ABSTRACT

Besides rubber production, one of the main goals of the genetic improvement of rubber tree *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg. is to develop vigorous clones. The objective of the present study was to evaluate the vigor of 34 elite juvenile rubber clones. To this end, three experiments were conducted in the municipality of Pontes Gestal, in the northwest region of the São Paulo State. Each experiment consisted of 10 treatments, and 2 controls in common to the 3 experiments. The experiments were arranged in the randomized block design, with three replications and ten plants per plot, in the 8 m x 2.5 m spacing. Individual and joint analyses of variance were performed. The means were compared using the Dunnett test at 5%. Significant effect of treatments was found in the three experiments and in the joint analysis. The most vigorous clones were not different from the controls in the comparison of means by the individual and joint analyses. The less vigorous clones were statistically different from the others and from the controls, reflecting this difference in the genetic variability observed. The breeding program must consider the lack of difference between the most vigorous clones and the controls when recombining superior clones, since genetic gain depends on variability.

Keywords: joint analysis; Dunnet test; rubber tree girth; genetic variability.

INTRODUCTION

One of the objectives of the genetic improvement program of rubber tree *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg. is to seek vigorous clones. The girth is considered a measure of vigor, which determines the age at which a rubber clone can be economically grown and defines the unproductive period of the rubber tree plantation (Gonçalves *et al*., 1999). Gonçalves & Marques (2014) point out that early tapping and good rubber production are possible only in clones that grow vigorously in the juvenile phase. Vigorous plants have a larger tapping area which is reflected in the production (Obouayeba *et al*., 2002). In addition, more vigorous clones are more resistant to wind damage (Gonçalves *et al*., 2006). Another beneficial aspect of vigor is the alternative use as wood when latex production is no longer advantageous (Kronka, 2014).

The importance of assessing the vigor of rubber tree clones has been highlighted in several studies (Gonçalves *et al*., 2011; Gouvêa *et al*., 2012; Silva *et al*., 2014; Alem, *et al*., 2015). The genetic improvement program of the Agronomic Institute of Campinas (IAC) has evaluated elite clones of different clone series in distinct regions of São Paulo State. The IAC 500 series was evaluated in the Northwest region of the state of São Paulo (Gonçalves *et al*., 2011), the IAC 400 series in the Midwest region (Gonçalves *et al*., 2007), and the IAC 300 series in the Center-North (Gonçalves *et al*., 2002) and Northwest (Gonçalves *et al*., 2001a) regions. Thus, the objective of the present study was to evaluate the vigor of 34 elite juvenile rubber clones.
MATERIAL AND METHODS

The experimental evaluation was conducted at the Córrego do Ouro farm, municipality of Pontes Gestal, in the Northwest region of the State of São Paulo, on the geographic coordinates 20° 12' 03'' S; 49° 39' 03'' W. The soil of the area is classified as Red-Yellow Argisol. The clones evaluated belong the collection of the Genetic Improvement Program of the Agronomic Institute of Campinas (IAC) (Table 1). Three experiments were arranged in a randomized block design, with three replications and ten plants per plot spaced 8.0 m between rows and 2.5 m between trees. Each experiment consisted of 10 treatments, using 2 controls (the Malaysian clone RRIM 600 and the Indonesian clone GT1) in common to the 3 experiments. Vigor was assessed by the girth measured at 1.30 m above ground, in three year-old trees.

The individual variances analyses were performed in the design with additional control blocks, joint analysis of variance, and the Dunnett Test at 5%, using the Genes Program (Cruz, 2013). The joint analysis of variance followed the mathematical model Cruz (2006):

\[ Z_{ijk} = \mu + T_{ei} + B_{j(k)} + E_k + T_{e}E_{ik} + \varepsilon_{ijk} \]

where:

- \( Z_{ijk} \): observation of the \( i \)th treatment in common, in the \( j \)th repetition of experiment \( k \);
- \( \mu \): overall mean;
- \( T_{ei} \): effect of the \( i \)th treatment;
- \( B_{j(k)} \): effect of the \( j \)th repetition of experiment \( k \);
- \( E_k \): effect of the \( k \)th experiment;
- \( T_{e}E_{ik} \): interaction effect between the \( i \)th treatment and the \( k \)th experiment;
- \( \varepsilon_{ijk} \): residual error.

Table 1: Rubber tree clones used in experiments in the municipality of Pontes Gestal, São Paulo State, with their respective genealogies

| Clone | Genealogy |
|-------|-----------|
| **Experiment 1** | |
| PB 312 | RRIM 600 (Tjir 1 x PB 86) x PB 235 [PB 5/51 (PB 56 x PB24) x PB S/78 (PB 49 x PB 25)] |
| IRCA 111 | PB 5/51 (PB 86 x PB 5/78) x RRIM 600 ((Tjir 1 x PB 86) |
| PB 314 | RRIM 600 (Tjir 1 x PB 86) x PB 235 [PB 5/51 (PB 56 x PB24) x PB S/78 (PB 49 x PB 25)] |
| RRIM 710 | RRIM 605 (Tjir 1 x PB 49) x RRIM 71 |
| RRIM 938 | RRIM 605 (PB 56 x PB24) x RRIM 703 [RRIM 600 (Tjir 1 x PB 49) x RRIM 500 (Pil B84 x PilA 44)] |
| RRIM 711 | RRIM 605 (Tjir 1 x PB 49) x RRIM 71 |
| RRIM 937 | RRIM 605 (PB 56 x PB24) x RRIM 703 [RRIM 600(Tjir 1 x PB 86) x RRIM 500 (Pil B84 x PilA 44)] |
| PB 350 | RRIM 600 (Tjir 1 x PB 86) x PB 235[PB 5/51 (PB 56 x PB24) x PB S/78 (PB 49 x PB 25)] |
| RRIM 600 | Tjir 1 x PB 69 |
| GT 1 | Primary clone |

| **Experiment 2** | |
| RRIM 713 | RRIM 605 (Tjir 1 x PB 49) x RRIM 71 |
| RRIM 714 | RRIM 605 (Tjir 1 x PB 49) x PB 49 |
| IAC 35 | Fx 25 ([F35L x AVROS 49) x RRIM 600 (Tjir 1 x PB 86] x RRIM 600 (Tjir 1 x PB 86) |
| IAC 40 | RRIM 608 ( Tjir 33 x Tjir 1) x AVROS 1279 (AVROS 256 x AVROS 374) |
| IAC 300 | RRIM 605 (Tjir 1 x PB 49) x AVROS 353(AVROS 164 x AVROS 160) |
| IAC 301 | RRIM 501 (Pil A44 x Lun N) x AVROS 1518 (AVROS 214 x AVROS 317) |
| PC 96 | PB 5/51(PB 56 x PB24) x RRIM 600 (Tjir 1 x PB 86) |
| PC 140 | PB 5/51(PB 56 x PB24) x RRIM 703 (RRIM 600(Tjir 1 x PB 86) x RRIM 500 (Pil B84 x PilA 44)] |
| RRIM 600 | Tjir 1 x PB 69 |
| GT 1 | Primary clone |

| **Experiment 3** | |
| PM 10 | - |
| PR 255 | Tjir 1 x PR 107 |
| PB 291 | - |
| IAC 400 | GT 711 x RRIM 600 (Tjir 1 x PB 86). |
| IAC 402 | GT 711 ill. |
| IAC 403 | GT 711 ill. |
| IAC 404 | PB 5/63 (PB 56 x PB 24) x AVROS 363 |
| IAC 405 | Tjir 1 x RRIM 623 (PB 49 x Pil B 84). |
| RRIM 600 | Tjir 1 x PB 69 |
| GT 1 | Primary clone |

ill. = illegitimate (clone obtained from an open pollination donor plant)
\( \mu \): experiment overall mean;  
\( \text{Te} \): effect of the \( i \)th control (treatment in common);  
\( B_{jk} \): effect of the \( j \)th block within the \( k \)th experiment;  
\( E_k \): effect of the \( k \)th experiment;  
\( \text{TeE}_{ik} \): effect of the interaction between the treatment in common and the experiment (environment);  
\( \epsilon_{ijk} \): random error

The genetic parameters estimated by this model were Coefficient of Variation (CV\%); Genotypic variability (\( \hat{V}_g \)); Coefficient of genotypic determination (\( \hat{H}_g^2 \)); Coefficient of genetic variation (CV\(_g\)\%).

**RESULTS AND DISCUSSION**

The treatment effect was significant for girth in the individual analyses of variances of the three experiments (Table 2). This significance indicates presence of genetic variability for vigor among these clones. In these experiments, in the unfolding of the treatments (clones) in genotypes and controls, it was observed that this variability is among genotypes, the two controls were not significantly different in any of the experiments. The control means were higher than the genotype means. However, the significant effect observed between genotypes and control indicates that the group of genotypes differed significantly from the group of controls only in experiments 2 and 3. The coefficients of variation (CV\%) varied from 7.06 to 10.81%. These values were low in experiments 2 and 3 and intermediate in experiment 1, according to Pimentel-Gomes (2000), who considers coefficients of variation below 10% as low and between 10 and 20% as intermediate. Therefore, the observed values indicate good experimental precision. The CV\% values in the three experiments were similar to those observed for clones (Alem et al., 2015) and progenies (Verardi et al., 2012) of rubber trees of the same age.

No significant effect of experiment was found in the joint analysis (Table 3), indicating no significant difference between experiments. The significance of the adjusted treatment, on the other hand, indicates genetic variability among the 26 clones evaluated. Regarding the estimation of parameters, in this analysis the coefficient of experimental variation \( 1\text{ty} \) is of genetic nature. The coefficient of variation (CV\(_g\) = 11.13\%) was higher than that estimated by Verardi et al., (2012) for progenies with the same age (CV\(_g\) = 5.81\%) and is in agreement with Gouvea et al. (2010), who evaluated the vigor of 23 rubber clones at the pre-tapping stage (CV\(_g\) = 10.41\%). This parameter expres-

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**Table 2:** Analysis of individual variances, coefficients of variation, and mean girth (cm) of three-year-old rubber clones of three experiments conducted in the municipality of Pontes Gestal, São Paulo State

| Source of Variation | D.F. | Mean Squares |
|---------------------|------|-------------|
|                     |      | Experiment 1 | Experiment 2 | Experiment 3 |
| Blocks              | 2    | 8.94        | 0.30         | 0.79         |
| Treatments          | 9    | 14.66**     | 11.86**      | 17.20**      |
| Genotypes (G)       | 7    | 17.50**     | 7.95**       | 17.02**      |
| Control (T)         | 1    | 0.28        | 0.54         | 8.40         |
| G vs T              | 1    | 9.19        | 50.57**      | 27.26*       |
| Residue             | 18   | 3.84        | 1.83         | 3.38         |
| C.V.(%)             |      | 10.80       | 7.06         | 9.70         |
| Overall Mean        |      | 18.14       | 19.19        | 18.94        |

*, ** significant at 1 and 5% by the F test, respectively.

**Table 3:** Analysis of joint variance and genetic parameters of the girth (cm) of three-year-old rubber tree clones of three experiments conducted in the municipality of Pontes Gestal, São Paulo State

| Source of Variation | D.F. | M.S. | F   |
|---------------------|------|------|-----|
| Blocks              | 6    | 3.25 | 2.96|
| Experiment          | 2    | 8.98 ns | 5.10|
| Adjusted treatment  | 25   | 15.47** | 6.23|
| Residue             | 56   | 3.03 |     |
| Overall Mean        |      | 18.76 |     |
| Coefficient of Variation (CV %) | 9.28 | | |
| Genotipic variability (\( \hat{V}_g \)) | 4.15 | | |
| Coefficient of genotypic determination (\( \hat{H}_g^2 \)) | 80.39 | | |
| Coefficient of genetic variation (CV\(_g\) %) | 11.13 | | |

*, ** significant at 1 and 5% by the F Test, respectively.
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Table 3: Analysis of joint variance and genetic parameters of the girth (cm) of three-year-old rubber tree clones of three experiments conducted in the municipality of Pontes Gestal, São Paulo State

The mean comparisons by the Dunnett’s test, at 5% probability, in the individual analyses are presented in Table 4. The means not accompanied by letters correspond to the clones that differed significantly from both controls.

In experiment 1, the controls were not significantly different from the 7 best clones. The only significant difference was found for clone RRIM 710, which had with lower performance than the two controls. In experiment 2, the clones RRIM 713, IAC 40, and IAC 300 differed from the two controls, with lower performance. In experiment 3, the clone PM 10 was significantly different from the two controls, with lower performance, whereas the other clones did not differ from the controls.

Table 4: Girth means (cm) in three-year-old rubber tree clones of experiment evaluated in Pontes Gestal, São Paulo State

The Dunnet test at 5% in the joint analysis is shown in Table 5. Of the 24 clones in the mean comparisons, only three were significantly different from the 2 controls, regarding to girth means, but with lower performance. The clones RRIM 710, IAC 300, and PM 10, one from each experiment were statistically different. All other clones performed as same as the controls. Alem et al. (2015) observed similar results in the vigor assessment of 14 rubber clones at the pre-tapping stage and found that no clone was statistically superior to the control. The similar performance of clones and the controls may be due to the fact that the clones are the result of crossings between previously selected materials (Table 1), with many of them being tertiary clones. According to Gonçalves et al. (2001b), primary clones derive from unknown parents obtained from the vegetative multiplication of donor trees with desirable characters. Secondary clones derive from donor trees obtained through controlled crosses between two primary clones, while tertiary clones derive from crosses in which at least one parent is secondary and so on. Thus, it is found that after consecutive selection

Table 5: Girth means (cm) of three-year-old rubber tree clones of joint analysis of three experiments evaluated in the municipality of Pontes Gestal, São Paulo State

Table 4: Girth means (cm) in three-year-old rubber tree clones of experiments evaluated in Pontes Gestal, São Paulo State

| Experiments | Clone  | Mean    |
|-------------|--------|---------|
| 1 RRIM 937  | 22.30 ab|
| 1 IRCA 111  | 22.08 ab|
| 3 IAC 404   | 21.24 ab|
| 1 RRIM 938  | 20.71 ab|
| 3 IAC 405   | 20.08 ab|
| 2 IAC 35    | 19.69 ab|
| 1 RRIM 711  | 19.45 ab|
| 3 IAC 400   | 19.15 ab|
| 3 IAC 403   | 19.11 ab|
| 2 IAC 301   | 19.06 ab|
| 1 PB 312    | 18.56 ab|
| 2 PC 40     | 18.48 ab|
| 1 PB 314    | 18.20 ab|
| 3 PR 255    | 17.89 ab|
| 3 PB 291    | 17.76 ab|
| 1 PB 350    | 17.50 ab|
| 3 IAC 402   | 17.45 ab|
| 2 RRIM 714  | 17.16 ab|
| 2 PC 96     | 17.14 ab|
| 2 RRIM 713  | 16.41 ab|
| 2 IAC 40    | 16.39 ab|
| 1 RRIM 710  | 15.16 ab|
| 2 IAC 300   | 14.71 ab|
| 3 PM 10     | 13.26 ab|
| 3 RRIM 600* | 20.99 a |
| GT 1*       | 20.26 b |

* Controls common to the three experiments
Means followed by the same letter are not significant different from the control by the Dunnet Test at 5%

Means followed by the same letter for each experiment are not significant different from the control by the Dunnet Test at 5%

*Controls.
cycles, the clones evaluated in the present study no longer surpass the controls with respect to vigor.

(Table 5. Girth means (cm) of three-year-old rubber tree clones of joint analysis of three experiments evaluated in the municipality of Pontes Gestal, São Paulo State) Overall, all results must be evaluated because there is evidence of genetic variability, but no significant difference was found between superior genotypes and controls. The observed genetic variability occurred because some clones were less vigorous. The individual and joint analyses showed no statistical difference between the clones with the best performance in vigor and the controls. This points to the need to be aware of the genetic variability regarding vigor in rubber tree breeding program and in germplasm bank. The success of the breeding program is highly dependent on the magnitude of the genetic base available in the germplasm banks for cultivar development (Queiroz & Lopes, 2007).

CONCLUSIONS
The genetic variability observed in the study is due to few clones having inferior performance.

The breeding program must consider the lack of difference between the most vigorous clones and the controls when recombining superior clones, since genetic gain depends on variability.

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