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Tracheid Length and Ring width Variations in Nigerian Plantation–grown *Pinus caribaea* (Morelet) and their interrelationship

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Abstract: Variations in tracheid length and growth ring width of wood samples of plantation-grown *Pinus caribaea* was investigated. Wood materials for the study were obtained from trees felled at Afaka Forest Reserve in the guinea savanna area of Nigeria. Test samples were prepared to facilitate an examination of radial and axial variations of the two parameters evaluated in the study. Linear and quadratic regression models were constructed for predicting the tracheid length from both growth ring and number and ring width. Results showed that both early and late wood tracheid lengths significantly increased from pith to bark. In contrast, the ring width decreased from pith to bark. Results of the correlation analyses revealed that the tracheid length was highly correlated with both ring number and ring width. The prediction equation using quadratic model showed that over 98 per cent of the variations in tracheid length was accounted for by ring number from pith to bark, while over 95 percent was accounted for by ring width. While the prediction equations for the linear models produced high coefficients of determination which lied between 0.787 and 0.959, those of the quadratic models gave higher coefficient values of 0.971 to 0.978.

Introduction

Tracheid length is an important wood property particularly, as it influences the pulp and paper quality and properties. Dinwoodie (1965) report that tracheid length was strongly associated with the number of bonding sites available for bonding of fibres during paper manufacturing. Similarly, the work of Leena (1990) revealed that tracheid length among others was an important parameter which affected softwood kraft pulp characterization. Meanwhile, research studies have demonstrated that tracheid length varies within a tree species and also changes considerably from the early wood zone to late wood zone. In these reported studies, tracheid length was found to increase from pith to bark for most coniferous wood species (Schmidt and Smith 1961; Panshin and de Zeeuw 1980, Bamber and Burley 1983, Sharma *et al* 1998, Kyrikjieeide 1992, Zheng *et al* 1995, Kibblewhile and Uprichard 1996, Lausberg *et al* 1996 and Twinasi 1996). Some of the factor advanced for tracheid length development included age, height in tree, season, cardinal points round the stem, rate of growth, silvicultural practices and wood defects, all of which combined with the genetic make up of the tree as well as the environmental and geographic factors, of its growth.

Findings contained in some of the above listed studies are however conflicting, most especially on the nature of the relationship between growth ring width (growth rate) and most wood properties. For example, Schmidt and Smith (1961) observed a negative influence of the ring width on tracheid length of *Pinus caribaea*. In contrast, the works of Guan *et al* (1966) and Lei *et al* (1977) showed fibre length to be positively correlated with ring width . The differences observed may perhaps be due to the various sources of materials used for the study, sampling procedures employed, sampled species, intrinsic and extrinsic factors governing the properties of wood samples used. Generally, wider growth rings have been associated with faster growth rate. It is therefore in the light of the foregoing, that the present work was embarked upon to evaluate the variation patterns in these two wood parameters – tracheid length and rings width as well as how they relate with one other. The knowledge of such findings will provide the tree grower with information on the degree of variation in tracheid length development and ring width formation in *Pinus caribaea*. ; the influence of ring width on tracheid length across growth increments from pith to bark; and the assessment of the growth history of the sampled species.

Materials and Method

Test material was obtained from tree species sampled from Afaka Forestry Reserve located in Kaduna (Latitude $10^0 37$'N and Longitude $79^0 17$'E at the altitude of 600m, with annual rainfall of 1300 mm and mean temperature of 31°C). Fifteen trees from a 26- year- old Pinus caribaea plantation were randomly selected. The selected trees were marked and felled while 2.5 cm thick discs were removed at the breast height, 2% and 50% of total tree height, in accordance with the procedure described by Mitchell and Denne (1979)

From each disc, 5cm wide radial strip was cut and planned to allow for easy identification of the growth rings and numbering from pith outwards. This was later cut into two halves for tracheid length determination. Each annual growth ring was physically separated into two components namely early wood and late wood. From each wood, splints were removed and macerated in an equal volume (1:1) of glacial acetic acid and 30% hydrogen peroxide. The test sample was boiled at 100°C for 6 hours in order to allow the macerated material to be bleached and softened. Samples were later washed free of the solution with water and mechanically separated by shaking. Two slides were prepared for each wood component from each growth increment. Twenty cells were measured at X40 magnification using the Rheichert Microscope.

The ring width was determined by measuring the width of the annual growth rings on the transverse surfaces of the discs. Measurements of each growth ring in the four cardinal positions were done using a double biconcave lens super-imposed over a calibrated transparent ruler. In this way, width was measured from the first formed early wood to the last formed late wood bands of each growth ring. The above experimental procedures were repeated on discs obtained from all the trees sampled for the study.

RESULTS AND DISCUSSION

Tracheid length

Average early wood tracheid length (EWTL) for the fifteen trees at all the sampling height ranged from 1.86mm to 5.74mm with a mean of 4.57mm and standard deviation of 1.0. Similarly, late wood tracheid length (LWTL) ranged from 2.29mm to 5.81mm with a mean of 4.83mm (Table 1). The trend in the radial variation as illustrated in Fig.1 (a-c), show both EWTL and LWTL to increase significantly with increasing ring number from pith to bark at the three sampling levels.

Table 1: Average values of tracheid length and ring width in 26-year- old *Pinus caribaea*

Wood Property	Range	Mean	Standard Deviation
Early wood tracheid length (mm)	1.86-5.74	4.57	1.0
Late wood tracheid length (mm)	2.29-5.81	4.83	1.0
Ring width (mm)	0.8-9.9	3.5	2.9

The rate of increase was significant in the first eleven growth rings, which corresponds to the juvenile period of tree growth. The rapid change in cell length during

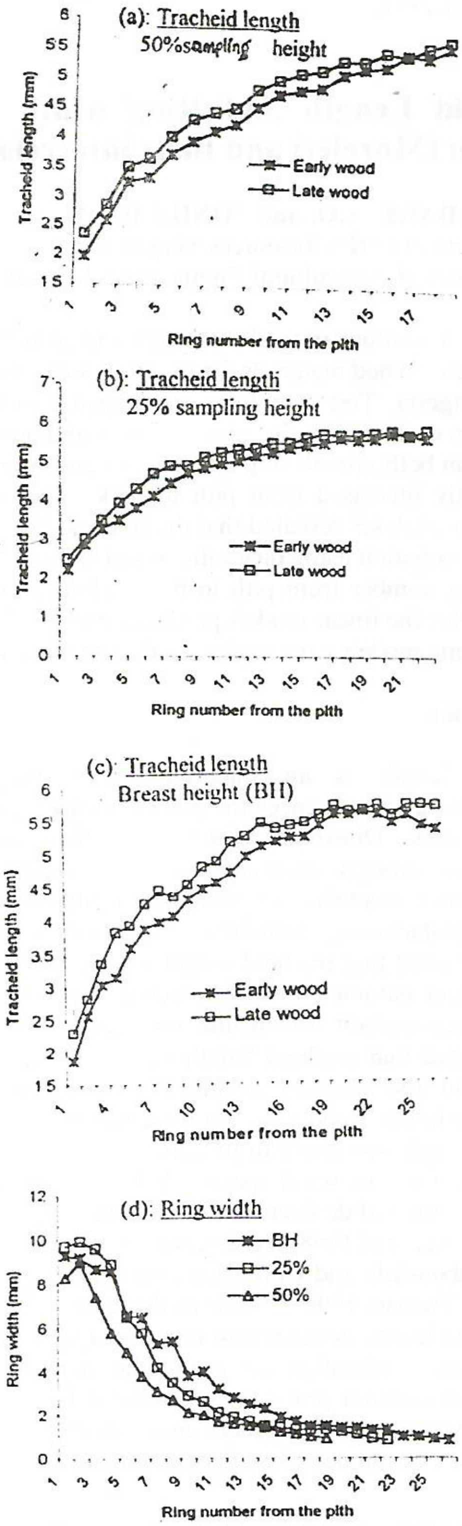

Figure 1: Radial variation in tracheid length and ring width from pith to bark in the wood sample of 26-year-old *Pinus caribaea*.

this period produced tracheids of shorter lengths as growth increases. However, as the tree matured in age, the rate of increase became gradual and a leveling off from the 17th growth ring towards the bark was observed. The results of the analysis of variance presented in Table 2 showed this trend to be significant and both wood types – early and late wood also differ in their length.

Table 2: Results of Analysis of Variance for tracheid length and ring width for wood samples of 26-year-old *Pinus caribaea*

Source of variation	Degree of freedom	Mean square	F-Value
Tracheid length			
Ring number (RN)	25	4.999	1590.74*
Wood type (WT)	1	1.421	452.32*
Sampling height	2	0.838	266.66*
RN*WT	25	0.018	5.66*
RN*SH	50	0.014	4.50*
WT*SH	2	0.014	4.52*
Error	26	0.003	
Corrected total	131		
Ring width			
Ring number	25	21.290	74.66*
Sampling height	2	9.287	32.57*
Error	38	0.287	
Corrected total	65		

* Significant at 5 percent probability level

The trend of variation as observed may be attributable to the activities of the fusiform initials from which the tracheid elements were derived. The high frequency of pseudo-transverse division of the cambia cells may have given rise to the shorter tracheid length in wood near the pith. However, as the tree matures with age, the cambia cells function in a reversed order with longer cells being produced. These findings are in conformity with the general pattern of cell length development reported for coniferous species (Panshin and De Zeeuw 1980).

Along the stem axis of the tree, both early wood and late wood increased from 4.59mm and 4.87mm at breast height level to 4.74mm and 4.98mm at 25% of total tree height and later decreased to 4.35mm and 4.59mm at 5% level. This trend is graphically illustrated in Fig.2. The result of the analysis of variance (Table 2) and test of means show tracheid length and ring width at the different sampling positions to be significant at 5% probability level with means at 50% of total tree height being significantly different from other sampling height of the trees. Panshin and De Zeeuw (1980) had observed that the longest cell is found between one-third and one half of the tree height. This is exactly the trend observed in this particular investigation. Similar trend was also reported by Pande *et al* (1995) on Indian-grown *Pinus caribaea*.

Ring Width Variation

The results of the mean ring width was 3.5mm with a range of 0.8mm to 9.9mm (Table 1). Ring width decreased with increasing ring number from pith to bark at the three sampling heights as illustrated in Fig. 1 (d). The rate of decrease was initially gradually within the first few growth rings especially at the breast height and 25% sampling levels. Thereafter, there was rapid change in ring width from the 4th growth rings to the 11th growth ring (considered the juvenile period). From this point towards the bark, the decrease in ring width was systematic at all the sampling levels. He results of the analysis of variance presented in Table 2 showed

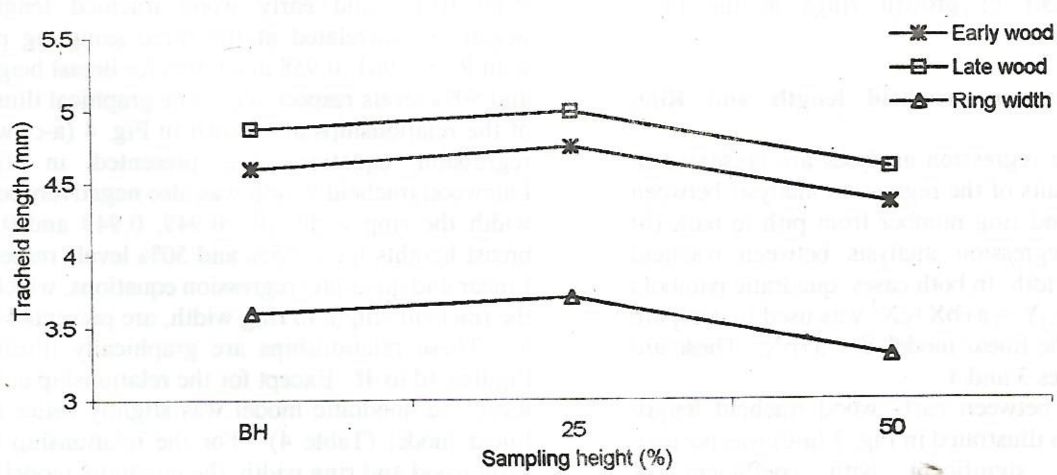

Fig. 2: Axial variation in tracheid length and ring width from breast height level to 50% of total tree height in the wood sample of 26-year-old *Pinus caribaea*

Table 3: Regression Equations and Coefficient of determination for the relationship between tracheid length and ring number of wood sample of 26-year-old *Pinus caribaea*.

Model type	Sampling height	Wood type	Equations	Coefficient of determination (R^2)
Linear	BH	Early wood	Y=2.9115+01247X	0.832
Y =a+bX		Latewood	Y=3.3503+0.1125X	0.809
	25%	Earlywood	Y=3.0781+0.1446X	0.849
		Latewood	Y=3.4638+0.1314X	0.787
	50%	Earlywood	Y=2.5699+0.1870X	0.921
		Latewood	Y=2.9444+0.1733X	0.899
Quadratic				
$Y=a+bX+cX^2$	BH	Earlywood	$Y=1.8952+0.3425X-0.0081X^2$	0.987
		Latewood	$Y=2.3926+0.3177X\ -0.0076X^2$	0.974
	25%	Earlywood	$Y=2.125+0.3818X-0.103X^2$	0.988
		Latewood	$Y=2.4315+0.3895X-0.0112X^2$	0.971
	50%	Earlywood	$Y=1.8973+0.3888X-0.016X^2$	0.985
		Latewood	$Y=2.204+0.3955X-0.0117X^2$	0.986

X represents ring number from pith to bark

the ring number effect to be significant at 5% level of probability. This pattern of radial variation could mean that the sampled trees of *Pinus caribaea* experienced rapid growth response in the early years of growth, which resulted in the production of wider growth rings. However, as the trees matured with age, the rate of growth slowly reduced, culminating in narrower growth rings development. As observed by Otegbeye (1995), wider growth ring appeared to be synonymous with rapid growth response. Thus, ring width may be used to assess the growth history of the species.

Axially, ring width significantly decreased from 3.6mm at breast height and 25% levels to 3.3mm at 50% level as illustrated in Fig. 2. Table 2 shows this variation pattern to be significant. It was envisaged that ring width would have increased internodally since the physiological age of tree decreases upward from base. However, the observed trend may be due to the limited number of sampling points along the stem axis and the differential number of growth rings at the three sampling positions.

Relationship between tracheid length and Ring number

The results of the regression analyses are presented in two parts: (a) results of the regression analysis between tracheid length and ring number from pith to bark (b) results of the regression analysis between tracheid length and ring width. In both cases, quadratic parabola model of the type, $Y = a+bX+cX^2$ was used to compare the results with the linear model Y + a+bX. These are presented in Tables 3 and 4.

The relationship between early wood tracheid length and ring number s illustrated in Fig. 3 (a-c) was positive and statistically significant with coefficient of determination, R^2 = 0.985, 988 and 0.987 fro breast height, 25% and 50% sampling height levels. These values were 15.5%, 13.5% and 6.4% higher than the R^2 values obtained for the linear model presented in Table 3. Indeed, Table 3 shows the comparison of these two models (linear and quadratic) with their regression equations. Similarly, the correlation between late wood tracheid length and ring number was positive with R^2 values of 0.974, 0.971 and 0.986 for breast height level, 25% and 50% of total tree height (Fig.3 (e-f). These values also showed an improvement of 16.5%, 17.4% and 8.7% over the linear model values listed in Table 3. At all the three sampling height, over 97% of the total variation in both early wood and late wood tracheid length was accounted for by ring number alone. The positive relationship obtained connotes increasing tracheid length with increase in ring number from pith to bark as earlier observed in Figures 1a to 1c.

Relationship between Tracheid length and Ring

Ring width and early wood trachied length were negatively correlated at the three sampling positions with R^2 = 0.961, 0.958 and 0.950 for breast height, 25% and 50% levels respectively. The graphical illustrations of the relationships are shown in Fig. 4 (a-c) while the regression equations are presented in Table 4. Latewood tracheid length was also negatively correlated width the ring width (R^2=0.949, 0.949 and 0.962 for breast heights level, 25% and 50% levels respectively). Linear and quadratic regression equations, which related the tracheid length to ring width, are presented in Table 4. These relationships are graphically illustrated in Figures 4d to 4f. Except for the relationship at the 50% level, the quadratic model was slightly better than the linear model (Table 4). For the relationship between early wood and ring width, the quadratic model was 2%

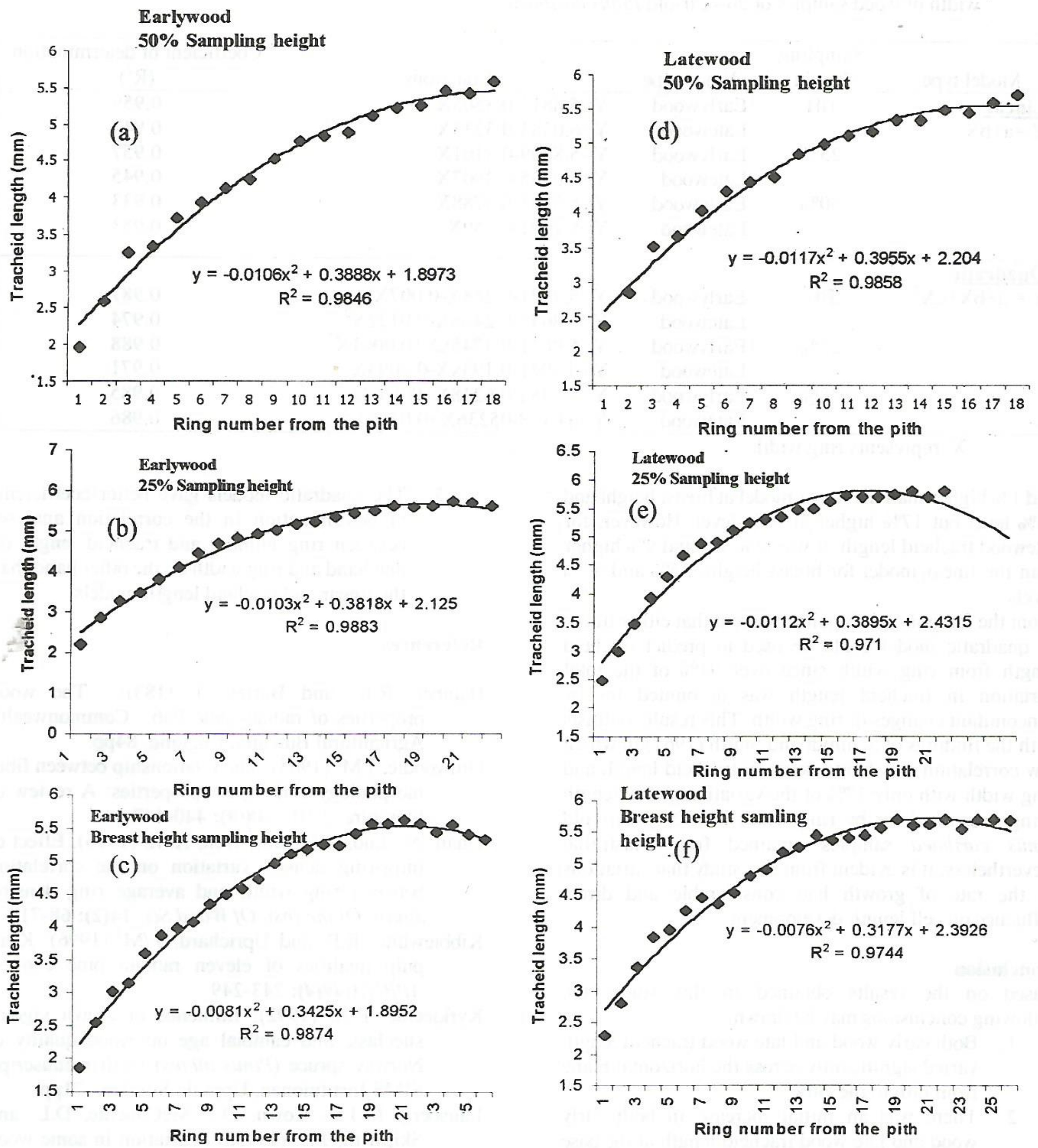

Fig. 3: The relationship between tracheid length (Y) and ring number (X) of the wood samples of 26-year-old *Pinus caribaea*.

Table 4: Regression Equations and Coefficient of determination for the relationship between tracheid length and ring width of wood samples of 26-year-old *Pinus caribaea.*

Model type	Sampling height	Wood type	Equations	Coefficient of determination (R^2)
Linear	BH	Earlywood	Y=5.8813-0.3565X	0.959
Y =a+bX		Latewood	Y=6.0363-0.3233X	0.943
	25%	Earlywood	Y=5.8699-0.3101X	0.957
		Latewood	Y=6.0335-0.2907X	0.945
	50%	Earlywood	Y=5.5983-0.3788X	0.933
		Latewood	Y=5.7791-0.359X	0.953
Quadratic				
$Y = a+bX+cX^2$	BH	Earlywood	$Y=5.7821-0.288X-0.007X^2$	0.987
		Latewood	$Y=5.8642-0.2408X-0.0122X^2$	0.974
	25%	Earlywood	$Y=5.9611-0.3745xX+0.0061X^2$	0.988
		Latewood	$Y=5.8921-0.193xX-0.0093X^2$	0.971
	50%	Earlywood	$Y=5.9484-0.6248X+0.0264X^2$	0.985
		Latewood	$Y=6.0128-05236X+0.0176X^2$	0.986

X represents ring width

and 1% higher than the linear model at breast height and 25% level but 17% higher at 50% level. However, for latewood tracheid length, it was 6%, 4% and 9% higher than the linear model for breast height, 25% and 50% levels.

From the foregoing, it is quite apparent that either linear or quadratic model could be used to predict tracheid length from ring width since over 94% of the total variation in tracheid length was accounted for by concomitant changes in ring width. This result contrasts with the findings of Schmidt and Smith (1961) in which low correlation was found between tracheid length and ring width with only 27% of the variation in cell length being accounted for by ring width in a 26- year- old *Pinus caribaea* samples obtained from Australia. Nevertheless, it is evident from this study that variations in the rate of growth had considerable and direct influence on cell length development.

Conclusion

Based on the results obtained in this study, the following conclusions may be drawn:

1. Both early wood and late wood tracheid length varied significantly across the horizontal plane from pith to the bark.
2. There was an initial increase in both early wood and late wood tracheid length at the base before decreasing towards the tree top.
3. Ring width generally decreased from pith to bark and from breast height to the top.
4. Tracheid length was negatively correlated with ring width while the relationship between this dependent variable and ring number was positive.
5. The quadratic models gave better coefficients of determination in the correlation analyses between ring number and tracheid length on one hand and ring width on the other hand than the linear and tracheid length models.

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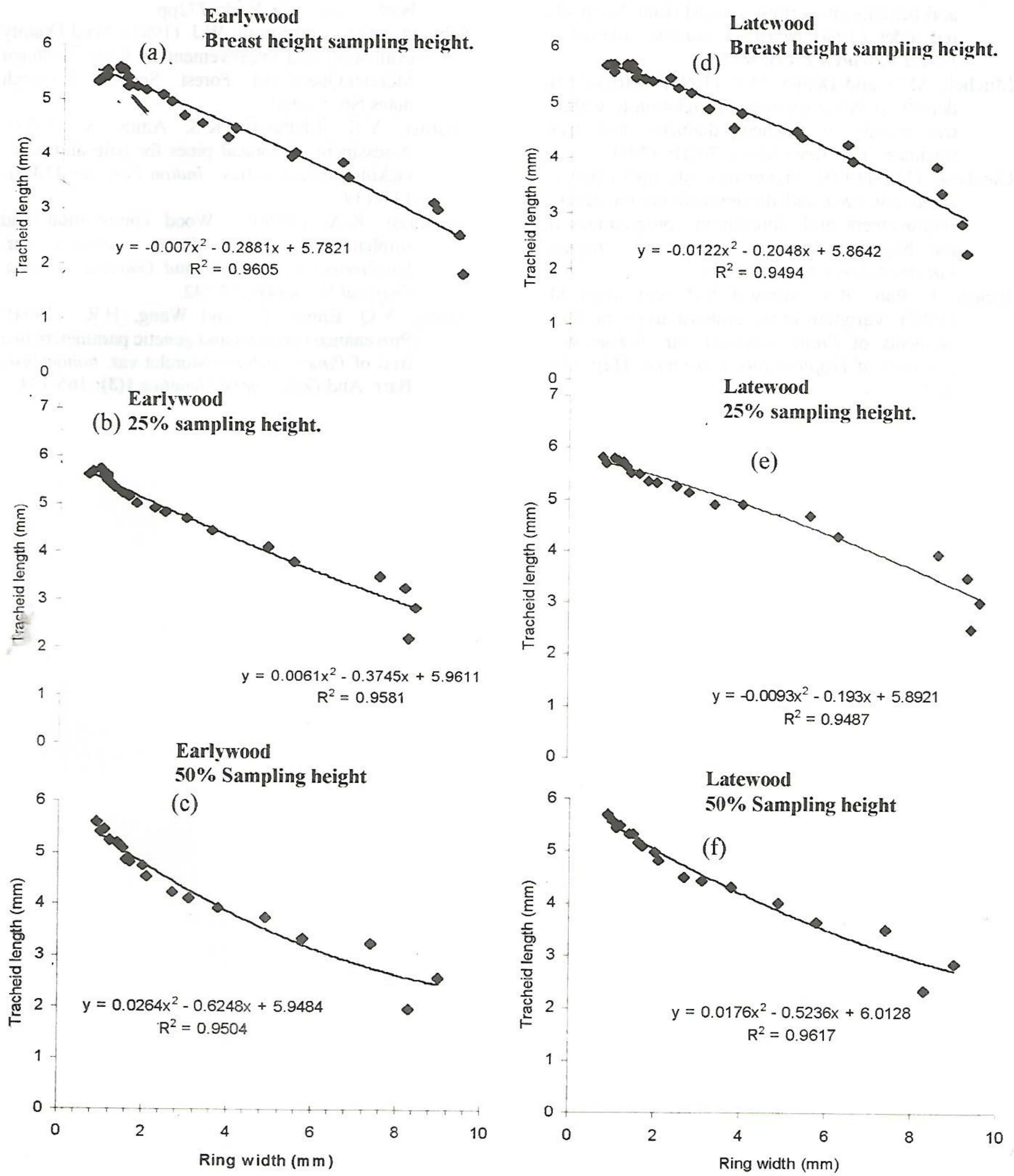

Fig. 4: The relationship between tracheid length (Y) and ring number (X) of the wood samples of 26-year-old *Pinus caribaea*.

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