Increasing Fiber Yield and Quality at Aracruz

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Abstract

Preliminary results for genetic and phenotypic parameters of eucalypt wood, cooking and pulp characteristics at five years old, were previously published (Demuner and Bertolucci, 1993). For the present work, the same estimates were determined considering nine clones established in three representative sites at six years of age. The objective was to evaluate the effect of clone x site interaction on genetic and phenotypic parameters. The broad sense heritability estimatives were high (> 0.8) for some characteristics such as basic density, lignin content, tensile strength, however for others, such as pulp yield and wood extractives, were low (< 0.4). This study has contributed significantly for the better understanding of genetic effect on wood and pulp properties, allowing a definition for the genetic improvement strategy at Aracruz.

Introduction

Aracruz Celulose has been developing an extensive programme on *Eucalyptus* genetic improvement since 1973, going through the introduction, testing of genetic material, evaluation and selection of superior trees within best families (Bertolucci and Penchel, 1992). At the same time, the company has decided to set the hardwoods cuttings programme on a operational scale, enabling the establishment of plantations consisting of 85% of clones and 15% of seedlings, annually.

Significant increase in productivity and wood quality have been achieved since then (Campinhos Jr. E Claudio-da-Silva Jr., 1990). The wood specific consumption decrease from 4.9 to 4.1 m^3/t pulp and a considerable increase in productivity of pulp yield from 5.9 to 10.9 t/ha.yr (Ikemori *et al.*, 1994), were obtained through the clonal plantation program.

The current strategy is built on intensive family and individual tree evaluation and selection with emphasis mainly on silvicultural characteristics. The best genotypes are used for breeding recombinations and also for the cloning programme. Only the superior trees are then evaluated for wood quality for pulp production. This strategy, supported by recent studies of genetic and phenotypic parameters (Bertolucci *et al.*, 1992; Demuner and Bertolucci, 1993) has been important for the additional gain on wood quality and productivity (Bertolucci and Penchel, 1992).

The present work evaluates the effects of clone x site interaction, at 6 years of age, over genetic and phenotypic parameters, for wood characteristics and for pulp properties. Index selection will be determined from these results, based on silvicultural characteristics and wood quality, aiming to classify and to recommend clones for the operational planting programme.

Materials and methods

The data are obtained from clonal tests established in three different management units, in a randomised block design, with nine treatments, three replications, seven tree row plots, with single border row, comprising 21 plants/replication. For wood and pulp technological analysis was considered only for a single tree per replication, selected according to its average volume. All nine clones are hybrids, where *Eucalyptus grandis* has probably been one of the parent species.

The technological characterization (cooking, washing purification, wood and pulp analysis) was conducted according to standardized TAPPI or SCAN procedures.

Each of the wood and pulp characteristic was used for a joint variance analysis for the three sites in order to evaluate the effects of the clone x site interaction on the genetic and phenotypic parameters. The statistic model used was:

$$Yijk = M + Cj + Si + CSij + b(i)k + Eijk,$$

where: Yijk is the individual tree observation, of the clone j, on k^{th} replication of i^{th} site; M is the overall mean; Cj is the effect of the j^{th} clone; Si is the effect of i^{th} site; CSij is the effect of interaction of j^{th} clone and i^{th} site; b(i)k is the effect of k^{th} replication nested within i^{th} site and Eijk is the experimental error associated to observation Yijk.

The nature of variance associated with clones x sites interaction, splitting into trivial and troublesome parts, was evaluated from the joint analysis of variance according to the methodology cited by Vencovsky and Barriga (1992). The broad-sense heritabilities were also estimated on a clone mean basis, aiming to determine the effect of the interaction on this parameter.

Table 1. Summary of three sites joint analysis of variance.

Characteristics	Mean Square			
	Sites	Clones	C x S	Error
		Wood		
Wood basic density	2742.23**	5874.77**	208.97	191.12
Lignin #	4.5030	6.4630 **	1.1220 *	0.5120
Pentosans	0.7312	2.9518 **	0.9068 *	0.4854
Extractives in ethanolholuene	0.0603	0.6380 **	0.0509	0.0587
Extractives in DCM	0.3727×10^{-2}**	0.1971×10^{-2}**	0.6063×10^{-3}*	0.3041×10^{-3}
Fiber width	3.9373 **	2.4739 **	0.4427	0.2752
Fiber width#	0.9170**	0.2610**	0.0530*	0.0230
Vessel diameter	481.9461 **	327.2042**	73.0500	45.6076
		Pulp		
Pentosans	1.2562	1.7969**	0.5657	0.7184
Extractives in DCM	0.2802×10^{-2}	0.3710×10^{-2}**	0.1177×10^{-2}*	0.6421×10^{-3}
Fiber length	0.0468 **	0.6867×10^{-2} **	01220×10^{-2}*	0.5066×10^{-3}
Coarseness	0.5463	1.4445**	0.2838*	0.1502
Number of fibers/gram	58.0454 **	23.0194 **	4.0930 **	1.0620
tensile index #	1.2700	330.2280 **	47.5070 *	22.6540
Apparent density	2137.1480	5812.8600 **	1665.7310 *	810.5380
Air resistence	15.9078 **	17.6867 **	2.9319 **	0.5069
Tear index	9.1012 **	2.0845	1.1200	1.04785
		Kraft Cooking		
Alkaline charge	0.0538	0.3967	0.1910	0.1695
Screened pulping yield	1.9260	8.6193	5.5132 **	2.1269
Production gain	11667.88	46181.89	28687.41 **	11074.88
Specific wood consumption	0.1565	0.5988 **	0.0283	0.0278

Table 2. Estimates of the genetic and phenotypic parameters.

Characteristics	σ^2_{cs}	Trivial	Troublesome	h^2_m
		Wood		
Wood basic density	5.9510	-	-	0.96
Lignin #	0.2030	57.0	43.0	0.82
Pentosans	0.1404	100.0	0.0	0.69
Extractives in ethanolholuene	-0.2600×10^{-2}	-	-	0.92
Extractives in DCM	0.1007×10^{-3}	61.9	38.1	0.69
Fiber width	0.0558	-	-	0.92
Fiber width #	0.0100	18.7	81.3	0.80
Vessel diameter	9.1475	-	-	0.78
		Pulp		
Pentosans	-0.0509	-	-	0.68
Extractives in DCM	0.1738×10^{-3}	68.4	31.6	0.68
Fiber length	0.2378×10^{-3}	14.0	86.0	0.82
Coarseness	0.0445	22.1	77.9	0.80
Number of fibers/gram	1.0103	65.2	34.8	0.82
Tensile index #	8.2840	2.1	97.9	0.85
Apparent density	285.0643	72.5	27.5	0.71
Air resistence	0.8083	13.1	86.9	0.83
Tear index	0.0241	-	-	0.80
		Kraft Cooking		
Alkaline charge	0.7167×10^{-2}	-	-	0.52
Screened pulping yield	1.1288	45.3	54.7	0.36
Production gain	5870.84	78.8	21.1	0.38
Specific wood consumption	0.1667×10^{-3}	-	-	0.95

#: Results at five years age. σ^2_{cs}: variance of clones x sites interaction, h^2_m: heritability coefficient on a clone mean basis.

Results and discussion

Initially, it should be emphasized that it was decided to evaluate a great number of characteristics, considered important for the industrial process, aiming to detect which ones could be utilized as criteria for recommending clones for the operational planting. Emphasis has been given to the results of the evaluation of the clone x site interaction and its effects on the estimative of genetic and phenotypic parameters of interest, such as heritability. The knowledge of this is fundamental for the choice of the most relevant characteristics (those which are important for the production of cellulose, and that have concrete gain possibility through selection) for establishing selection indices and for defining the degree of investments and prediction of gains.

Clone x site interaction

Tables 1 and 2 show that 13 characteristics were significant for the interaction between clones and sites, from which, six showed predominance of troublesome interaction, indicating possible inversion on the ranking of clones from one site to the other.

These results, in practical terms, indicate that it is important to pay attention to those variables, because of the existence of troublesome genotype x environment interaction may cause problems in the tree improvement program. On the other hand, if well known and applied, troublesome interactions may be an important tool for achieving gains. Van Buijtenen (1992) discusses this aspect, concluding that in these cases the tree breeder faces two alternatives to solve the problem: to try to find genotypes which have good performance in a wide range of sites (stable clones), or to select genotypes specifically adapted to each type of site.

Both ways already have been followed in genetic improvement program in several crops and for various characteristics (Hallauer, 1988; Vencovsky *et al.*, 1990; Ramalho *et al.*, 1991), but it is a relatively new subject for defining selection strategies in trees for wood quality characteristics.

As it has been done for silvicultural characteristics (Davide, 1992), the strategy in the utilization of stable clones seems to be the most interesting question concerning wood quality, as it facilitates the forest operations, without harming the quality of the final product.

Heritability

Table 2 shows the results of broad-sense heritability coefficient on a clone mean basis for all characteristics considered in this work, estimated from joint analysis of variance of the three sites.

In general, the estimates were high, mainly for wood and pulp characteristics, confirming the tendency observed for the age of five years (Demuner and Bertolucci, 1993). Again, cooking characteristics showed the lowest heritability estimates (except the wood specific consumption), indicating that the majority of the phenotypic variance can not be set via selection. The explanation for these results relies on the fact that they are characteristics of the end of the process, strongly affected by lignin content and wood extractives (Vasconcellos Dias and Claudio-da-Silva Jr., 1985). For those characteristics, studies on genetic correlations are in progress, aiming to evaluate the possibility of use of indirect selection.

An important result was a high heritability estimate for the specific wood consumption. This property is very important for the company's planning, because it refers to the quantity of wood necessary to produce one ton of pulp. The estimated value (0.95), shows a high degree of confidence for the selection of superior genotype, showing that the current strategy of selection of clones, concerning pulp productivity per hectare is right and it has great potential to assure continuous significant gains.

It is import to emphasize that, the specific wood consumption is affected by the basic density and by the pulping yield. In an analysis of the heritabilities for those two characteristics, it is noticed that only the heritability for basic density could explain the heritability estimate of the specific wood consumption, indicating that basic density is the most relevant factor. Once again the importance of this characteristic as a selection criteria has been reported, particularly considering its strong effect on several other paper properties (Demuner *et al.*, 1991).

Besides the definition of the tree selection strategy for wood quality, the estimates of the genetic and phenotypic parameters from this present work are been used to guide the studies which have been done on molecular markers (RAPD). So far, QTL's (Quantative Trait Loci) which explain 24.7% of phenotypic variance for wood basic density have been achieved (Grattapaglia *et al.*, 1994). In the same work the authors mentioned that QTL detection power was considerably lower for screened pulp yield. These results are consistent with the results of the present study, since characteristics with high heritability must be controlled by a reduced number of genes, which makes it easier to detect the QTL's.

Conclusions

- The evaluation of clone x site interaction and its effect on the estimates of genetic and phenotypic parameters of wood and pulp, has shown similar results to the ages of five and six years, suggesting that when it concerns the reliability of selection, the age for selecting can be anticipated, thus accelerating the genetic improvement programme. Experiments with younger age are been evaluated, aiming at the study of the clone x site x age interaction.
- Six characteristics showed predominance of clone x site troublesome interaction, out of the 21 evaluated.

The use of stable clones seems to be the best alternative, because it facilitates the forest operations, without harming the uniformity of the final product.

- The broad-sense heritability estimates on a clone mean basis for wood and pulp characteristics were generally high at six years, similarly to that obtained at age of five. Those results indicate high confidence in recommending clones selected in those experiments. However, the achievement of genetic gains should be more difficult, for some cooking characteristics.

- The application of the estimates of genetic and phenotypic parameters for supporting the studies on molecular markers have been providing the detection of QTL's which control important characteristics, such as the wood basic density. In this case, the information of genetic maps should be included in the index selection determination, aiming at higher accuracy and to reduce the time required for the superior genotype selection.

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References

Bertolucci, F.L.G. and Penchel, R.M., 1993.Clonagem do eucalipto: efeitos sobre a produtividade e qualidade da madeira. Ciencia Hoje., 16: 16-21.

Bertolucci, F. de L.G., Demuner, B.J. and La Torraca, S., 1992. M. Estimativas de parametros geneticos e fenotipicos para caracteristicas da madeira e polpa de eucalipto. In: 13° Encontro Nacional da Tecnicelpa, Figueira da Foz.

Campinhos Jr., E. and Claudio-da-Silva Jr., E., 1990. Development of the *Eucalyptus* tree of the future. In: Proceedings of Espra Spring Conference, Seville.

Davide, A.C., 1992. Avaliacao da adaptabilidade e da estabilidade fenotipica de progenies de *Eucalyptus pellita* F. Muell, introduzidas da Australia. Ph.D thesis dissertation, Curitiba, 114pp.

Demuner, B.J. and Bertolucci, F.L.G., 1993. Selecao florestal: uma nova abordagem a partir de estimativas de pararnetros geneticos e fenotipicos para caracteristicas da madeira e polpa de eucalipto. In: Proceedings do 26° Concresso Anual da ABTCP, Sao Paulo, pp. 411-423.

Demuner, B.J.; Vianna Doria, E.L.; Claudio-da-Silva Jr., E. and Manfredi, V., 1991. The influence of the eucalypt fiber characteristics on paper properties. In: International Paper Physics Conference (TAPPI). Kona, 1991.

Grattapaglia, D.; Bertolucci, F.L.G.; Penchel, R.M. and Sederoff, R., 1994. Molecular genetic mapping of economically important traits in *Eucalyptus grandis*. In: Proceedings of the 1994 Biological Sciences Symposium, Minneapolis, pp. 133-137.

Hallauer, A.R., 1988. Genotype-environment interaction. In: Proceedings of the Second International Conference on Quantitative Genetics, Sinauer Associates Inc. Publishers, Massachusetts.

Ikemori, Y.K.; Penchel, R.M. and Bertolucci, F.L.G., 1994. Integrating biotechnology into eucalypt breeding. In: Proceedings of the International Symposium of Wood Biotechnology, Tokyo, pp. 77-84.

Ramalho, M.A.P.; Santos J.B. dos and Pinto, C.A.B.P., 1991. Genetica na agropecuaria. Lavras, Editora Globo, 359pp.

Van Buijtenen, J.P., 1992. Fundamental genetic principles. In: Handbook of quantitative forest genetics. Kluwer Academic Publishers, Chap. 2, pp. 29-68.

Vasconcellos Dias, R.L. and Claudio-da-Silva Jr., E., 1985. Pulp and paper properties as influenced by wood density. In: Transactions of the 8th Fundamental Research Symposium, Oxford.

Vencovsky, R. and Barriga, P., 1992. Genetica biometrica no fitomelhoramento. Ribeirao Preto, Sociedade Brasileira de Genetica, 486pp.

Vencovsky, R.; Cruz, C.D. and Silva, A.C., 1990. Uma avaliacao do potencial de diferentes locais para a discriminacao genotipica entre cultivares de milho (*Zea mays* L.). Revista Brasileira de Genetica, 13(2): 323-334.