GENETIC VARIATION AND REALIZED GENETIC GAIN FROM RUBBER TREE IMPROVEMENT

Paulo de Souza Gonçalves[1]*; Adriano Tosoni da Eira Aguiar[1]; Reginaldo Brito da Costa[2]; Elaine Cristine Piffer Gonçalves[3]; Erivaldo José Scaloppi Júnior[4]; Roberto Botelho Ferraz Branco[5]

[1]*APTA - Instituto Agronômico - IAC, Programa Seringueira, C.P. 28 - 13020-970 - Campinas, SP - Brasil.*
[2]*UFMT - Programa Ciências Florestais e Ambientais, Av. Fernando Corrêa, s/n - 78060-900 - Cuiabá, MS - Brasil.*
[3]*APTA - Regional Alta Mogiana, C.P. 35 - 15830-000 - Colina, SP - Brasil.*
[4]*APTA - Regional Noroeste Paulista, C.P. 61 - 15500-000 - Votuporanga, SP - Brasil.*
[5]*APTA - Regional Centro Leste, C.P. 271 - 14001-970 - Ribeirão Preto, SP - Brasil.*
**Corresponding autor <paulog@iac.sp.gov.br>*

ABSTRACT: Breeding cycle in rubber extends to 20–30 years between pollination and yield assessment, distributed over three selection stages. Five hectares of small scale trial of rubber tree [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell.-Arg.], was established in the Northwestern region of São Paulo State, Brazil. The population comprises 98 clones mostly derived from intensively selected plus tree in the natural forest of rubber tree in the Amazon. Three open pollinated progeny tests were established in three experimental stations. Seedlings from 98 progenies including a commercial check (CC) were planted in each one of the three locations. Assessments were made when the plants were one, two and three years old. The variation among progenies for girth was highly significant in all locations examined. In the combined analysis of variance over three locations, differences among progenies were also detected, while progeny × location interaction effect was not significant. Narrow sense heritability estimates on individual tree basis (h_i^2) were variable depending on the characteristic, age of assessment and experimental location. Realized genetic gains were calculated for the plant characteristics at the age of three years, by comparing the performance of improved (selected) materials to unimproved materials (CC). The total genetic gain from the genetically tested first generation clone population at Votuporanga is estimated as 25% for girth, 14% for rubber yield and 25% for bark thickness. Improvement of rubber tree by selection, establishment of clonal population (isolated garden) and progeny testing is a very promising and profitable operation.
Key words: *Hevea brasiliensis*, variance, covariance, heritability correlation, genetic test

VARIAÇÃO GENÉTICA E GANHOS OBTIDOS POR MEIO DO MELHORAMENTO GENÉTICO DA SERINGUEIRA

RESUMO: Partindo-se da polinização à recomendação de clones para o plantio, o ciclo de melhoramento da seringueira, o qual compreende três ciclos de seleção leva em torno de 20–30 anos. Cinco hectares de uma população clonal de seringueira [*Hevea brasiliensis* Willd. ex Adr. de Juss.) Muell.-Arg.] foram instalados em Votuporanga, região Noroeste do Estado de São Paulo. A população inclui 98 clones, cuja maioria é derivada de árvores selecionadas na floresta nativa de seringueira na Amazônia. Três testes de progênies de polinização aberta foram conduzidos nas estações experimentais de Pindorama, Jaú e Votuporanga. Mudas de 98 progênies inclusive a testemunha (CC) foram plantadas em cada um dos três locais. Foram feitas avaliações quando as plantas apresentaram um, dois e três anos respectivamente. A variação entre progênies para crescimento de perímetro do caule foi altamente significantes em todos os locais testados. Nas análises de variâncias conjuntas com os três locais também foram observadas diferenças entre progênies, e que o efeito da interação progênie × local não foi significativo. Estimativas de herdabilidade no sentido restrito em nível de árvore individual (h_i^2) foram variáveis dependentes das características, idade de avaliação e local dos experimentos. Foram calculados ganhos genéticos para as características da planta na idade de três anos através da comparação de desempenho nos materiais selecionados para os não selecionados (CC). O ganho genético total da primeira população geneticamente testada da população clonal de Votuporanga foi calculado como 25% para perímetro caule, 14% para produção de borracha e 25% para espessura da casca. Melhoramento da seringueira por meio da seleção, implantação de uma população clonal e teste de progênie com os clones é uma operação lucrativa e muito promissora.
Palavras-chave: *Hevea brasiliensis,* variância, covariância, herdabilidade de correlação, teste genético

INTRODUCTION

Rubber tree [*Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell.-Arg.] is native to rain forests of the Tropical region of the Great Amazon basin of South America. This area, between Equator and 15º S is distinctly characterized by its flat land with altitudes not exceeding 200 m with a wet equatorial climate (Strahler, 1969). Monthly temperature is 25º to 28ºC with abundant rainfall of more than 2000 mm/year, without any real dry season. The amount of precipitation is at least twice the evaporation losses on yearly basis (Pushparajah, 2001).

Hevea the prime source of commercial rubber, is a deciduous perennial tree of the family Euphorbiaceae. Rubber is the strategic raw material for more than 40,000 products, including 400 medical devices (Mooibroek & Cornish, 2000). Primarily due to its molecular structure and high molecular weight (> 1 million daltons) it has resilience, elasticity, abrasion resistance and impact resistance that cannot easily be mimicked by artificially produced polymers.

Breeding cycle in rubber extends to 20–30 years between pollination and yield assessment, distributed over three selection stages. This justifies standardization of early selection methods to optimize and shorten the cycle as much as possible. One component of early selection is the identification of traits at young age that have correlated responses with yield at maturity, and the other is combined management of different selection stages to improve the accuracy of estimation of genetic value.

Breeding methodologies utilized for maximizing genetic gain are based on breeding objectives with the specific aim of providing farmers with high yielding clones. Such methodologies are backed by the theory of quantitative genetics, which derives clones well adapted to a given environment. Elements of breeding methodologies are available with major contribution from Tan (1987); Simmonds (1989); Gonçalves et al. (1998); Gonçalves et al. (2005) and Priyadarshan & Clément-Demange (2004).

The objective of this investigation is to study the genetic variability for growth and quality characteristics in *Hevea* to identify clones with high breeding value for selection and to estimate realized genetic gain from first stage clonal population.

MATERIAL AND METHODS

Plant material

Open pollinated seeds were collected from all 98 phenotypically selected clones most of them derived from intensively selected plus tree in the natural rubber tree forest in the Amazon region. All seed from a clone, regardless of the ramets from which they were collected were considered to be members of the same open pollinated progeny, i.e., they all shared the same genetic mother. Seeds were sown in polyethylene bags. A year later three experimental plantings were established.

Experimental locations

At each location, 98 progenies plus a control, also called commercial check (CC), GT 1 progenies were planted in randomized complete block design including three (Pindorama and Jaú) or four (Votuporanga), replications. Progenies plus CC were randomly assigned within replications in 10 plant row plot arrangement for Jaú and Pindorama and 8 plant row plots for Votuporanga. The rubber tree cultivation regions in São Paulo State are characterized as:

(i) Jaú experimental station (22º17' S, 48º34' W, altitude 580 m). The soil is a medium-textured, deep and well drained Rhodic Hapludox, with a flat topography. An Aw (köppen) climate predominates in this region, with a defined dry season, annual mean temperature of 21.6ºC, average humidity of around 70% with extremes of 77% in February and 59% in August. The mean annual rainfall is around 1,344 mm.

(ii) Pindorama experimental station: latitude 21º13' S, longitude 48º56' W, altitude 560 m, with a medium textured, deep, abruptic and well drained Typic kandiustalf. The climate is tropical, with a wet summer and a dry winter period. Mean monthly temperatures vary from 16.6 to 28.9ºC, and annual mean rainfall is 1,390 mm. The period from October to April usually has favorable precipitation for growth and production. Precipitation deficiencies and low temperatures occur from May to September.

(iii) Votuporanga experimental station: latitude 20º25'S, longitude 49º50' W, altitude 450 m. The soil is a medium textured Typic Kandiudalf, and the climate, tropical, with a hot wet summer and dry winter, with low temperatures and rainfall. Mean monthly temperatures varies from 20 to 25ºC and annual mean rainfall ranges from 1,087 to 1,537 mm. The winter drought varies from four to six dry months, with an average water deficiency of 180 mm.

Since the geomorphology of the experimental planting at Votuporanga was quite heterogeneous, to reduce the variability within replications, the number of replications was increased with equivalent reduction in plot size. The spacing in all plantings was 2 × 2 meters. The characteristics of the locations and the experimental plantings are shown in Table 1.

Table 1 - Details of experimental locations and planting dates from three different test locations where 98 *Hevea* progenies were evaluated in São Paulo State, Brazil.

Remarks	Locations		
	Pindorama	Jaú	Votuporanga
Number of progenies	98	98	98
Planting material	Seedlings	Seedlings	Seedlings
Spacing (m)	2.00 × 2.00	2.00 × 2.00	2.00 × 2.00
Planting density	10 rows plants	10 rows plants	8 rows plants
	10 plants/plot	10 plants/plot	8 plant/plot
Design of experiment	RBD[1]	RBD	RBD
Numbers of replications	3	3	4
Total area (ha)	1.17	1.10	1.56
Elevation (m) (mean sea level)	560	580	450
Latitude (S)	21º13'	22º17'	20º25'
Longitude (EE)	48º56'	48º34'	49º50'
Temperature (annual mean)	22.2ºC	21.60ºC	22.3ºC
Annual rainfall (mm) (mean annual)	1.390	1.344	1.420
Soil type	Rhodic hapludox	Kandiustalf	Kandiudalf
Terrain	Flat to undulating	Flat to undulating	Flat
Year of planting	2000	2000	2000

[1]Randomized block design.

Measurements

Girth was measured in all three locations at the ages of one, two and three years. Rubber yield and bark thickness was measured only at the age of three years. In the first year, diameter was recorded because plants were too small to measure the girth. Measurements were converted into girth assuming that plants were measured 0.20 m above ground level by a slide caliper. The other two girth measurements were recorded 0.50 m above the ground.

Yield determination as dry rubber was carried out using the Hamker Morris-Mann test (HMM) (Tan & Subramanian, 1976), as follows: thirty tappings were done with a half-spiral alternate daily (1/2S d/2) tapping system at a height of 20 cm from the ground. The yield was recorded by cup coagulation. The "coagula" were air dried for two months until they reached a constant weight. The results were expressed in grams per tapping. Virgin bark samples were removed from the trunk as plugs at 20 cm high on the opposite side of the tapping panel. Bark thickness was measured using the sample for each progeny.

Statistical evaluation

Data were checked for suspected outliers (measurements outside the normal values) before analyses. Such values may arise from various reasons, as recording errors during measurements or mechanical damages of plants in the growing locations. Analysis of variance for each character measured or assessed were conducted in two stages due to missing plants within plots and the need for the estimation of the within plot variance, following well established procedures (Namkoong, 1979; Becker, 1984). Initially the mean squares within plot variance (σ^2_w) were estimated from individual plant data. Then, analyses based on plot means were made applying the general model of two way classification:

$$Y_{ij} = \mu + r_i + f_j + rf_{(ij)} + w_{ij}$$

where : Y_{ij} = the mean plot value of the j^{th} progeny that is in the i^{th} replication all Y_{ij} values are treated as if they had the same number of observations; μ = overall mean; r_i = effect of i^{th} replication; f_j = effect of j^{th} progeny; $rf_{(ij)}$= interaction effect of progeny × replications; w_{ij} = the mean of the n_{ij} deviations;

The variance of plot means ($Y_{ij.}$) is $\sigma^2_w/rf\ (1/n_{11}+1/n_{12}+\ldots..1/n_{rf}) = \sigma^2_w/n_{h.}$, where n_h is the harmonic mean of the number of plants within plots. The within plot mean square variance (σ^2_w) was used for estimating heritability values, while the average variance of plot mean (σ^2_w/n_h) is used in the analyses of variance for testing the replications × families interaction effect.

Combined analyses of variance over locations

Genotype × environment interaction arises from the fact that some genes may have effects that differ from one environment to another. Such interactions, if exist, may cause decreased performance when a population selected under one environment is used under another. The size and extent of the interaction is very important for the movement of recombinant material of the rubber tree species. Therefore, data girth measured at the ages one, two and three years old, common to all (three) experiments, were pooled over locations and combined analyses of variance were performed following the procedures outlined in detail by Cochran & Cox (1957). Since the numbers of replications were not equal in all locations (three in Pindorama and Jaú and four in Votuporanga) and the number of trees within plots also varied, the analyses for getting the effect of locations, progenies and progenies × locations were based on plot means.

Genotype × environment interaction (G × E) effect at the progeny level was also tested for significance using the type B (r_b) genetic correlation (Hodge & White, 1992; Sierra-Lucero et al., 2002). This correlation express the genetic relationship that may exist between measurements of the same character taken in different environments and it is expressed as: $r_b = \sigma^2_f / (\sigma^2_f + \sigma^2_{fp})$; Values of r_b near one indicates no (G × E) interaction, while values near zero indicates highly significant interaction. The variance components of progenies (σ^2_f) and progeny × location interaction (σ^2_{fp}) were estimated from the pooled over location ANOVA.

Genetic parameter estimates

Mean squares were equated to expected mean squares and variance components and heritability estimates were obtained. The degree to which progeny members are closely related is proportional to the degree to which progenies differ (Namkoong, 1979). Thus the variances among progenies (σ^2_f) obtained from the analyses are interpreted as one quarter of additive genetic variance.

$$\sigma^2_f = Cov\,(H.S.) = 1/4\sigma^2_A$$

Narrow sense heritability estimates on individual plant basis (h^2) for each one characteristic and location were estimated as the ratio of the additive genetic variance (σ^2_A) to total phenotypic variance (σ^2_{ph}):

$$h^2 = \sigma_A{}^2/\sigma_{ph}{}^2 = 4\sigma_f{}^2 / (\sigma^2_w + \sigma^2_{rf} + \sigma^2_f)$$

The values obtained from the above formula are applicable in the specific environmental conditions under which they have been estimated and are biased upwards when applied to different environmental conditions.

Estimation of realized gain

In clonal population the clones originally selected in the first phase are crossed and the progenies produced are evaluated in progeny tests and estimates of the genetic value of the parental clones are made. The clones, which prove to be poor parents are culled from the clonal population and only the best (genetically tested), are used for future breeding. Realized genetic gains were estimated for both stages of the selection program i.e., for the unrogued and rogued clonal population and selected clonal population of Votuporanga. Since unimproved commercial checks (CC) were included in all plantings, the gain for the first stage of selection was computed by subtracting the mean of the unimproved (CC) from the overall mean of the progenies of the selected clones included in the clonal population; the difference was expressed in percentage of the commercial check. After culling the clonal population on the basis of progeny testing (genetic thinning) an additional gain is obtained. This gain was calculated by subtracting the overall progeny mean of the test (excluding CC) from the mean of the reselected progenies, to be maintained in the clonal population. Finally the total realized genetic gain from rogued clonal population was taken by the addition of the gain of the two stages of selection (mass selection plus progeny testing).

RESULTS AND DISCUSSION

Growth characteristics

Survivals at the stage of three years were variable among progenies and locations. At Pindorama the survivals among progenies ranged from 81% up to 100% with overall mean of the test planting 96%. Twelve progenies had 100% survival at the age of three years. This high survival is related to favorable growth conditions and specifically to very high moisture holding capacity of the soil. In Votuporanga with less favorable conditions the survivals varied among progenies from 55% up to 100% with overall mean 85%. Finally in Jaú, survival was worst ranking among families from 50% up to 90% with overall mean 70% (Table 2). Analyses of variance (not presented) have shown that the differences among progenies within locations were significant ($p < 0.05$), while the differences among locations were highly significant ($p < 0.01$). Total girth at the age of three years was related to survival rate. It was higher (25.90 cm) at Votuporanga with the highest survival and lowest (17.74 cm) at Jaú experimental planting. The differences among progenies for one, two and three years old and rubber yield at the age of three years old, were statistically significant. Large variability among open pollinated progenies of *Hevea* for growth traits, at the age of three years old, has been also reported by Costa et al. (2000a).

Variance components and heritability estimates

Knowledge of variation and the degree of inheritance of the characteristics of interest are the fundamental basis upon which a well designed *Hevea* improvement program must be based. Heritability estimates were variable depending on the location, age and characteristics to which they refer (Table 3).

In Pindorama the h_i^2 for girth were 0.50, 0.62 and 0.67 at the ages of one, two and three years old, respectively. The h_i^2 for rubber yield at the age of three year was found 0.64 and that for bark thickness 0.98. It seems that in this experimental planting the h_i^2 values increase as plants become older. This was expected since the environmental variation is reduced, as plants become older. Similar results have also been reported in *Hevea* (Costa et al., 2000b). They found that girth heritability increased from 0.60 at the age of three years to 0.80 at the age of five years.

In the planting of Jaú the h_i^2 values for girth were 0.69, 0.79 and 0.67 at the ages one, two and three years old, respectively, while the corresponding h_i^2 values for three years old rubber yield was 0.31, and that for bark thickness 0.68. Heritability estimates of girth at the Votuporanga experimental planting were very close to those obtained from Pindorama (Table

Table 2 - Overall mean values for girth at the age of one, two, and three years, rubber yield, bark thickness and survival of three open experimental plantings where 98 *Hevea* progenies were evaluated in São Paulo State, Brazil.

Characteristic	Pindorama[1]	Jaú	Votuporanga
Girth year 1 (cm)	4.3015 (4.9178-3.6404)	4.3909 (5.36-3.33)	4.1991 (4.95-2.90)
Girth year 2 (cm)	7.5809 (9.6298-5.9583)	7.0654 (8.76-4.98)	9.2401 (11.17-7.66)
Girth year 3 (cm)	22.0381 (26.6316-18.1080)	17.7401 (21.45-13.58)	25.8996 (29.38-17.83)
Rubber yield 3 (g)	0.9887 (2.0750-0.5434)	0.9436 (1.47-0.58)	0.6163 (0.916-0.31)
Bark thickness 3 (mm)	3.8030 (4.7059-3.1087)	3.7600 (4.40-2.97)	3.8518 (4.42-3.093)
Survival %	96 (81-100)	70 (50-90)	85 (55-100)
Year of planting	2000	2000	2000

[1]Values in parenthesis are progeny means ranges.

Table 3 - Estimates for girth at the age of one, two and three years, rubber yield and bark thickness variance components and narrow sense heritability (h_i^2) on individual plant basis of three open pollinated experimental plantings, where 98 *Hevea* progenies were evaluated in São Paulo State, Brazil.

Characteristics	Variance components[1]				
	σ^2_g	σ^2_w	σ^2_{rg}	σ^2_{ph}	h^2_i
1. Pindorama					
Girth year 1 (cm)	0.1155**	0.3466	0.0973	0.9232	0.5005
Girth year 2 (cm)	0.8147**	2.4442	1.2660	5.2739	0.6179
Girth year 3 (cm)	6.1911**	18.5732	2.3425	36.8383	0.6722
Rubber yield 3 (g)	0.1187**	0.3562	0.0509	0.7478	0.6350
Bark thickness 3 (mm)	0.2125**	0.6376	0.04509	0.8665	0.9811
2. Jaú					
Girth year 1 (cm)	0.3026**	0.9077	0.2292	1.5247	0.6938
Girth year 2 (cm)	0.7812**	2.3435	0.4806	3.4908	0.7951
Girth year 3 (cm)	4.3822**	13.1467	2.0229	26.1630	0.6700
Rubber yield 3(cm)	0.0248**	0.0744	0.0360	0.3153	0.3145
Bark thickness 3 (mm)	0.1368**	0.4105	0.0903	0.7993	0.6847
3. Votuporanga					
Girth year 1 (cm)	0.1763**	0.5289	0.1483	1.2707	0.5550
Girth year 2 (cm)	0.5922**	1.7765	0.3529	5.3622	0.5417
Girth year 3 (cm)	5.8270**	17.4809	0.6432	41.3448	0.6637
Rubber yield 3 (g)	0.0165**	0.0485	0.0022	0.2882	0.2241
Bark thickness 3 (mm)	0.1201	0.3602	0.0234	0.8060	0.5959

[1]σ^2_g, σ^2_{rg}, σ^2_w and σ^2_{ph} are variance components estimates for progenies, within plot, replications × progenies and total phenotypic variance, respectively. [2]$p < 0.01$

3). Heritability values (h_i^2) for growth characteristics in rubber tree have also been studied by Gonçalves et al. (2006) at the age of seven years; from the analysis of 67 different genotypes including five locations, they estimated h_i^2 values of 0.65, 0.86 and 0.87 for girth, rubber yield and bark thickness, respectively. These values are in close agreement with those found in the present study. The higher h_i^2 values for girth at the ages of 1 (0.69) and 2 (0.79) years, estimated in the Jaú planting, may be the result of the higher location quality of this location in comparison with the other two or the better location uniformity within replications.

Early natural selection against the slower growing plants is expected to be stronger on better sites with the consequence of the reduction of the environmental variance. Gonçalves et al. (2005) working on mature trees found positive correlation (r = 0.54) between h_i^2 and mean annual increment (r = 0.67), indicating that location productivity influences positively h_i^2 values. However, there are contradictory results found in the literature. Costa et al. (2000a) found no relationship between h_i^2 values and location index in rubber and concluded that the degree of genetic control and location uniformity were the same on location of both high and low girth. Narrow sense heritability for girth estimated from the pooled analyses of variance across the three locations was 0.79, 0.82 and 0.89 at the ages one, two and three years old, respectively (Table 4). The differences among progenies and among locations were highly significant, while the progeny × location interaction effect was not significant in all ages. This indicates that although there are some differences in the rankings of the progenies, the faster growing (on the average) remain in the top and the slower are found in the bottom.

The type B genetic correlation (r_b) at the progeny level was found close to unity, indicating that progeny ranks are relatively stable across locations. This is in agreement with not significant progeny × location interaction effect found from the pooled analyses of variance. Genotype × environment interaction is not a significant source of variation and therefore the clone selected from the clonal population of Votuporanga can be freely used over the environmental conditions of the three locations that are representative of the broad area of the São Paulo State plateau. Although there are strong interactions for a few progenies the genetic gain does not seem to be influenced when the best progenies are selected on the basis of average performance at all locations. Although the results obtained are based on relatively young progeny tests (three years), they can be used for preliminary decisions, such as initial selection of the clonal population. To increase the efficiency of the breeding and testing *Hevea* program at Instituto Agronômico (IAC), a research institute in São Paulo State, Brazil, Gonçalves et al. (2005) analyzed 12 first generation progeny tests to find the optimum time for growth assessment. Under reasonable assumptions for age-age correlation and heritability changes over time, they concluded that the expected genetic gain per year in the breeding program was the greatest for selection between, two and three years. Since gain rates will be heavily influenced by time, early selection for girth and for recombinant development will be advantageous (Namkoong, 1979). However, these results must be interpreted with caution since age-age correlation is not always precisely estimated and the performance of the genotypes at young ages, in most of the cases, is imperfectly related to that at maturity (Olson & Lindgren, 2001). It is of interest to keep in mind that juvenile selection, is a form of indirect selection, the efficiency of which is determined by heritabilities at the juvenile and mature age and the correlation that exists between the characteristics measured at these two ages.

Realized genetic gain

Realized genetic gain was estimated at the age of three years. Data for girth, rubber yield and bark thickness common to three locations was pooled and progeny means were obtained over the three locations.

Table 4 - Estimates of variance components and narrow sense heritability (h^2_i) for girth at ages one, two and three years rubber yield and bark thickness from the combined analyses of variance of three open pollinated experimental plantings where 98 *Hevea* progenies were evaluated in São Paulo State, Brazil.

Characteristics	Variance components[1]			h^2_i
	σ^2_{g2}	σ^2_{gl}	σ^2_w	
Girth year 1	0.1404	0.0601	0.5943	0.7925
Girth year 2	0.4509	0.0558	2.1881	0.8231
Girth year 3	4.5863	0.5225	16.4002	0.8981
Rubber yield 3	0.2614	0.2479	0.1593	0.6812
Bark thickness 3	0.2772	0.0876	0.4694	0.4206

[1] σ^2_g, σ^2_{gl}, σ^2_w are estimates of variance components for progenies, progenies × locations and within plot, respectively. [2]$p < 0.01$.

Table 5 - Realized genetic gain for girth, rubber yield and bark thickness from two stages of selection (mass selection plus progeny testing) at the age of three years (Pindorama, Jaú and Votuporanga tests combined).

Characteristic	Girth	Rubber yield	Bark thickness
Overall mean of all progenies	11.3815 (cm)	0.8432 (g)	3.8021 (mm)
Mean of commercial check (CC)	9.1612	0.5315	2.1213
Realized genetic gain from selection made in clonal population ($\Delta G_1\%$)	14.3626	8.2030	15.1011
Mean of the 80% of the selected progenies (20 % are removed on the basis progeny testing)	11.9010	1.3030	4.2020
Mean of all progenies	11.3815	0.8432	3.8021
Genetic gain from removing 20% of the inferior clones after progeny testing ($\Delta G_2\%$)	10.2016	6.2017	10.1116
Total genetic gain from genetically tested, (discarded) isolated garden ($\Delta G_1 + \Delta G_2$)	24.5642	14.4047	25.2127

The overall progeny mean values were 11.38 cm, 0.84 cm and 3.80 mm for girth, rubber yield and bark thickness, respectively. The mean values for the commercial check (control) were 9.16 cm girth, 0.53 g for rubber yield and 2.12 mm for bark thickness. Therefore the realized gain for the selection made in clone population is estimated to be 14.36% for girth, 8.20% for rubber yield and 15.10% for bark thickness (Table 5).

Economic studies (Bergman, 1968) have shown that 2 to 5% increase in yield alone over commercial planting is enough to justify the cost of a rubber tree improvement program. Therefore the realized gain (10%) for girth, in the present study, resulting from removing makes it clear that rouging is a beneficial part of a tree improvement program and must be practiced if optimal expectations from the first generation clonal population is to be obtained. The total gain from the first generation genetically thinned (roguing) clonal population is summed to 10% for girth, 6% for rubber yield and 10% for bark thickness (Table 5). Since the intensity of the second stage of selection was quite low (80% of the clones were saved and only the rest 20% were removed), higher gains should be expected if this intensity increases. However there is a need to keep broad the genetic base in the rogued clonal population, in order to provide adequate genetic diversity in the improved commercial plantations. This is especially needed in *Hevea*, with very long cycle of yield (over 40 years), that require well adapted trees (clones) with adequate genetic variation, capable to respond successfully to environmental conditions. Reduction of the genetic base of the seed produced can also be a result from differential fertility of the clones and absence of synchronous flowering.

Although the results of the present study are not directly comparable with the available literature because of different species, age of evaluation, characteristics of interest and environmental conditions, some important results found in the literature are discussed here. Estimates of realized genetic gain in rubber tree have been reported in the past by many investigators (Moreti et al., 1994; Boock et al., 1995; Gonçalves et al., 1995, 1996, 1998). Costa et al. (2000b) have reported results from an extensive study including three open pollinated progeny tests of the rubber tree program of the IAC in São Paulo State. At the age of three years, realized genetic gain for rubber yield varied within and among locations in the different selection methods. When the accuracy values associated to genetic gain are greater, the expected progress with selection was also greater, i.e. the greater the precision in selection the greater the gain.

The realized genetic gain in the present study has been estimated from relatively young materials (three years). Since the performance of genotypes at young ages in many cases are imperfectly related to that at maturity, further evaluation will be made as the trees become older.

ACKNOWLEDGEMENTS

To Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Tecnológico (CNPq) for financial support.

REFERENCES

BECKER, W. **Manual of quantitative genetics**. 4 ed. Washington, D.C.: Pullman, 1984. 190p.

BERGMAN, A. **Variation in flowering and its effect on seed cost study of seed orchards of loblolly pine**. Raleigh: North Carolina State University, 1968. 55p. (Technical, Report, 38).

BOOCK, M.V.; GONÇALVES, P.S.; BORTOLETTO, N.; MARTINS, A.L.M. Herdabilidade, variabilidade genética e ganhos genéticos para produção e caracteres morfológicos em progênies jovens de seringueiras. **Pesquisa Agropecuária Brasileira**, v.30, p.673-681, 1995.

COCHRAN, W.G.; COX, G.M. **Experimental designs**. New York: John Wiley, 1957. 611p.

COSTA, R.B.; RESENDE, M.D.V.; ARAÚJO, A.J., GONÇALVES, P.S. HIGA, A.R. Selection and genetic gain in rubber (*Hevea*) populations using a mixed mating system. **Genetics and Molecular Biology**, v.23, p.671-679, 2000a.

COSTA, R.B.; RESENDE, M.D.V.; ARAÚJO, A.S.; GONÇALVES, P.S.; MARTINS, A.L.M. Genotype-environment interaction and the number of test sites for the genetic improvement of rubber trees (*Hevea*) in São Paulo State, Brazil. **Genetics and Molecular Biology**, v.23, p.179-187, 2000b.

GONÇALVES, P.S.; BORTOLETTO, N.; FONSECA, F.S; BATAGLIA, O.C.; ORTOLANI, A.A. Early selection for growth vigor in rubber tree genotypes in northwestern São Paulo State (Brazil). **Genetics and Molecular Biology,** v.21, p.515-521, 1998.

GONÇALVES, P.S.; MARTINS, A.L.M.; BORTOLETTO, N.; CARVALHO, A.Z. Broard sense heritability values and possible genetic gains in clonal selections of *Hevea*. **Brazilian Journal of Genetics,** v.18, p.605-609, 1995.

GONÇALVES, P.S.; MARTINS, A.L.M.; BORTOLETTO, N.; TANZINI, M.R. Estimates of genetics parameters and correlations of juvenille characters based on open pollinated progênies of *Hevea*. **Brazilian Journal of Genetics,** v.19, p.105-111, 1996.

GONÇALVES, P.S.; MORAES, M.L.T.; BORTOLETTO, N.; COSTA, R.B.; GONÇALVES, E.C.P. Genetic variation in growth traits and yield of rubber trees (*Hevea brasiliensis)* growing in Brazilian State of São Paulo. **Genetics and Molecular Biology,** v.28, p.765-772, 2005.

GONÇALVES, P.S.; SILVA, M.A.; GOUVÊA, L.R.L.; SCALOPPI JÚNIOR, E.J. Genetic variability for girth growth and rubber yield in *Hevea brasiliensis*. **Scientia Agricola**., v.63, p.246-254, 2006.

HODGE, O.R.; WHITE, T.L. Genetic parameter estimates for growth traits and different ages slash pine and some implications for breeding. **Silvae Genetic**, v.41, p.252-262, 1992.

MOOIBROEK, H.; CORNISH, K. Alternative sources of natural rubber. **Applied Microbioly and Biotechnology,** v.53, p.355-365, 2000.

MORETI, D.; GONÇALVES, P.S.; GORGULHO, E.P.; MARTINS, A.L.M.; BORTOLETTO, N. Estimativas de parâmetros genéticos e ganhos esperados com a seleção de caracteres juvenis em progênies de seringueira. **Pesquisa Agropecuária Brasileira**, v.29, p.1099-1109, 1994.

NAMKOONG, G. **Introduction of quantitative genetics in forestry**, Washignton, D.C.: USDA-Foresty Service, 1979. 342p. (Technical Bulletin, 1588)

OLSON, T.D.; LINDGREN B.L.I. Balancing genetic gain and relatedness in seed orchards. **Silvae Genetic,** v.50, p.222-227, 2001.

PRIYADARSHAN, P.M.; CLÉMENT-DEMANGE, A. Breeding *Hevea* rubber: formal and molecular genetics. **Advances in Genetics**, v.52, p.115, 2004.

PUSHPARAJAH, E. Natural rubber. In: LAST, F.T. (Ed.) **Tree crop ecosystems**. Amsterdam: Elsevier Science, 2001. v.19, p.379-409.

SIERRA-LUCERO, V.; McKEAND, S.; HUBER, D.; ROCKWOOD, D.; WHITE, T. Performance differences and genetic parameters for four Coastal Provenances of loblolly pine in southeastern United States. **Forest Science**, v.48, p.732-742, 2002.

SIMMONDS, N.W. Rubber breeding. In: WEBSTER C.C.; BAULKWILL, W.J. (Ed) **Rubber**. Harlow: Longman Scientific & Technical, 1989. p.85-124.

STRAHLER, A.N. **Physical geography**. 3ed. New York: John Wiles, 1969. 733p.

TAN, H. Strategies in rubber tree breeding. In: ABBOT, A.J.; ATKIN, R.K. (Ed) **Improving vegetative propagated crops**. London: Academic Press, 1987. p.28-54.

TAN H.; SUBRAMANIAN, S. A five parent diallel cross analysis for certain characters of young *Hevea* seedlings. In: INTERNATIONAL RUBBER CONFERENCE, 1., Kuala Lumpur, 1975. **Proceedings.** Kuala Lumpur: Research Institute of Malaysia, 1976. p.13-26.

Received June 25, 2007
Accepted May 05, 2008