WILLOW CM PULPS FOR NEWSPRINT. II. RELATIONSHIPS BETWEEN WOOD CHARACTERISTICS AND PULP PROPERTIES

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The aim of this work was to establish relations, through multiple regressions, that allow the prediction of the properties of CMP pulp from willows for newsprint, from the viewpoint of wood characteristics. Another objective was to verify whether the traditional factors used to characterize softwood mechanical pulps are still applicable to hardwood chemimechanical pulps. Linear and quadratic multiple regression models were evaluated by the results of a previous work, on the chemimechanical pulping of six willow clones (*Salix sp*) from two different plantation sites. The variables measured on wood, considered as independent variables, were the following: basic density, fiber length, fiber width, cell wall thickness, lumen width, moisture content, hot water and alcohol-benzene extractive content, total extractives, soluble materials in 1% sodium hydroxide, insoluble, soluble and total lignin, and cellulose content of wood. The independent pulp variables were fractions of MacNett classification, Forgacs' "L" factor, intrinsic fiber strength (measured by zero span tensile test), water retention value (WRV) and pulp drainability (°SR). The dependent variables used were specific volume, tear and tensile index, brightness, opacity, light scattering coefficient (s) and light absorption coefficients of handsheets (k). The best fit models were obtained by considering fiber fractions and pulp weakening and, to a lesser extent, the properties of wood. Therefore, one could reasonably predict numerous chemimechanical pulp properties that could be used as a first selection criterion for obtaining clones for pulp with better mechanical and optical properties.

Keywords: *Salix*, clones, wood characteristics, pulp properties, linear and quadratic regression

INTRODUCTION

Due to their low density and good brightness, willows and poplars are recommended for high-yield pulp production. In Argentina, Papel Prensa S.A. uses alkaline sulfite pulp of willow (*Salix sp*) as part of its stock for newsprint, magazines and printing papers.[1]

The behavior of a species *versus* each pulping process depends on its intrinsic physical and chemical characteristics.[2-4] The relationships between wood characteristics and pulp properties can be quantified by means of multiple regression models and multivariate analysis. The validation of these models allows predictions on the behaviour of the fiberised material from wood and fibers and also the physical and chemical characteristics. The use of these predicted variables is advantageous, as wood characteristics can be determined prior to pulping.

Numerous authors have tried to correlate the wood properties with the quality of the pulp different results being attained under similar processing conditions. Generally, none of the wood variables provided the best adjustment for all properties.[5] These relationships have been further studied in chemical pulping,[6,7] and in pure softwood mechanical pulps.[8] However, records on these relationships for chemimechanical pulps of hardwood – particularly Salix – species are quite few,[9,10] no work having been devoted, up to now, to the subject.

The response of mechanical pulps to tensile and tear strength, or to the optical and printing properties can be explained by the delicate equilibrium of the three fractions that form these pulps (fibers, fines and fiber bundles) and also by their function in pulp web formation. Strength values are related to the ratio of whole fibers and fibrillation of their walls. The presence of fines increases the development of fiber bonding.[10-12] The typical optical and printing properties of these pulps are strongly associated with the sheet structure and the presence of fines, all of them promoting light scattering.[13-15]

In 1963, Forgacs microscopically characterized softwood mechanical pulps (SGW and RMP). He specified that the average fiber length in the pulp and the shape of these particles are the determinant factors affecting the strength of this kind of pulps. He defined an “L Factor” to characterize the length of the fiber fraction and an “S Factor” to characterize the superficial area of these particles. These factors were subsequently used in the quantification of mechanical pulp fractions.[8,14,15,16]

The aim of the present work was to establish, through multiple regressions, relations that allow predicting the properties of CMP pulp of willows for newsprint, from the characteristics of the wood. Another objective was to verify whether the traditional factors used to characterize softwood mechanical pulps were still applicable to hardwood chemimechanical pulps.

MATERIALS AND METHOD

The work was carried out using results from a previous work.[17]

The chips were prevaporized for 40 minutes. The chemical treatment was carried out in a 7-L laboratory digester (M/K System Inc., Model M/K 409), under the following conditions:

Liquor-to-wood ratio	=	5.5/1
Na_2SO_3 and NaOH wood	=	2.6% on o.d.
Cooking temperature	=	80 ºC
Time at temperature	=	40 min

The chips were steamed and refined in a Bauer atmospheric refiner of 5 HP with discs of 8 inch in diameter, equipped with a closed water circuit for re-circulating the fines. Two or three refining stages were necessary to attain 175-200 CSF (50-55 ºSR, objective value of post screening freeness).

Linear and quadratic multiple regression models were evaluated to assess the prediction capacity of the variables considered as independent, taking as dependent variables the mechanical and optical properties of the pulps. The types of equations applied were as follows:

$$Y=b1X1 + b2X2 + \ldots$$
$$Y=b11X1 + b12X1^2 + b21X2 + b22X2^2 + \ldots$$

The interactions between the independent variables were not included as they had no physical sense.

The variables were standardized, subtracting from each value the arithmetic mean and dividing the result by the standard deviation of the sample. This method is used to unify the relative weight of the variables measured with different scales. When working with standardized variables, the independent term is eliminated (because the mean of all values is zero), and the absolute value of the coefficient of the variable indicates its relative weight in the equation. The X values in the equation represent positive and negative values around the mean.

The regressions were obtained by putting all the independent variables considered in the equation and by eliminating the non-significant ones one by one (backwards). In some cases, a certain value was excluded, considering that it altered the equation, as it behaved in an abnormal way (unusual residual). To avoid colinearity problems, the independent variables with correlation values superior to 0.5 were eliminated from the equations. The significance of the equation was assessed by comparing the R^2 values adjusted by the degrees of freedom. The equations having $R^2 > 0.60$ are considered significant.

The regression models were executed and assessed with specific software.

Five dendrometric variables (tree height, diameter, bark percentage, annual rings, number of knots), twenty-five wood variables (including humidity, basic density, fiber morphology (length, width, lumen and wall thickness), proportion of elements (fibers, vessel elements, parenchyma cells), fiber relationships (length/ width, lumen/width, wall thickness/ lumen), fibrillar angle, parameters of chemical composition, decay, marks of flood, stains, reaction wood, tyloses), eight pulp suspension properties and seventeen pulp sheet properties were measured. The methodology used for pulp characterization is extensively described in the first part of this work.[17]

Wood defects were not taken into account as independent variables, because their quantification was not precise. Finally, the thirty five properties that gave the statistical differences between trees or clones were considered for the regression equation.[18]

Even though the measured variables can not be manipulated, and thus, can not be considered statistically independent, with the objective of predicting the properties of chemimechanical pulps from wood properties, they were considered as independent, and sheet properties – as dependent.

Variables measured on wood, taken as independent variables:

X1	=	Db	= Basic density (TAPPI T 258-om-94)
X2	=	Lf	= Fiber length (optic microscope with image analyzer)
X3	=	A	= Fiber width (optic microscope with image analyzer)
X4	=	Lu	= Lumen width (optic microscope with transversal cuts)
X5	=	E	= Thickness of the fiber walls (optic microscope on transversal cuts)
X6	=	Eac	= Hot water extractives (TAPPI T 207 cm-99)
X7	=	Eab	= Alcohol-benzene extractives (TAPPI T 204 cm-97)
X8	=	Et	= Total extractives (X7 + X8)
X9	=	Ss	= Soluble in sodium hydroxide 1% (TAPPI T 212 om-98)
X10	=	Li	= Insoluble lignin (TAPPI T 22cm-98)
X11	=	Ls	= Soluble lignin (TAPPI T UM 250)
X12	=	Lt	= Total lignin (X11 + X12)
X13	=	C	= Cellulose (Seifert, 1965) (17)
X14	=	Hc	= Hemicelluloses (by difference)

Variables measured on pulps, considered independent:

X15	=	R30	= Fraction retained in mesh 30 (Bauer Mac Nett Classification)
X16	=	R50	= Fraction retained in mesh 50 (Bauer Mac Nett Classification)
X17	=	R100	= Fraction retained in mesh 100 (Bauer Mac Nett Classification)
X18	=	R150	= Fraction retained in mesh 150 (Bauer Mac Nett Classification)
X19	=	R270	= Fraction retained in mesh 270 (Bauer Mac Nett Classification)
X20	=	P270	= Fraction that passes mesh 270 (Bauer Mac Nett Classification)
X21	=	WRV	= Water retention value of the pulp
X22	=	°SR	= Drainage resistance
X23	=	Rf	= Intrinsic strength of the fibers (zero span tensile strength)
X24	=	L	= Forgacs' L factor
X25	=	Lw	= Length of pulp fibers as weighed average fiber lengths by weight

Variables measured on pulp and assessed as dependent:

Y1	=	Bulk	= Bulk
Y2	=	Tear I	= Tear index
Y3	=	TI	= Tensile index
Y4	=	BI	= Burst index

Y5	=	Brightness	= Brightness
Y6	=	Opacity	= Opacity
Y7	=	S	= Light scattering coefficient
Y8	=	K	= Light absorption coefficient

RESULTS AND DISCUSSION

Linear regressions

The regression models were constructed by progressively incorporating groups of independent variables.

Initially, 14 physical, chemical and microscopic characteristics (called variables 1), were checked out as independent variables; they included basic density, fiber length, fiber width, fiber wall thickness, lumen width and the complete chemical composition. To avoid colinearity problems, the independent variables with correlation values superior to 0.5 were eliminated from the equations. Table 1 presents the significant linear equations with the variables mentioned above.

Table 1
Linear regression equations relating pulp physical properties and wood physical, microscopic and chemical characteristics (variables 1)

Properties	Equation	R^2	Note
Bulk	+ 0.69 Li + 0.94 Ls – 0.41 C	88	without line 10
Tear I	–	Ns	–
TI	- 0.47 Li – 0.60 Ls – 0.62 Ss	85	without line 10
BI	- 0.42 Db – 0.34 Li + 1.04 C	78	without line 6
Brightness	- 0.49 Lu – 0.47 Li	65	–
Opacity	+ 0.31 Lu + 0.43 Li + 0.42 C	84	without line 11
S	–	Ns	–
K	+ 0.84 Li	76	without line 10

Ns: non significant

Significant equations were established for most pulp properties, even though coefficients R^2 are not too high. For the tear index and scattering coefficient, no significant adjustments were obtained.

The insoluble lignin appeared in all equations. In terms of mechanical properties, such as TI and BI, their incidence was negative, because lignin restrains fiber fibrillation, thus decreasing their bonding capacity and positively influencing opacity, as its refraction index is much higher than that of cellulose. The same holds true for the absorption coefficient k, which is one of the main sources of coloured groups in wood. For this reason, its effect on brightness was negative.

All equations present terms involving wood chemical composition, evidencing the importance of these variables in the construction of prediction models for CMP pulps of hardwoods. Notably, the morphological properties had no effect on the physical ones. One reason may be that the differences in fiber length, fiber width and thickness of the fiber walls in hardwoods are considerably inferior to those in softwoods. Another reason is that most fibers are degraded, so that their morphological dimensions are altered in the final pulps. Even though one should notice that if wood lignin content has some effect on sheet bulk, it must be because the high lignin content is associated with the wood fiber structure (bulky fibers contain much lignin). To verify the influence of the state of the fibers and pulp particle size on the properties of the final sheets, classification fractions and intrinsic resistance of the pulp fibers were incorporated as independent variables. The results are presented in Table 2.

The classification fractions appear in all equations, opacity equation excepted.

Table 2
Linear regression equations relating pulps physical properties and wood properties plus pulps fractions (variables 2)

Properties	Equation	R^2	Note
Bulk	- 0.77 Rf – 0.29 R50	90	without line 10
Tear I	–	Ns	–
TI	+ 0.54 Rf + 0.45 R50	85	without line 10
BI	+ 0.44 Rf + 0.69 R50	88	without line 6
Brightness	- 0.46 Lu – 0.33 Eab – 0.74 R270	88	–
Opacity	+ 0.31 Lu + 0.43 Li + 0.42 C	84	without line 11
S	- 0.38 Ss – 0.75 R30 + 0.39 Rf	86	–
K	+ 0.45 Lu + 0.60 R270	88	without line 10

Ns: non significant

Fraction R50 (of the unbroken fibers), with a fiber length between 775μ and 994μ, representing between 19 and 25 % of the fibrous material, significantly increased pulp strength. This fraction showed high external fibrillation and almost destroyed the walls (Fig. 1).

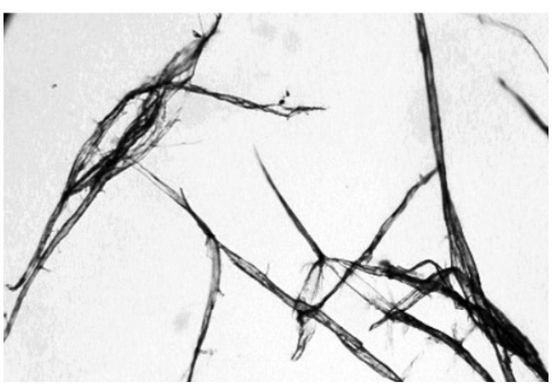

Figure 1: R50 fraction showing high external fibrillation

Generally, the tensile and burst indices are negatively correlated with the bulk of the sheets. In this case, highly fibrillated fibers enhance fiber bonding (as usual in mechanical pulps), increasing the sheet strength and reducing bulk. The strength of individual fibers had a similar influence. Interestingly, fiber strength is combined with the R50 fraction from the equations. It seems that these highly fibrillated fibers increase the sheet strength, although the individual strength of fiber also plays some role, as too much fibrillation means disappearance of the fiber structure (Fig. 2).

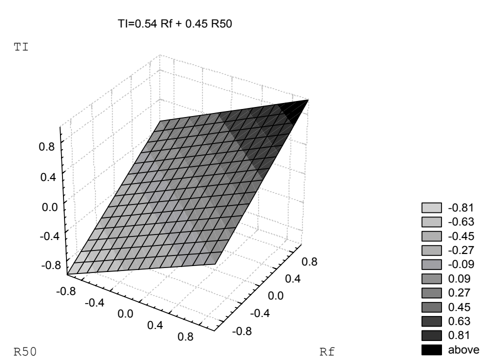

Figure 2: Tensile index (TI) *vs.* fraction R50 and fiber strength (Rf)

Consequently, from this point of view, the behaviour of these willow chemimechanical pulps looks like that of a mechanical rather than a chemical pulp. The fraction of fines (R270) produces a decrease in brightness and an increase in k (Fig. 3), which might be a consequence of a higher lignin proportion in the component elements of its fraction. This was the first significant equation for the light scattering coefficient, s, which is negatively affected by the presence of shives (R30), by the soluble sodium hydroxide and intrinsic fiber strength.

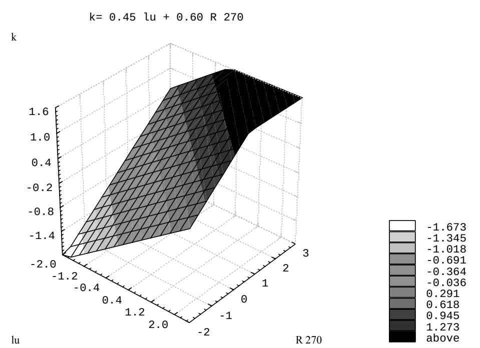

Figure 3: Light absorption coefficient (k) *vs.* lumen (Lu) and fraction of fines (R270)

Linear and non-linear regressions

Quadratic terms were incorporated into the models besides the linear ones, to prove whether they really increase the regression coefficients, thus contributing to establishing better equations for tear index and scattering coefficient.

The equations found, relating the wood characteristics (variables 1) and the pulp properties are presented in Table 3.The adjustments made did not improve with the inclusion of the variables in quadratic form. Lignin was again present in all the equations.

The graphical representations of the equations obtained for TI, opacity and absorption coefficient k are shown in Figures 4 and 5. The content of soluble sodium hydroxide decreases tensile resistance. In the absence of a linear term, insoluble lignin, owing to its negative quadratic effect, produces a maximum incidence around the central point, decreasing towards the extreme values of the variable (Fig. 4). Figure 5 shows the existence of quadratic variable without their corresponding lineal values, and indicate the presence of a maximum or minimum mean value (standardized variable equal to zero), depending on its sign in the equation. Basic density slightly decreases opacity, whereas fiber length, on the contrary, increases it. This last effect gets intensified at high lengths. The insoluble lignin content also increases it, even though its influence decreases towards the extreme values of the variable.

Basic density negatively affects the absorption coefficient, while fiber length has a positive incidence on k, being higher when the values of length increase.

No significant equations were established for tear index and light scattering coefficient.

To check the influence of the pulp conditions (fiber size distribution, fibrillation, etc.), equations using as independent variables only the classification fractions, the drainage degree (ºSR), the water retention value (WRV) and fiber intrinsic strength in the pulp were composed, as shown in Table 4.

Table 3
Linear and quadratic regression equations, between pulp physical properties and wood characteristics (variables 1)

Properties	Equation	R^2	Note
Bulk	$- 0.37\ lf^2 + 0.39\ Li^2$	66	without line 1
Tear I	–	Ns	–
TI	$- 0.74\ Ss – 0.23\ Li^2$	75	without line 10
BI	$+ 0.65\ lf – 0.44\ Lt$	66	without line 10
Brightness	$- 0.78\ Lt$	46	without line 9
Opacity	$- 0.40\ Db + 0.24\ lf^2 + 0.94\ Li – 0.47\ Li^2$	86	without line 9
s	–	Ns	–
k	$- 0.58\ Db + 0.30\ lf^2 + 0.25\ Li^2 + 0.71\ Lt$	88	–

Ns: non significant

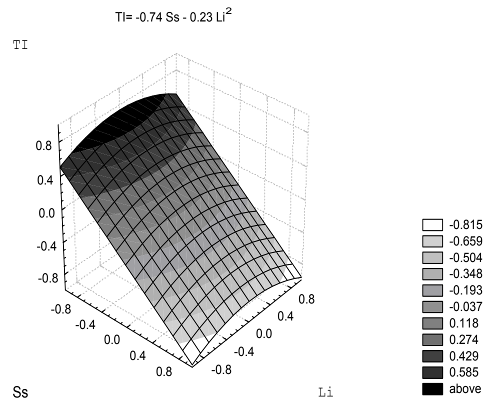

Figure 4: Tensile index (TI) *vs*. NaOH soluble (Ss) and insoluble lignin (Li)

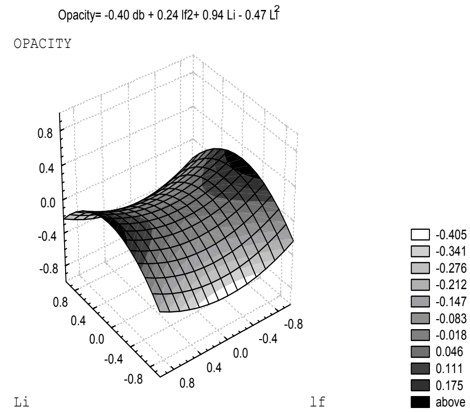

Figure 5: Opacity *vs*. insoluble lignin (Li) and fiber length (Lf), with basic density in its mean value (Db = 0)

Fiber size distribution and fiber state in pulps influence its properties, a significant equation for tear strength being thus obtained.

Fraction R50 increased significantly pulp strength (Table 4). The addition of the fractions that passed 150 mesh (P150, totalling 30% of the pulp, with lengths inferior to 500µ), affected negatively the tear and burst strength values. Table 4 shows the significant influence of intrinsic fiber strength over the studied range.

This variable has a positive impact on tensile, a negative one on bulk and none on burst. The water retention values of the pulps (WRV), as well as the classification fractions, R30, R100, R 150 and R270, are to be found only in the optical properties equations.

The graphical representation of the equations obtained for tear and tensile indices are shown in Figures 6 and 7, respectively.

Table 4
Linear and quadratic regression equations relating pulp physical properties and fiber size distribution plus fibrous material state

Properties	Equation	R^2	Note
Bulk	$- 0.97\ Rf$	86	without line 6
Tear I	$+ 0.37\ R50^2 – 0.61\ P150 – 0.43\ Rf^2$	74	–
TI	$+ 0.45\ R50 + 0.54\ Rf$	85	without line 2
BI	$+ 0.75\ R50 – 0.48\ R150 – 0.25\ P150$	93	without line 10
Brightness	$+ 0.44\ R50 + 0.36\ R100^2 – 0.63\ R150 – 0.28\ R150^2 – 1.05\ R270$	93	without line 9
Opacity	$+ 1.26\ R100 + 1.33\ R270 + 0.51\ P150 + 0.38\ WRV$	89	without line 1
S	$- 0.64\ R30 + 0.55\ R50 – 0.20\ WRV^2$	87	without line 6
k	$- 0.55\ R30^2 + 0.55\ R50^{2\,+} + 0.24\ P150 + 0.40\ WRV^2$	82	without line 11

Ns: non significant

Strength is positively influenced by the extreme values of fraction R50, while only the mean values of fiber intrinsic strength increase it (Fig. 6). When the classification fractions were replaced by Forgacs' L Factor (R30 + R50), the equations listed in Table 5 were obtained.

Significant equations, including Forgacs' L Factor (R30 + R50), were established for most of the properties, generally combined with fiber strength and water retention value. Even though the adjustments are not the best, the equations are simplified.

Only in the case of the light scattering coefficient, the drainage degree and water retention values seem significant.

When wood properties are combined with the pulp characteristics, the equations listed in Table 6 are obtained.

Fraction R50 (whole fibers) affects most of the adjustments, having a positive incidence on the strength values, while basic density and insoluble lignin negatively affect the tensile and burst strength.

The equations of tear I, k and s present no wood variables among their terms. The graphical representations of the equations obtained for TI, brightness and s are shown in Figures 7 to 9. High values of fractions R50 and R270 increase tensile strength, as they contribute with whole fibers and fibrillar fines that increase bonding. The insoluble lignin has less influence on tensile, especially at its mean values (Fig. 7).

Within the studied ranges, higher values of density and lower values of fines (R270) increase pulp brightness (Fig. 8).

A higher quantity of unbroken fibers (R50) with an intermediate water retention value (WRV) increases the scattering coefficient (Fig. 9).

Table 7 presents the correlation coefficients R^2 adjusted for different sets of independent variables. The set of variables 1 (physical, chemical and microscopic wood properties) produces only poor equations for some optical properties.

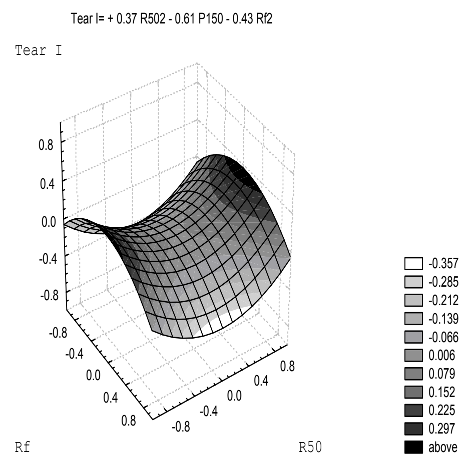

Figure 6: Tear index (tear I) *vs*. fraction R50 and fiber intrinsic strength (Rf), with P150 at its mean value (P150 = 0)

The equations obtained with linear models and Variables 1 (physical, microscopic and chemical wood characteristics) were better.

Table 5
Linear and quadratic regression equations relating pulp physical properties and L Factor plus the state of the fibrous material

Properties	Equation	R^2	Note
Bulk	- 0.97 Rf	86	without line 6
Tear I	--	Ns	--
TI	+ 0.83 Rf	70	--
BI	+ 0.45 Rf + 0.56 L – 0.41 WRV	76	without line 11
Brightness	$+ 0.62 L^2 – 0.75 Rf^2$	73	without line 2
Opacity	$+ 0.37 Rf + 0.60 Rf^2 – 0.69 L – 0.70 L^2$	77	without line 12
S	+ 0.80 Rf – 0.60 L – 0.27 SR – 0.32 WRV	88	without line 4
K	$+ 0.80 Rf^2 – 0.62 L^2$	77	without line 9

Ns: non significant

Table 6
Linear and quadratic regression equations relating pulps physical properties and the combination of wood and pulp characteristics (variables 2), plus the state of the fibrous material

Properties	Equation	R^2	Note
Bulk	$- 0.20\ Ss^2 – 0.92\ Rf$	92	without line 6
Tear I	$+ 0.37\ R50^2 – 0.61\ P150 – 0.43\ Rf^2$	74	–
TI	$- 0.81\ db – 0.26\ Li^2 + 1.05\ R50 + 0.62\ R270$	95	without line 12
BI	$- 0.43\ db – 0.38\ Li + 1.02\ R50 – 0.29\ R50^2 + 0.25\ R270^2$	94	–
Brightness	$+ 0.55\ db – 0.32\ R150 – 0.68\ R270$	91	without line 11
Opacity	$- 0.65\ lf – 0.41\ R50 + 0.59\ R100 + 1.66\ R270$	80	–
S	$- 0.64\ R30 + 0.55\ R50 – 0.20\ WRV^2$	87	–
K	$- 0.55\ R30^2 + 0.55\ R50^{2+} + 0.24\ P150 + 0.40\ WRV^2$	82	–

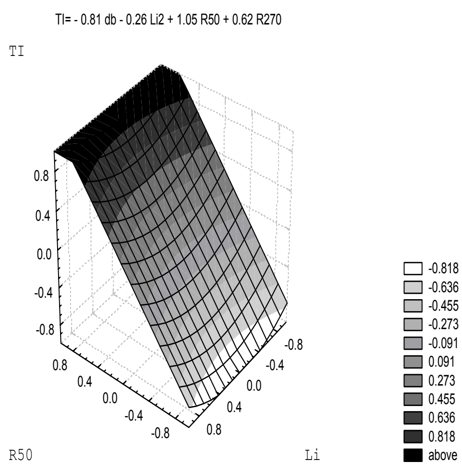

Figure 7: Tensile index (TI) *vs.* insoluble lignin (Li) and fraction R50, with basic density (Db) and fraction R270 at its mean values (= 0)

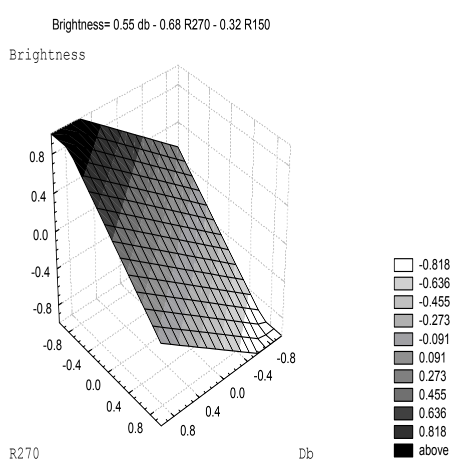

Figure 8: Brightness *vs*. basic density (Db) and fraction of fines (R270), with R150 at its mean value (= 0)

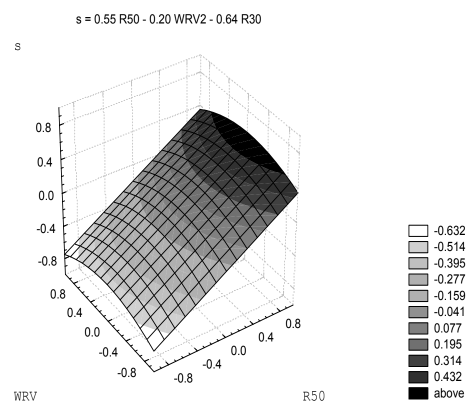

Figure 9: Light scattering coefficient (S) *vs*. water retention value (WRV) and fraction R50, with R30 at its mean value (= 0)

Only two properties did not change with this set of variables (Tear I and S), although the quadratic models did not adjust significant equations in this case, either. The linear models adjust better to this set of independent variables and are easier to interpret.

On the addition of variables 2 (measuring particle shape and fiber state), all adjustments (except opacity) improved their R2 coefficients. With this set of variables in the quadratic model, tear strength acquires a significant equation.

Among the strength values, tensile obtained the highest values of R2, followed by burst. As to the optical properties, brightness obtained the best adjustment, while the R2 of the other properties was reasonably good.

For most properties, the adjustments improve when the wood characteristics are combined with fiber state and fractions (variable 2), which indicates the importance of the effects of mechanical stage on hardwood chemimechanical pulps.

Table 7
R^2 adjusted for different sets of independent variables

	Variables 1		Variables 2	
	Linear Table 1	Quadratic Table 3	Linear Table 2	Quadratic Table 6
Bulk	88	66	90	92
Tear I	85	75	85	95
TI	Ns	Ns	Ns	74
BI	78	66	88	94
Brightness	84	86	84	80
Opacity	65	Ns	88	91
S	Ns	Ns	86	87
K	76	88	88	82

In spite of the previous observations, the use of wood independent variables (variables 1) allows a reasonable prediction of several chemimechanical pulp properties. Accordingly, they can be used as selection criteria, to obtain clones with better mechanical and optical properties. The most important determinations comprise basic density, fiber length, lumen, insoluble and soluble lignin (total lignin), soluble sodium hydroxide and cellulose.

CONCLUSIONS

No wood characteristic explains, by itself, the behavior of willow chemimechanical pulps.

The 50-mesh retained fraction presents a better adjustment than the R30 + R50 sum. Intrinsic fiber strength is an important factor in the regression equations, followed by the fraction of fines (retained in mesh 270).

The mechanical and optical properties of hardwood chemimechanical pulps do not respond to the parameters defined for softwood mechanical pulps (Forgacs' L Factor).

However, even though the L Factor, °SR and WRV do not improve the adjustments, the equations obtained are simpler and the number of measurements is reduced.

Lumen, fiber length, basic density, insoluble lignin, cellulose and soluble sodium hydroxide contents are pulp features that best predict the quality of willow chemimechanical pulps.

Unlike pure mechanical pulps, the use of these physical, chemical and anatomical wood characteristics as independent variables allows a reasonable prediction of several chemimechanical pulp properties. Consequently, they can be used as a first selection criterion to obtain clones with better mechanical and optical properties.

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REFERENCES

[1] R. Repetti, *Seminario sobre calidad de madera en la producción forestal*, Buenos Aires, *CIEF Actas*, 1990, pp.11-30.
[2] G. C. Deka, B. M. Wong and D. N. Roy, *J. Wood Chem. Technol.*, **12**, 197 (1992).
[3] C. Pipan, *25º Congreso Técnico sobre Celulosa y Papel*, *ATIPCA*, *Trabajos técnicos*, Buenos Aires, 1989, pp. 55-92.

[4] A. J. Panshin and C. De Zeeuw, "Textbook of Wood Technology", McGraw-Hill, 4th edition, 1980.
[5] M. C. Area and G. B. Gavazzo, *26º Congreso Técnico sobre Celulosa y Papel*, *ATIPCA*, *Trabajos técnicos*, Buenos Aires, 1990, pp. 469-483.
[6] F. F. Wangaard, *Tappi J.*, **45**, 548 (1962).
[7] T. Ona, T. Sonoda, K. Ito, M. Shibata, Y. Koyima, J. Ohshima, S. Yokota and N. Yoshizawa, *Wood Sci. Technol.*, **35**, 229 (2001).
[8] O. L. Forgacs, *Pulp Paper Magazine Canada*, *Conv. Issue*, **64**, T89 (1963).
[9] F. Ruzinsky, M. Tomasec, B. Kokta and J. J. Garceau, *Cellulose Chem. Technol.*, **30**, 267 (1996).
[10] T. Jones and J. Richardson, *Appita J.*, **52**, 51 (1999).
[11] C. A. Lindholm, *Paperi ja Puu*, **10**, 593 (1980).
[12] C. A. Lindholm, *Paperi ja Puu*, **12**, 803 (1980).
[13] U. B. Mohlin, *Int. Mechanical Pulping Conf.*, *Preprints*, vol. 1, Helsinki, 1989, pp. 49-57.
[14] K. Oleander, U. Gren and M. Htun, *Int. Mechanical Pulping Conf.*, USA, *TAPPI Proceedings*, 1991, pp. 81-86.
[15] P. A. Reme and T. Helle, *Nordic Pulp Paper Research J.*, **13**, 263 (1998).
[16] F. Carrasco, B. V. Kokta, A. Ahmed and J. J. Garceau, *TAPPI Pulping Conf.*, Orlando, Book 1, 407 (1991).
[17] S. Monteoliva. M. C. Area and F. Felissia, *Cellulose Chem. Technol.*, 41, 263 (2007).
[18] S. Monteoliva, *Doctoral Thesis*, Universidad Nacional de La Plata, 2005.

APPENDIX

Tables A1, A2, A3, A4 and A5 present the results of the variables measured on woods and pulps as standardized variables.

Table A1
Wood properties as standardized variables

Clone	Site*	Density	Fibers length	Fibers width	Fiber lumen	Fiber wall thickness
		g/cm^3	μm	μm	μm	
13-44	2	1.61	-0.56	-2.00	-1.68	0.11
	1	1.40	-0.73	-0.94	-0.97	0.08
250-33	2	-0.03	0.22	0.11	-0.58	0.85
	1	-0.39	0.43	-0.40	0.07	-0.74
131-27	2	-0.45	-0.81	0.82	0.22	0.53
	1	-0.48	-0.23	-0.85	0.60	-1.54
131-25	2	-0.56	0.17	1.34	1.82	-0.99
	1	-1.18	-0.36	0.76	1.06	-0.37
26992	2	-0.95	-0.78	-0.85	-0.46	-0.12
	1	-1.04	-1.06	0.55	1.08	-0.97
American	2	0.97	1.39	0.96	-0.49	1.68
	1	1.12	2.32	0.50	-0.68	1.48

*Site 1: Delta; 2: Continental

Table A2
Complete chemical analysis as standardized variables

Clone	Site*	Alcohol-benzene extractives	Hot water extractives	Total extractives	1% NaOH soluble	Insoluble lignin	Soluble lignin	Total lignin	Cellulose	Hemi-celluloses
		%db	%db	%db	%db	%db	%db	%db	%db	%db
13-44	2	0.85	1.03	1.04	1.04	-0.29	1.24	0.04	-0.55	-0.01
	1	-0.80	-0.89	-0.92	1.31	0.06	-0.07	0.04	0.43	0.30
250-33	2	1.16	1.84	1.73	1.15	-0.17	-0.51	-0.36	-0.74	-0.42
	1	-0.62	-0.83	-0.81	-1.01	0.75	-1.38	0.45	0.43	-0.11
131-27	2	0.27	0.94	0.78	0.54	-0.63	-0.51	-0.89	-0.94	1.23
	1	-0.60	-0.14	-0.31	-1.03	0.40	0.36	0.58	1.08	-1.77
131-25	2	0.71	1.01	0.98	0.55	0.98	-0.95	0.85	-1.26	0.20
	1	0.24	-0.73	-0.44	0.00	1.78	-0.07	2.05	-0.81	0.20
26992	2	0.70	0.40	0.54	0.12	-1.90	1.67	-1.70	-0.61	1.65
	1	1.11	-0.68	-0.10	0.11	-0.17	0.80	0.04	-0.03	0.09
American	2	-0.97	-0.80	-0.92	-0.97	-1.32	0.80	-1.30	0.95	0.40
	1	-2.06	-1.16	-1.56	-1.80	0.52	-1.38	0.18	2.05	-1.77

*Site 1: Delta; 2: Continental; % db: dry basis

Table A3
Fractions of Bauer-MacNett classification, Forgacs' L Factor and weighed average fiber lengths by weight (Lw) of pulps as standardized variables

Clone	Site*	Fractions of Classification (% db)						Factor L	Lw Total
		R30	R50	R100	R150	R270	P270	R30+R50	(μm)
13-44	2	-1.87	-0.50	1.50	0.74	-1.02	0.70	-1.73	-1.56
	1	0.05	0.16	0.81	0.51	-0.44	-0.70	0.14	-0.43
250-33	2	0.40	-0.16	-0.39	0.17	0.01	0.07	0.19	0.89
	1	-0.68	1.30	0.68	0.92	0.42	-1.26	0.34	0.34
131-27	2	-1.29	-0.84	0.53	-1.71	-1.03	1.89	-1.51	-1.69
	1	0.51	-0.67	0.25	-0.34	-0.33	0.09	-0.05	0.46
131-25	2	1.04	-0.67	-0.68	1.07	0.19	-0.16	0.35	0.38
	1	-0.80	-1.10	-0.75	0.26	0.39	1.57	-1.32	-1.40
26992	2	1.73	-1.12	0.78	-1.38	-1.36	-0.19	0.57	0.59
	1	0.26	0.73	0.49	1.21	0.30	-1.44	0.67	0.80
American	2	0.35	1.79	-1.81	-0.16	0.39	-0.08	1.43	0.84
	1	0.29	1.08	-1.40	-1.29	2.47	-0.49	0.92	0.78

*Site 1: Delta; 2: Continental; % db: dry basis

Table A4
Pulping yields and pulp physical properties as standardized variables

Clone	Site*	ºSR	WRV	Bulk	I. T.	I.R.	I.E.	Strain	Fiber strength	TEA	Air resistance
			%	cm^3/g	Nm/g	mNm^2/g	$kPam^2/g$	%	N/cm	J/m^2	S
13-44	2	0.20	-0.63	1.19	-0.86	-1.51	-0.96	-0.58	-1.06	-0.69	-1.07
	1	-0.81	-0.54	-0.36	-1.12	0.66	-0.01	-0.77	-0.55	-0.88	-0.17
250-33	2	0.87	0.43	-0.32	-0.39	0.69	-0.11	-0.14	0.23	-0.34	-0.53
	1	-0.48	-0.51	-0.84	1.28	1.63	0.80	0.74	0.64	0.94	1.41
131-27	2	0.87	0.02	-0.53	-0.02	-0.31	-0.27	-0.47	0.64	-0.36	-0.33
	1	-0.48	0.66	0.52	0.02	-0.21	-0.67	-0.45	1.08	-0.37	-0.40
131-25	2	0.20	1.68	0.76	-0.61	-0.67	-1.30	-0.77	-1.16	-0.77	-0.71
	1	-2.16	-0.07	1.61	-1.26	-1.51	-1.43	-1.29	-1.60	-1.17	-0.97
26992	2	0.53	1.04	1.13	-0.60	0.97	0.10	-0.40	-0.86	-0.46	-0.42
	1	0.53	0.95	-1.11	1.46	0.13	1.35	0.61	1.35	0.97	2.12
American	2	-0.81	-1.62	-0.63	0.51	0.87	0.92	1.73	0.30	1.09	-0.01
	1	1.54	-1.41	-1.43	1.58	-0.75	1.58	1.82	1.01	2.04	1.08

*Site 1: Delta; 2: Continental

Table A5
Pulp optical properties as standardized variables

Clone	Site	Brightness	Opacity	k	S	Color		
						L*	a*	b*
		% ISO	%	m^2/kg	m^2/kg			
13-44	2	1.17	-0.72	-1.18	0.69	0.48	-0.89	-0.53
	1	0.87	0.16	-0.17	-0.62	0.44	-0.75	-0.27
250-33	2	-0.12	-0.43	-0.30	-0.46	0.28	0.30	0.54
	1	-0.59	0.81	0.54	1.49	0.12	0.47	-0.35
131-27	2	0.99	-0.12	-0.69	0.56	0.44	-1.24	-0.69
	1	0.18	0.69	0.48	1.16	0.21	-1.46	-1.76
131-25	2	-1.42	0.29	0.89	-1.74	-3.11	1.44	1.68
	1	-1.05	0.82	1.18	0.05	0.07	-0.73	0.55
26992	2	0.54	-1.30	-1.03	-1.67	0.45	0.14	1.01
	1	-1.16	0.90	0.85	0.12	0.03	1.51	0.38
American	2	1.43	-2.17	-1.76	-0.04	0.61	0.52	0.76
	1	-0.85	1.06	1.19	0.45	0.00	0.69	-1.34

*Site 1: Delta; 2: Continental