THE INFLUENCE OF EUCALYPT FIBER CHARACTERISTICS ON PAPER PROPERTIES

Demuner, B. D.
Process Technology Division

Vianna Doria, E. L.
Analysis Division

Claudio-da-Silva Jr., E.
General Manager Technology

Manfredi, V.
Process Technology Division

Aracruz Celulose S.A.
Caixa Postal 46
29.190 - Aracruz, ES
Brazil

ABSTRACT

It is today well established that paper properties are strongly related to the chemical and anatomical characteristics of the fibers. Some of these relations, particularly for kraft pulps obtained from a large number of trees of different species and hybrids of eucalypt are discussed in this study.

The importance of wood basic density/fiber flexibility for paper quality is once again clearly evidenced. The results also demonstrate that the number of fibers per gram and pulp pentosans content contribute to a more complete picture of the relationships between fiber and paper characteristics, and thus identify possible forestry selection and quality control parameters to meet increasing paper quality needs.

KEYWORDS

Eucalypt, Eucalypt Kraft Pulp, Wood Basic Density, Fiber Coarseness, Number of Fibers per Gram, Pentosans, Paper Properties, Tree Breeding.

INTRODUCTION

The old days of papermaking being more art than science are gone. The enormous availability of different fibre types in the market provide the papermaker with significant degrees of freedom to meet the ever increasing demands of various paper grades. Paper science and engineering today provide most of the fundamental understanding needed for the design and manufacture of advanced and sophisticated materials.

However, while the availability of improved technologies for pulp processing and converting into paper is significant, there still seems to be a gap in the basic knowledge needed in order to blend different fibre types to meet target basic paper properties. This is also of particular interest to pulp producers, who may actually control fibre characteristics in tree breeding programs.

The literature reveals much information in this respect, but sometimes the results have limited practical use. A great deal of research has been dedicated to the study of the effects of fiber strength, cell wall thickness, width and length, and their relations to paper properties (1-24). Many other studies have evaluated the effects of wood basic density (21-29) and fiber flexibility (1,6,30-34).

Recent literature (6,8,17-22) has confirmed the significant effects of fiber integrity, cell wall thickness, fiber length and coarseness on paper properties. There are indications that characteristics such as the number of fibers per gram also affects paper quality (1-3). All this information may sometimes be too complicated for common use by the papermaker, as well as for the tree breeder.

The objective of this study is to contribute to the understanding of the relationships between fiber and paper properties, through the selection of features which can be easily measured and controlled. A data bank obtained from analysis of 251 different eucalypt clones throughout 11 years of research has been used in this work. The results are also expected to establish paper quality selection criteria for forestry improvement programs.

BACKGROUND

A critical evaluation of numerous studies of different wood species and the various relationships between fiber and paper characteristics (1-24) reveals a number of limited generalizations and also contradictions. Those are probably derived from the use of different experimental designs, sometimes inappropriate application of statistical models, and also limited data availability. Other possible factors for these discrepancies could be :

-the large natural variability of wood characteristics among trees of the same species, and even variations within each tree;

-the different pulping processes used and their respective variations;

-the large variety of paper grades and the numerous consumer quality demands;

-the complexity involved in the definition and evaluation of factors that determine each paper property.

Some of them have attempted to establish mathematical models to predict paper properties from fiber characteristics (6,8,15,20-22,35). In one of these earlier models Page (35) proposed to predict tensile strength from length, perimeter, density, shear tension and strength of the fibers, and relative bonded area of the handsheets.

Clark (15) tried to simplify this model, by reducing the number of variables (fiber length, coarseness, cohesiveness, and strength and handsheet density) and adopting characteristics of easier evaluation.

More recently, the significant effects of cell wall thickness, length, coarseness and strength of the fiber upon paper properties have been confirmed in both theoretical models (6,22) and overall evaluations of cause and effects (18-21).

Although the experimental sophistication and a more scientific approach are quite noticeable on more recent studies, the basic situation of limited daily applicability of such results still remains.

Another approach, basically concerned with wood quality, has led to consideration of the effect of wood basic density as a basic predictor of paper quality (21-28). The results indicate that hardwoods (8,22,23) in general, and particularly eucalypts (14,24-29) display good relationships between wood basic density and fiber flexibility and conformability, which in turn reflect on the consolidation of the paper structure (1,6).

There is evidence that wood of higher basic density have less flexible fibers due to high moments of inertia of the fiber cross sections, as a consequence of thicker walls (1). Such fibers are thus more resistant to the action of consolidation forces during paper web formation, at the same refining level, resulting in lower paper strength, with more open structures and higher bulk, opacity and surface roughness (2,3,24).

On the other hand, studies involving eucalypt fibers with virtually the same flexibility, have indicated that the number of fibers per gram (inversally proportional to coarseness, which is influenced by thickness, width and fiber wall density) has also a significant contribution to paper properties (1,2). This property is indirectly included in other models (15, 35), but it has not been explicitly recognized as a fundamental characteristic, which is also independent from fiber flexibility, and is today very easy to measure.

The wide natural variability of fiber properties available in an eucalypt forest development program should provide unusual combinations of characteristics, which may be used to develop a simple model, possibly based upon parameters easy to measure and to control through breeding.

RESULTS AND DISCUSSION

Data Variability

Paper properties selected to be evaluated against fiber characteristics were tensile index, bulk, Gurley air resistance and surface roughness. It can be observed (Table 1) that for the 251 trees analysed there is a wide variation for pulps produced at same kappa = 20, and beaten for 1,500 PFI revolutions.

TABLE 1 - PAPER PROPERTIES - RESULTS OBTAINED FOR 251 EUCALYPT TREES - AFTER 1,500 PFI REVS.

PAPER PROPERTIES	CI	MINIMUM VALUE	MAXIMUM VALUE
TENSILE INDEX, Nm/g	87.5 ± 2.0	51.3	122.7
BULK, cm^3/g	1.15 ± 0.02	1.21	1.95
GURLEY-AIR RESISTANCE, sec/100 ml	16.8 ± 2.3	0.6	109.4
BENDTSEN ROUGHNESS, ml/min	135 ± 12	46	931

CI = Confidence Interval - Significant At 95%.

A large natural variability was also observd for wood and fiber characteristics of the different species and hybrids (of same age) evaluated in this study (Table 2). Except for the estimated fiber strength, from zero-span measurements, properties such as wood basic density (414 to 693 kg/m3), the number of fibers per gram (11 to 25 million/g) and the pentosans content (12% to 19%) showed a wide range of variation, which was quite useful in the statistical modelling.

Weighted average fiber length for the 251 trees also displayed a significant variation (0.68 to 1.05 mm), but in the following analysis it was prefered to use the number of fibers per gram as the independent variable related to fiber length, as the former is also adjusted by fibre coarseness, and most importantly, it is easier to interpret physically with respect to fiber bonding in the sheet structure.

Statistical Analysis of the Results

Detection of Outliers and Multicollinearity

The purpose of the statistical treatment was to evaluate possible mathematical relationships between a few fibre properties and paper characteristics.

After the elimination of outliers, both the normal distribution and homogeneity of the variances were verified. In addition, a research was carried out to evaluate the existence of multiple correlations between the independent variables(multicollinearity).

Indeed, one of the problems associated with models containing a variety of independent variables is the presence of multicollinearity, which is defined as a interdependence of these variables. This is, to a greater part, due to many variables in the model expressing the same information.

Multicollinearity does not invalidate the regression analysis in model building. Rather, it tends to increase the variance of the predicted values, thereby generating answers for values that were not included in the model.

The application of both R-Square and Principal Component Analysis (PCA) Procedures of the Statistical Analysis System - SAS Software (36) allowed the identification of multicollinearity between wood chip basic density, cell wall thickness and Luce's factor (37) as well as between fiber length, coarseness and the number of fibers per gram (as expected).

Wood basic density, a key parameter in forestry selection, was chosen due to its close relation to fiber flexibility and paper properties (1,6). The number of fibers per gram was selected for reasons described earlier.

The statistical analysis did not reveal any significant correlation between wood basic density, fiber strength, pentosans content and the number of fibers per gram. Therefore, it was evident that such variables could offer the best possibilities to define the main parameters that contribute to paper properties.

Regression Models: Paper Properties vs Fiber Characteristics

The regression model building involves the selection of a sub-group of variables that can best adjust the linear model, by producing the highest coefficient of determination (R^2). The use of the R-Square Procedure - SAS (36), has allowed the identification of the best sub-group of variables in the model.

The results indicated that wood basic density, the number of fibers per gram and the pentosans content were the parameters that contributed most significantly (99.99%) to the development of the considered paper properties (Table 3).

TABLE 2 - FIBER CHARACTERISTICS - RESULTS OBTAINED FOR 251 EUCALYPT TREES.

FIBER CHARACTERISTICS	CI	MINIMUM VALUE	MAXIMUM VALUE
WOOD CHIP BASIC DENSITY, kg/m^3	526 ± 7	414	693
WEIGHTED AVERAGE FIBER LENGTH, mm	0.82 ± 0.01	0.68	1.05
FIBER COARSENESS, mg/100 m	8.17 ± 0.11	5.95	10.81
NUMBER OF FIBERS PER GRAM, million	17.49 ± 0.33	11.22	25.06
FIBER CELL WALL THICKNESS, µm	2.66 ± 0.06	2.07	5.24
LUCE'S SHAPE FACTOR	0.51 ± 0.02	0.35	1.00
PULP PENTOSANS CONTENT, %	15.5 ± 0.2	12.2	19.2
ZERO-SPAN TENSILE INDEX, Nm/g	161 ± 0.7	146	178

CI = Confidence Interval - Significant At 95%.

Wood basic density showed the greatest contribution to the variation in paper properties, as indicated by the R^2 coefficient. At least 50% of the variance of paper properties was attributable to this variable.

The inclusion of the number of fibers per gram and the pentosans content in the model allowed improvements of up to 13% in the R^2 values. The number of fibers per gram (expectedly related to the number of fiber-to-fiber contact points (38-40)), influenced mostly the surface roughness (Partial R^2 = 10%) and the air resistance (Partial R^2 = 9%). The contribution of pentosans content in the model was approximately 3%.

For such a simple linear model, based upon data derived from a material with a large degree of natural variability, the degree of obtained explanation was quite satisfactory.

TABLE 3 - MULTIPLE LINEAR REGRESSIONS - PAPER PROPERTIES vs WOOD CHIP BASIC DENSITY AND FIBER CHARACTERISTICS - RESULTS FOR 251 EUCALYPT TREES - AFTER 1,500 PFI REVOLUTIONS (REGRESSION COEFFICIENTS FOR THE BEST FIT FOR EACH PROPERTY ARE DESCRIBED IN TABLE 4).

PAPER PROPERTY	DEPENDENT VARIABLES	R^2	F
	-BD	0.60	378
TENSILE INDEX	-BD + NF	0.65	229
	a - bBD + cNF + dPE	0.68	178
	+BD	0.74	733
BULK	+BD - NF	0.78	449
	a + bBD - cNF - dPE	0.80	341
	-BD	0.50	251
ln(AIR RESISTANCE)	-BD + NF	0.59	179
	a - bBD + cNF + dPE	0.60	125
	+BD	0.61	395
ln(ROUGHNESS)	+BD - NF	0.71	303
	a + bBD - cNF - dPE	0.74	236

BD=Wood Chip Basic Density (Range 414 to 693 kg/m³).
NF=Number Fibers Per Gram (Range 11.2 to 25.1 million).
PE=Pentosans Content (Range 12.2 to 19.2 %).
All Results Are Significant At 99.99% Confidence Level.

TABLE 4 - REGRESSION COEFFICIENTS FOR THE BEST FIT FOR EACH PROPERTY DESCRIBED IN TABLE 3.

PAPER PROPERTY	COEFFICIENTS FOR MULTIPLE LINEAR REGRESSIONS			
	a	b	c	d
TENSILE INDEX	105.52	- 0.16	+ 1.30 x 10^{-6}	+ 2.80
BULK	1.00	+ 0.002	- 0.009 x 10^{-6}	- 0.028
ln(AIR RESISTANCE)	3.74	- 0.01	+ 0.13 x 10^{-6}	+ 0.10
ln(ROUGHNESS)	4.24	+ 0.005	- 0.06 x 10^{-6}	- 0.08

Fundaments of Obtained Relationships

Wood Chip Basic Density

As also indicated in other models (24-28), the wood basic density was mathematically responsible for most of the variation in paper properties. This is somewhat expected from observation of Figures 1-4, where data from laboratory pulps beaten for 1500 PFI revolutions have been plotted. Although it is highly influenced by other anatomical and chemical factors (29), the basic density of wood is strongly influenced by thickness of the fiber cell wall.

Thicker walled fibers produce a more open paper structure, with high bulk, opacity, porosity and surface roughness, at any given refining level. These characteristics have significant effects on paper strength properties, which are known to depend mostly on the number and strength of fiber-to-fiber bonds. In other words the large contibution of wood basic density to variations in paper properties is mostly due to its close relationship with fiber flexibility, and this aspect is of particular interest to the tree breeder, since wood density can be controlled in a genetic improvement program.

Number of Fibers per Gram

Although the data in figures 1-4 indicates quite clearly that fiber flexibility has a major impact on the properties of paper, the observed scattering may be reduced by considering in the model other fibre properties which may also impact fiber bonding. Another fiber property which is also easy to measure, varies quite considerably and is possible to be affected in a breeding program is fiber length.

While much research has been done into the effects of fiber length on paper properties (1-24), the greatest challenge has been to isolate the effect of fiber flexibility and to further clarify its close relationship to wood basic density. A number of modelling experiments have been specifically designed with this objective.

One of them involved the pulping and bleaching of wood chips from the heartwood and sapwood separately, for different trees (2). In this study the fiber cross-sectional dimensions were essentially the same for both selected wood in each tree, but fiber length was considerably different.

The results in Table 5 indicated that bulkier sheets, with higher porosity, and lower opacity and strength are obtained from longer fibers of virtually the same flexibility (estimated by Luce's factor or moment of inertia) as their shorter counterparts.

In another experiment, the eucalypt pulps from three different trees were analysed. Again, the main variable was the weighted average fiber length, and the conclusions were basically the same (Table 6).

When plotted against wood basic density it can be seen that both fiber length and coarseness (dependent on wall thickness and cell wall density) are poorly related to the former (Figures 5 and 6), which had also been confirmed earlier in the multicollinearity analysis. Such facts, when coupled with the results described in Tables 5 and 6 have indicated that fiber length and coarseness may have significant effects on the consolidation of paper, and hence on its properties, independently of fiber flexibility.

The number of fibers per gram is a compound property, derived from the reciprocal of fiber length x fiber coarseness. The selection of this property as an independent variable in the model was based on its expected physical implication in terms of paper consolidation and properties. The probability (and hence the number) of fiber bonding may be directly proportional to the number of fibers per unit mass of paper.

From the earlier derivations of Kallmes and Corte (38-40) the total number of fiber-fiber crossings (NC) in a random sheet structure, at constant fiber length, grammage and sheet area, is expected to be proporcional to the number of fibers per unit mass (NF) =

$$NC \propto (NF)^2$$

Consequently one would expecte to get a less open network, with higher degree of consolidation (and hence bonding) and a larger number of fiber-air interfaces with more fibers per gram in the sheet.

Indeed, the results in figures 7-10 quite clearly demonstrate that a higher consolidation in the paper web may be expected with more fibers per gram in the structure (38-40). The result is stronger and smoother sheets, with lower bulk and porosity. Due to the larger number of fiber-air interfaces, such sheets have also higher opacity than those made from a lower number of fibers (Tables 5 and 6).

The data also indicates that the relationship between paper properties and number of fibers per gram is expectedly linear, and not proportional to $(NF)^2$, as indicated by calculations in the Kallmes-Corte model. This was confirmed in the statistical analysis.

Being independent from fiber flexibility, and also easy to measure and possible to control genetically, the inclusion of this fiber property in a model to predict paper properties may lead to significant practical interpretations of a number of phenomena in papermaking, as well as a to better control of the raw material.

Figure 1

TENSILE INDEX VS WOOD CHIP BASIC DENSITY
1,500 PFI REVOLUTIONS

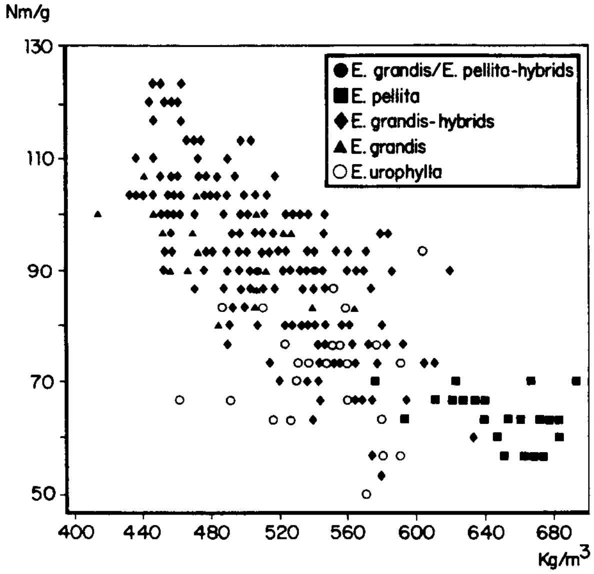


Figure 3

ln (AIR RESISTANCE) VS WOOD CHIP BASIC DENSITY
1,500 PFI REVOLUTIONS

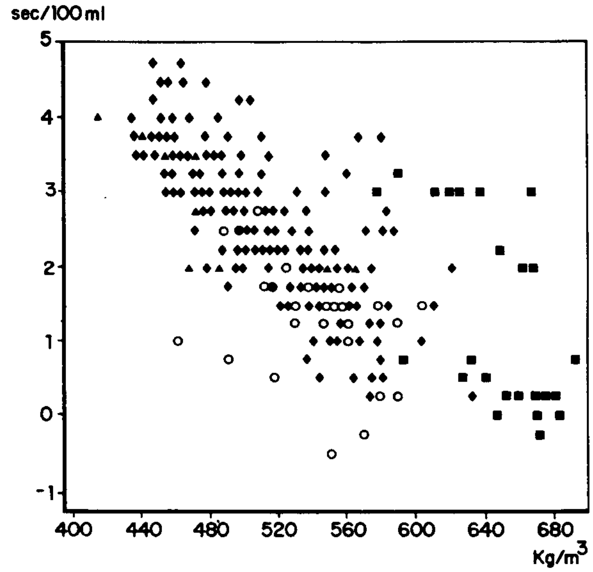


Figure 2

BULK VS WOOD CHIP BASIC DENSITY
1,500 PFI REVOLUTIONS

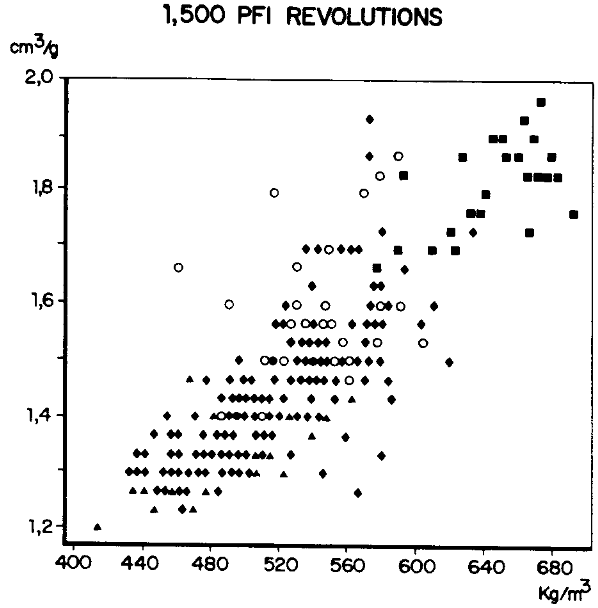


Figure 4

ln (ROUGHNESS) VS WOOD CHIP BASIC DENSITY
1,500 PFI REVOLUTIONS

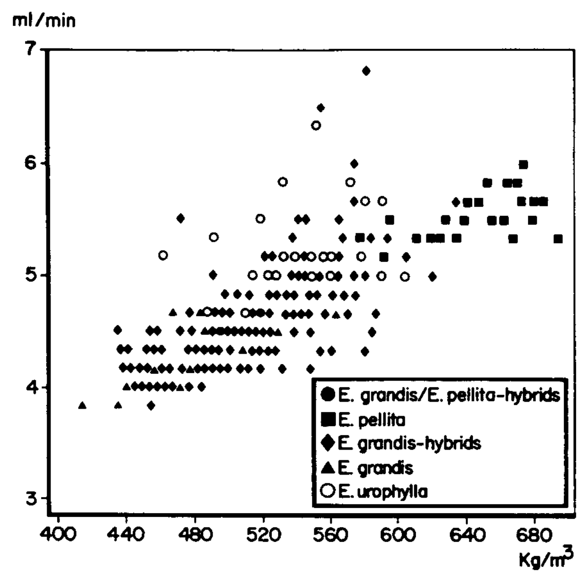


TABLE 5 - LABORATORY BLEACHED EUCALYPT PULPS FROM SAME TREE - THE INFLUENCE OF FIBER LENGTH ON PAPER PROPERTIES OF UNBEATEN HANDSHEETS (2).

FIBER AND PAPER CHARACTERISTICS	HEARTWOOD FIBERS	HEARTWOOD + SAPWOOD FIBERS (40/60 MIXTURE)	SAPWOOD FIBERS
MOMENT OF INERTIA (FIBER CROSS SECTION), μm^4	1,851	1,613	1,577
LUCE'S SHAPE FACTOR	0.59	0.58	0.57
KAJAANI FIBER LENGTH, mm	0.85	0.74	0.64
NUMBER OF FIBERS PER GRAM, million	16.7	21.6	27.2
TENSILE INDEX, Nm/g	35.9	40.6	43.3
GURLEY-AIR RESISTANCE, sec/100 ml	1.03	2.16	3.84
APPARENT DENSITY, kg/m^3	574	615	662
LIGHT SCATTERING COEFFICIENT, m^2/kg	38.5	41.4	44.0

TABLE 6 - LABORATORY BLEACHED EUCALYPT PULPS - FIBER LENGTH VS PAPER PROPERTIES - RESULTS OF HANDSHEETS AFTER 1,500 PFI REVOLUTIONS (3).

FIBER AND PAPER CHARACTERISTICS	PULP A	PULP B	PULP C
WEIGHTED AVERAGE FIBER LENGTH, mm	0.60	0.63	0.66
FIBER COARSENESS, mg/100 m	8.2	8.2	8.5
NUMBER OF FIBERS PER GRAM, million	21.7	20.5	16.5
TENSILE INDEX, Nm/g	62.7	58.8	52.4
GURLEY-AIR RESISTANCE, sec/100 ml	18.6	7.5	5.2
BULK, cm^3/g	1.44	1.53	1.58
LIGHT SCATTERING COEFFICIENT, m^2/kg	41.2	37.8	36.2

Figure 5

FIBER COARSENESS VS WOOD CHIP BASIC DENSITY

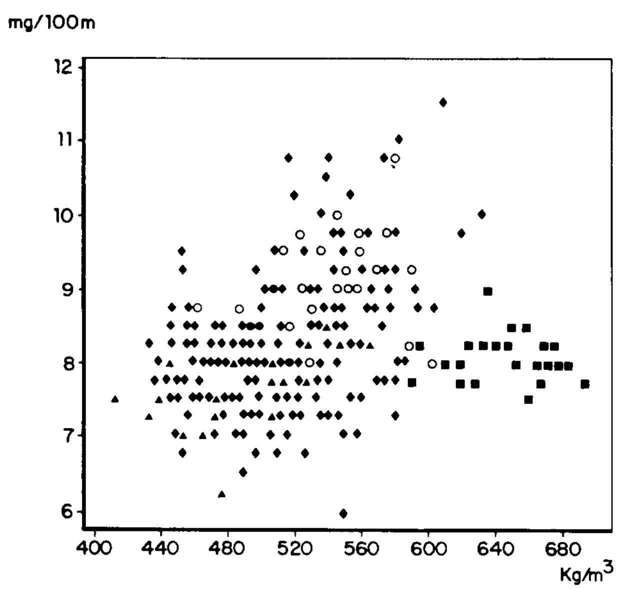


Figure 6

WEGHTED AVE. FIBER LENGTH VS WOOD CHIP BASIC DENSITY

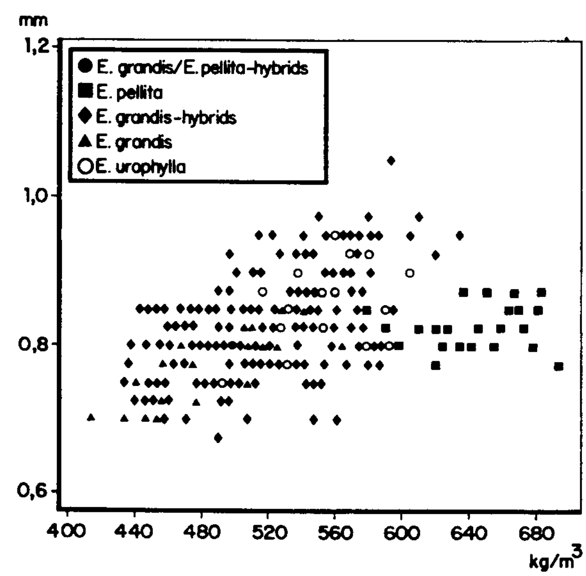


Figure 7

TENSILE INDEX VS NUMBER OF FIBERS PER GRAM
1,500 PFI REVOLUTIONS

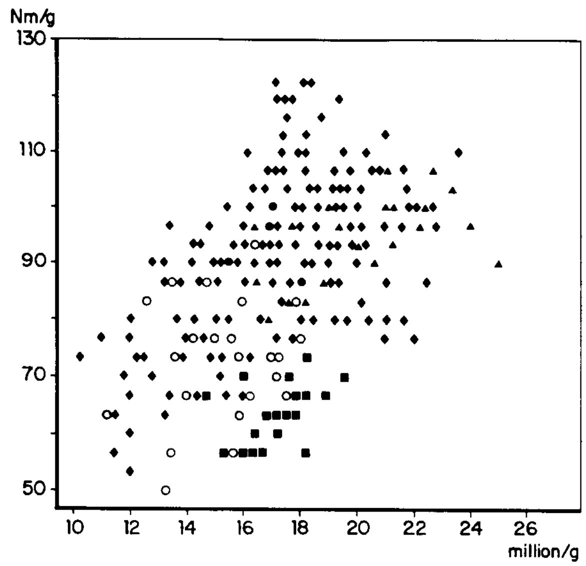


Figure 8

BULK VS NUMBER OF FIBERS PER GRAM
1,500 PFI REVOLUTIONS

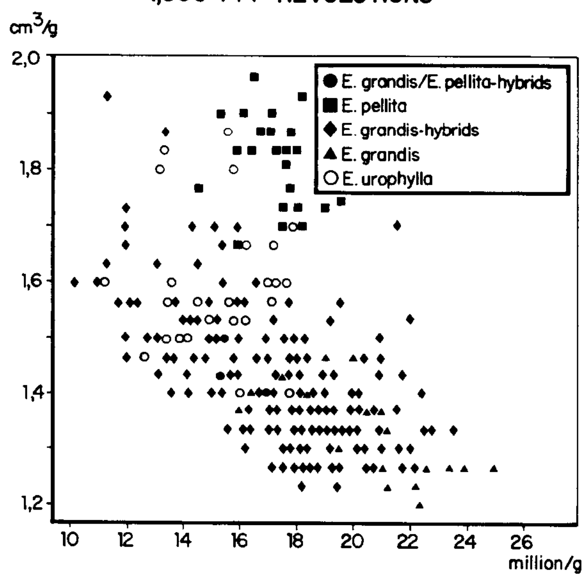


Figure 9

ln (AIR RESISTANCE) VS NUMBER OF FIBERS PER GRAM
1,500 PFI REVOLUTIONS

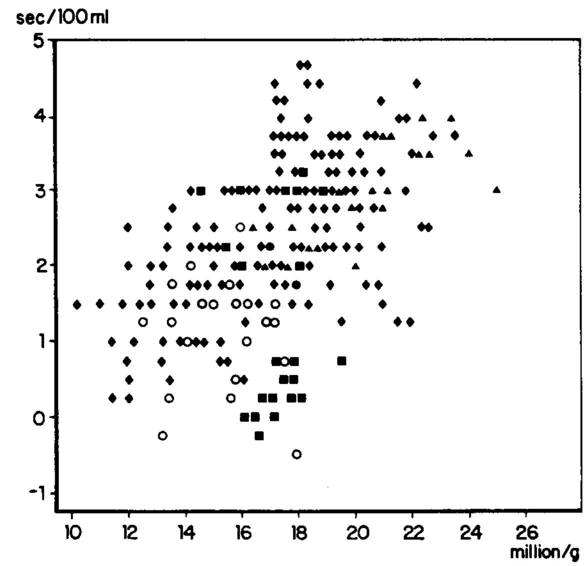
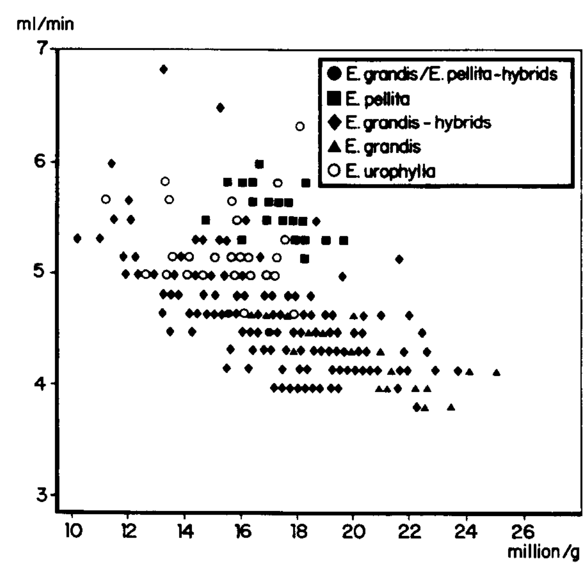


Figure 10

ln (ROUGHNESS) VS NUMBER OF FIBERS PER GRAM
1,500 PFI REVOLUTIONS



Pulp Pentosans Content

The hemicelluloses are critical for papermaking. Pulp fibers without hemicelluloses can hardly be beaten, and the ease of fiber flexibilization as well as the likelyhood of fiber contacts and strength of bonds are dependent on the hemicelluloses. Particularly for eucalypts, whose hemicelluloses are mostly xylans in bleached kraft pulps (41), the significance of pentosans for paper properties has been frequently mentioned (15, 42-44).

The results obtained in this study, for different species and hybrids of eucalypt, (pulp xylan content between 12% and 19%), indicate that the pentosans content has a significant effect on paper properties, as illustrated in Figures 11 - 14. This contribution was confirmed by R^2 and F values when pentosans content was considered in the linear model (Table 3).

Pulps with more pentosans showed tendency to produce paper with higher tensile strength and lower bulk, porosity and surface roughness at the same level of PFI beating. The pentosans, with amorphous and hydrophilic structures, contributed to an improved interaction of the fibers during the paper web formation. No other fiber chemical property was found to influence paper properties significantly.

Application of Regression Models

The models described here were developed to obtain maximum applicability, for the tree breeder, the quality assurance officer in the pulp mill, and the papermaker. The three defined independent variables, which allow between 60 and 80% explanation of the variance in paper properties are quite easy to measure and to control.

Wood basic density is a key parameter in forestry and pulp mill operations. It has a high degree of inheritability, and can be controlled within defined limits. In other words, fiber flexibility (and hence paper consolidation) can be defined in the forest.

As observed, the number of fibers per gram is another fundamental property, also influencing sheet consolidation. Being derived from fiber length it is also prone for genetic manipulation via silvicultural traits. And with today's automatic analysers, its accurate measurement can be made routinely. Additionaly the various possible combinations of fiber flexibility with number of fibers per gram may lead to the development of anusual raw materials.

The pentosans in pulp appear as the most important chemical characteristics to monitor, provided pulps are all produced with minimum fiber degradation. Its control may start in the forest, since wood pentosans tend to correlate well corresponding kraft pulps of same kappa (24). However it is not yet clear whether this property can be easily manipulated via genetic engineering and silviculture.

The pentosan content in pulp can also be quite affected by the mode of operation of modern continuous kraft digesters, particularly those with split alkali charges, and alternate directions of liquor flows, also with varying temperature and concentration of dissolved solids. Therefore it provides the pulp mill with a key quality control parameter.

CONCLUSIONS

The data obtained from the analysis of 251 trees of different species and hybrids of eucalypts was used in the development of multiple linear regression models, with the objective of estimating paper properties from selected fiber characteristics.

A very simple model was derived, based upon only three wood and fiber properties, which are also very easy to measure, and possible to control. Wood basic density, which reflects the influence of fiber flexibility, the number of fibers per gram, indicating the importance of possible number of fiber contact, to sheet consolidation, and the pentosans content, whose action may be through enhanced fiber flexibilization and strength of fiber bonds, were the properties found to explain up to 80% of selected paper properties.

The applicability of the model is quite strightforward, and it is expected that it will provide important guidelines for the tree breeder, the quality assurance officer in the pulp mill and the papermaker to meet the increasing paper quality demands.

EXPERIMENTAL

Raw Materials, Cooking, Fiber Measurements and Pulp Analysis

The wood, fiber and paper properties evaluated in this study were obtained from 251 eucalypt trees, at 7 years of age. **Eucalyptus grandis**, E. **pellita**, E. **urophylla**, and hybrids of E.**grandis** from open pollinization, and also hybrids of E. **grandis** with E. **pellita** were used.

The chips were obtained in industrial equipment using all the commercial volume of the trees. The chip basic density was determined according to TAPPI standards.

Figure 11

TENSILE INDEX VS PULP PENTOSANS CONTENT
1,500 PFI REVOLUTIONS

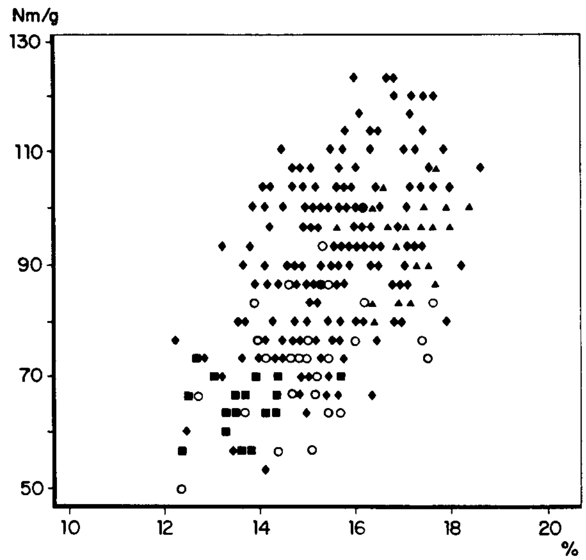


Figure 12

BULK VS PULP PENTOSANS CONTENT
1,500 PFI REVOLUTIONS

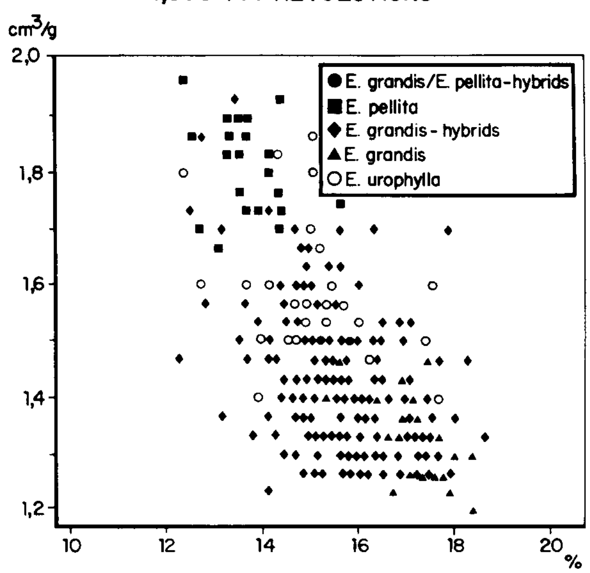


Figure 13

ln (AIR RESISTANCE) VS PULP PENTOSANS CONTENT
1,500 PFI REVOLUTIONS

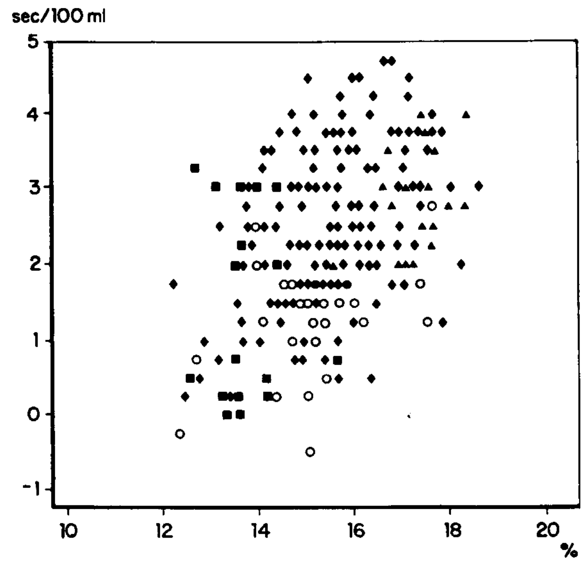
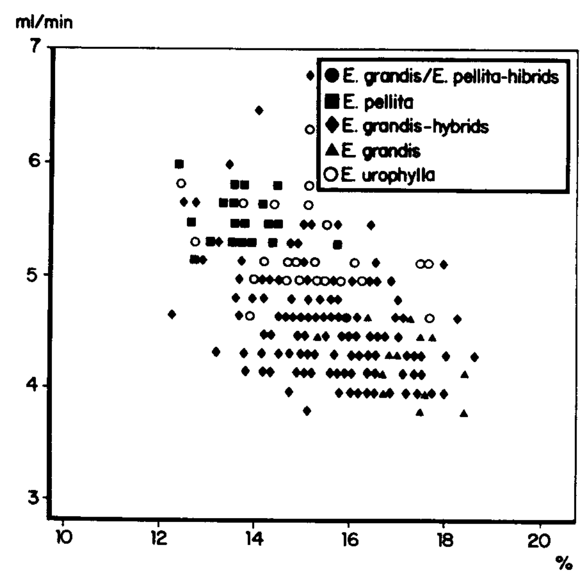


Figure 14

ln (ROUGHNESS) VS PULP PENTOSANS CONTENT
1,500 PFI REVOLUTIONS



Kraft cooking was conducted in a laboratory digester equiped with forced liquor circulation. Pulping to constant pulp kappa number = 20 ± 1 was obtained throuth variation in effective alkali charges, at constant time and temperature. Adequate chip impregnation before cooking and constant operational conditions during brownstock washing pulp screening were maintained.

The PFI beating, handsheet preparation and paper testing were conducted according to SCAN Standards.

Fiber length, coarseness and number of fibers per gram were determined by the Kajaani Automatic Analyser FS-100. Fiber width and cell wall thickness were measured in wood cross sections, using a photomicroscope coupled to a Q-920 image analyser.

Pentosans content in pulp was determined using TAPPI T223 ts-63 and confirmed via HPLC sugar analisys, following acid hydrolysis.

Statistical Evaluation of Data

All statistical evaluation was performed using the Statistical Analysis System - SAS Software (36). After elimination of outliers, the normal distribution, homogenous variance and multicollinearity were verified, in order to apply the multiple regression analysis.

For detection of multicollinearity, two techniques (regression and PCA) were used. Once the existence of multicollinearity was confirmed, only the variables which included the most relevant information and presented greatest ease in measurement were considered.

Selection of Variables

The constrution of regression models considered the selection of sub-groups of variables that most contributed to the accuracy, or, in other words, best adjusted to the model producing the greatest coefficient of determination (R^2).

The R-Square and PCA procedures were used to select independent variables with the greatest contribution to R^2 with 99.99% significance, with the former allowing the analysis of 2^m possible regression equations for m variables present in the model.

The use of artificial data sets generated by PCA did not result in greater availability of the information than that obtained by R-Square. Based on results obtained until now, R-Square offers a safe and easy means of obtaining the best sub-group of variables contained in the model.

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