; LVD CR -latex vessel density contiguous to rays; LVD NCR- latex vessel density non contiguous to rays; DC 1LVR -distance from cambium to 1[st] latex vessel row, SBT- Soft bark thickness; NLVR SB- Number of latex vessel rows in soft bark; DR SB- Distance between adjacent rows in SB; IHB- thickness of inner hard bark; NLVR IHB- number of latex vessel rows in inner hard bark; DR IHB-distance between adjacent rows in inner hard bark; NSR IHB- number of stone cell rows in inner hard bark; OHBT-thickness of outer hard bark; TBT- total bark thickness; SCA IHB- stone cell area in inner hard bark; SCA OHB- stone cell area in outer hard bark; Girth- girth of the tree; Slope- leaning angle of trees; LAI- laticifer area index

showed negative role on laticifer inclination. Likewise, in the IHB region also, the most significant positive character identified was phloic ray inclination in IHB. However, the sieve tube length played a significant negative role on the inclination of latex vessels.

Trees with laticifers inclined to both left and right

The regression analysis for trees with both leftward-rightward inclined latex vessels and phloic rays is presented in Table 10. The rightward inclination of latex vessels was positively influenced by the rightward inclination of phloic rays in SB, along with negative influence of latex vessel density non-contiguous to rays. The leftward inclination of latex vessels in SB was also influenced positively by the leftward inclination of phloic rays in SB and diameter of the sieve tubes and negatively by the rightward inclination of phloic rays.

In the IHB region, the rightward inclined latex vessels were also positively influenced by

Table 8. **Correlation of laticifer inclination with the other characters in soft bark and inner hard bark (in trees with both left and rightward inclination)**

		Character	Soft bark		Inner hard bark	
			Inclination of LV to left	Inclination of LV to right	Inclination of LV to left	Inclination of LV to right
Soft bark		**Inclination of LV to left**	1.000	0.076	0.036	0.360
		Inclination of LV to Right	0.076	1.000	-0.140	0.867 **
	Rays contiguous to LV in SB	ray width	-0.282	0.217	-0.269	0.249
		ray height	0.262	-0.178	0.062	-0.214
		height/width ratio	0.324	-0.255	0.164	-0.299
		total ray frequency	-0.212	0.284	0.225	0.026
		freq. of multiseriate rays	0.032	0.163	0.309	-0.009
		frequency of biseriate rays	-0.010	0.314	0.135	0.268
		frequency of uniseriate rays	-0.278	-0.022	-0.045	-0.149
	Rays in LV free zone in SB	**Inclination of rays to left**	0.521 *	0.120	-0.142	0.202
		Inclination of rays to right	0.226	0.686 **	-0.303	0.809 **
		ray width	-0.283	0.025	-0.141	0.100
		ray height	0.260	-0.285	0.360	-0.232
		height/width ratio	0.333	-0.211	0.244	-0.236
		total ray frequency	0.137	0.035	-0.215	-0.171
		freq. of multiseriate rays	-0.031	-0.098	-0.179	-0.304
		frequency of biseriate rays	-0.082	0.213	0.206	0.098
		frequency of uniseriate rays	0.307	-0.031	-0.328	0.003
Inner hard bark		Inner hard bark				
		Inclination of lvs to left	0.036	-0.140	1.000	-0.163
		Inclination of lvs to right	0.360	0.867 **	-0.163	1.000
	Rays contiguous to LV in IHB	ray width	0.336	-0.219	0.118	0.036
		ray height	0.124	-0.358	0.106	-0.201
		height/width ratio	-0.223	-0.031	-0.092	-0.186
		total ray frequency	-0.047	0.314	-0.202	0.144
		freq. of multiseriate rays	0.000	0.182	-0.113	0.028
		frequency of biseriate rays	0.420	0.314	0.105	0.118
		frequency of uniseriate rays	-0.372	-0.053	0.145	-0.024
	Rays in LV free zone in IHB	**Inclination of rays to left**	0.590 *	0.021	0.533 *	0.087
		Inclination of rays to right	0.091	0.855 **	-0.081	0.939 **
		ray width	-0.180	0.083	-0.438	0.101
		ray height	0.146	-0.397	0.254	-0.207*
		height/width ratio	0.189	-0.291	0.404	-0.207
		total ray frequency	-0.043	0.092	0.114	0.048
		freq. of multiseriate rays	-0.043	0.092	0.114	0.048
		frequency of biseriate rays	a	a	a	a

.....*continued*

frequency of uniseriate rays	0.191	0.032	0.141	0.184
All other parameters				
STL	-0.439	0.266	-0.396	0.139
STD	-0.129	0.411	-0.141	0.306
LV dia.	-0.065	-0.082	0.066	-0.071
FIC	-0.328	-0.213	-0.307	-0.248
TLV Den	-0.072	-0.627 **	0.288	-0.600 **
LVD CR	-0.370	-0.163	0.290	-0.294
LVD NCR	0.298	-0.710 **	0.054	-0.529 *
DC 1 LVR	0.117	-0.157	0.177	-0.111
SBT	-0.109	0.329	-0.358	0.252
NLVR SB	0.110	0.399	-0.545 *	0.449
DR SB	0.056	-0.177	0.233	-0.257
IHBT	-0.360	-0.205	0.388	-0.324
NLVR IHB	-0.409	-0.061	0.462	-0.284
DR IHB	0.298	-0.217	-0.137	0.043
NSR IHB	-0.403	-0.196	0.392	-0.361
OHBT	0.508 *	0.221	0.548 *	0.277
TBT	-0.100	0.410	0.381	0.380
SCA IHB	0.141	-0.385	-0.015	-0.289
SCA OHB	0.408	-0.619 **	0.378	-0.387
Girth	-0.050	0.467 *	0.318	0.506 *
Slope	0.082	-0.346	0.089	-0.234
LAI	-0.181	0.179	0.318	0.127

* Significant at $p < 0.01$ ** Significant at $p \leq 0.05$ [a] variable is absent

STL -sieve tube length; STD-sieve tube diameter; LV Dia- latex vessel diameter; FIC- frequency of interconnections /unit area; TLV Den -total vessel density; LVD CR -latex vessel density contiguous to rays; LVD NCR- latex vessel density non contiguous to rays; DC 1LVR -distance from cambium to 1st latex vessel row, SBT- Soft bark thickness; NLVR SB- Number of latex vessel rows in soft bark; DR SB- Distance between adjacent rows in SB; IHB- thickness of inner hard bark; NLVR IHB- number of latex vessel rows in inner hard bark; DR IHB-distance between adjacent rows in inner hard bark; NSR IHB- number of stone cell rows in inner hard bark; OHBT-thickness of outer hard bark; TBT- total bark thickness; SCA IHB- stone cell area in inner hard bark; SCA OHB- stone cell area in outer hard bark; Girth- girth of the tree; Slope- leaning angle of trees; LAI- laticifer area index

the rightward inclination of phloic rays in IHB. The number of stone cell rows in IHB depicted a negative influence on the number of latex vessels inclined to left in the IHB region.

Inclination of laticifers and phloic rays in the juvenile growth phase

Inclination of laticifers was observed towards the right at 3.84° in the seedling progenies of the cross combination RRII 105 x MT 1005, whereas in the progenies of the cross RRIM 600 x AC 495, the angle of inclination was 2.55° towards the right. Similar rightward inclination at 5.01° was also observed in the young budded plants of RRII 105. In the case of young buddings of RRIM

Table 9. **Regression analysis on laticifer inclination in soft bark and inner hard bark (in trees having only rightward inclination)**

Dependent variable	Independent variable	Regression coefficient	t- Stat	R^2 Value
Latex vessels inclination in SB	Inclination of rays in SB	0.835	11.240 *	0.808
	Sieve tube diameter	-0.135	-3.210 *	
Latex vessels inclination in IHB	Inclination of rays in IHB	0.663	9.691 *	0.776
	Sieve tube length	-0.003	-3.139 *	

* Significant for $p \leq 0.01$

600, mixed pattern of inclination was noticed, where three plants depicted rightward inclination (3.30°) and one plant was with 2.14° leftward inclination (Table 2).

In both the seedling progenies, the phloic rays showed rightward inclination within a range of 2.69°- 3.15°. Similar result was also recorded in the young buddings of RRII 105, but the angle of inclination was slightly higher (5.62°) than that of the seedling progenies. In RRIM 600, the phloic rays of three plants had 3.60° rightward inclination and one plant had leftward inclination of 1.75° (Table 4). The observation on inclination values shows that the two tissue systems, phloic rays and laticifers are aligned in the same orientation within the bark of *H. brasiliensis.* Observations on inclination of phloic rays and laticifers during juvenile stages also confirmed the uniform pattern of these tissue systems, similar to that observed in the mature stage.

It is noteworthy to observe the occurrence of leftward inclined latex vessels in RRIM 600 trees confirming the findings of Gomez and Chen (1967). The parentage relationship of these clones with reference to laticifers inclination demands future studies. For example, one of the parents of the clone RRIM 600 is PB 86, which is found to be a clone with laticifers inclined towards left, as evident from the present study. Therefore it is assumed that the inclination of laticifers / other phloic elements may be a genetic character. This requires further investigation.

The present study revealed that there exist interclonal variations in the inclination of laticifers towards right or left with a range of

Table 10. **Regression analysis on laticifer inclination in soft bark and inner hard bark (in trees having left and rightward inclination)**

Dependent variable	Independent variable	Regression coefficient	t- Stat	R^2 Value
Latex vessels inclination to right in SB	Inclination of rightward rays in SB	0.259	5.778*	0.839
	LVs density non contiguous to rays	-0.566	-2.954*	
Latex vessels inclination to left in SB	Inclination of leftward rays in SB	0.576	4.115*	0.706
	Sieve tube diameter	0.053	3.088*	
Latex vessels inclination to right in IHB	Inclination of rightward rays in IHB	0.965	14.123*	0.947
	Number of stone cell rows in IHB	-0.234	-3.748*	
Latex vessels inclination to left in IHB	Not analysed			

* Significant for $p \leq 0.01$

2.60° to 8.42° and 2.51° to 4.27°, respectively. Whereas in the case of clones that showed mixed pattern of laticifers inclination, the range of inclination towards the right was 1.08° to 4.01°, and towards the left was 1.15° to 2.10°. According to Gomez and Chen (1967), if more than half of the trees consistently displayed leftward orientation of laticifers, and then right hand half spiral cut should be recommended. Based on the present study, it is therefore suggested that the tapping practice being followed at present, needs further refinement based on the inclination of laticifers in each *H. brasiliensis* clone.

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