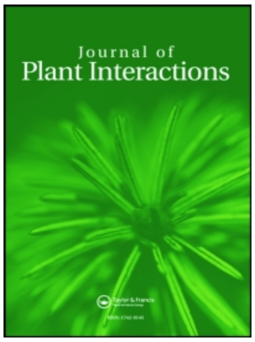

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RESEARCH ARTICLE

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Genotype × environment interaction of *Hevea* clones in traditional and non-traditional rubber growing regions of Vietnam

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ABSTRACT

The main objective of this research was to assess genotype × environment interactions and the stability status of 24 *Hevea* clones along with 2 checks in terms of latex yield and girth growth under two different environmental conditions representing for traditional and non-traditional rubber growing regions of Vietnam. Genotype × environment interactions were found to be highly significant for both latex yield and girth at opening, indicating that the latex yield and girth growth of the studied rubber clones were significantly affected by the environmental conditions of the location. Stability analyses indicated that LH 94/359, LH 91/579 and LH 94/481 were the best clones for highest latex yield and adaptability to traditional, non-traditional and both rubber growing regions of Vietnam, respectively. In terms of girth at opening, the stability analyses revealed that these clones were also accepted as the average girth growth and adaptability to both rubber growing regions of Vietnam.

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Genotype × environment interaction; girth growth; *Hevea brasiliensis;* latex yield; RRIV's clones; stability analysis

Introduction

Information about phenotypic stability and adaptability is definitely useful for the selection of crop varieties as well as for breeding programs. The phenotypic performance of a genotype is not necessarily the same under diverse agro-ecological conditions (Ali et al. 2003; Correa et al. 2003; Akçura et al. 2005; Gurmu et al. 2009; Farshadfar et al. 2012; Sayar et al. 2013). Some genotypes may perform well in certain environments, but fail in several others. Genotype × environment (G × E) interactions are extremely important in the development and evaluation of plant varieties because they reduce the genotypic-stability values under diverse environments (Hebert et al. 1995; Akçura et al. 2005). The concept of stability has been defined in several ways and several biometrical methods including univariate and multivariate ones have been developed to assess stability (Lin et al. 1986; Becker & Leon 1988; Crossa 1990). The most widely used one is the regression method, based on regressing the mean value of each genotype on the environmental index or marginal means of environments (Romagosa & Fox 1993; Tesemma et al. 1998). A good method to measure stability was previously proposed by Finlay and Wilkinson (1963) and was later improved by Eberhart and Russell (1966).

Rubber tree (*Hevea brasiliensis* Willd. ex A. de Juss. Müell. Arg.) which produces natural rubber was introduced into Vietnam in 1897 from Bogor (Indonesia) by Alexandre Yersin (Lam et al. 2012). Since then it has been considered as one of the most important crops and widely cultivated in Vietnam. The main objectives of *Hevea* breeding are to increase yield and vigor through methods that can shorten the breeding cycle of the crop, estimate the genetic parameters and correlates of these characteristics. The first rubber selecting and *Hevea* breeding activities in Vietnam were started by a French rubber company, Société des plantations des Terres Rouges (STPR) in 1932. Subsequently, the breeding program had been proceeded continuously by the governmental organization, L'Institut des Recherchers sur le Caoutchouc en Indochine (IRCI) until 1955. Due to the interruption caused by the war, the breeding program was resumed in 1980 by the Rubber Research Institute of Vietnam (RRIV). *Hevea* breeding in Vietnam has resulted in great genetic progress with the mean latex yield gradually increasing from about 703 kg/ha/year in 1980s to 1222 kg/ha/year in 2000 and up to 1740 kg/ha/year in 2013. With the total area under rubber trees of 920,500 ha in 2013, Vietnam is the third natural rubber producer in the world, producing 949,100 tonnes that shared about 7.9% of the world's natural rubber production. Areas under rubber trees are mainly in the Southeast region, followed by the Highlands, Central Coastal regions and the new areas developed in the Northern part of Vietnam. It is known that the traditional rubber growing tract offers ideal environmental conditions with a mean annual temperature of 28 ± 2°C, and a well spread rainfall of 2000–4000 mm extending from 100–150 days per year (Pushparajah 1983). Regarding these criteria, the Southeast region of Vietnam has offered the good environmental conditions for cultivation of rubber trees, and Binh Duong province has been considered as the traditional rubber growing region of the country. However, the shortage of available land ensuing from competition with other crops led rubber plantation to be extended to many non-traditional regions including the North Central Coast region of Vietnam. As a non-traditional rubber growing region, Nghe An province presents various stress factors, particularly climate features such as prolonged low temperature and low solar radiation in the winter, very high air temperature in the summer and strong wind. Among those stress factors, low temperature is the major factor limiting the development and production of the rubber tree. In addition to damage and

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retarded growth or even sudden death, the low temperature is responsible for the stopping of latex production for 1–3 months per year (Rao et al. 1998; Jacob et al. 1999; Tuy et al. 2012).

Currently, a large number of stability studies have been carried out on different crop plants as well as on rubber tree. It is known that the productivity performance of *Hevea brasiliensis* is represented mainly by the yield stability. Thus, breeders search for genotypes that show stability for high yield over the years and locations. A genotype is considered stable when its performance across environments does not deviate from the average performance of a group of standard genotypes (Gonçalves et al. 2003). Several methods have been proposed to analyze genotype × environment interactions through phenotypic stability (Lin et al. 1986; Becker & Leon 1988; Piepho 1998; Truberg & Huhn 2000). Among these, joint regression is the most popular method to provide a conceptual model for phenotypic stability (Becker & Leon 1988; Romagosa & Fox 1993; Gonçalves et al. 2003). In addition, joint regression is a simple method of calculation and application (Becker & Leon 1988; Gonçalves et al. 2003). The regression of the yield of an individual genotype on environment mean yields is determined. The genotype × environment interaction from analysis of variance is portioned into heterogeneity of regression coefficients (bi) and mean square deviations from regressions (S^2di). These parameters have then been widely used in analysis of the stability and adaptability of genotypes tested in different environmental conditions. A genotype with regression coefficient equal to unity ($bi = 1$) and deviation from regression as small as possible are considered ($S^2di = 0$) as stable (Eberhart & Russell 1966). According to the joint regression model, a stable genotype is the one with a high mean yield, $bi = 1$ and $S^2di = 0$ (Eberhart & Russell 1966).

On rubber tree, a large number of studies on genotype-environment interactions were conducted in Sri Lanka (Jayasekera 1983; Jayasekera et al. 1994; Withanage et al. 2005), Indonesia (Daslin et al. 1986), Nigeria (Onokpise et al. 1986; Omokhafe & Alika 2003; Omokhafe et al. 2004a, b), Malaysia (Tan 1995), India (Menattoor et al. 1991) and Brazil (Gonçalves et al. 1992, 1998, 1999, 2003, 2008, 2009; Costa et al. 2000; Gouvêa et al. 2012; Silva et al. 2013, 2014). Several of these studies used the method developed by Eberhart and Russell (1966) to determine the genotype × environment interaction on growth and/or latex yield of *Hevea* clones (Gonçalves et al. 1992, 2003, 2008, 2009; Omokhafe & Alika 2003; Omokhafe et al. 2004a, b; Gouvêa et al. 2012; Silva et al. 2013, 2014). It was reported that adaptability and stability analyses involving statistical procedures allow the identification of *Hevea* clones of which the performance is more stable and responses to the environmental variations are predictable (Silva et al. 2014).

Recently, a large number of promising *Hevea* clones derived from hand-pollination programs (RRIV's clones) have been included in several experimental clonal trials established in traditional regions and non-traditional regions throughout the country. However, information on the adaptation of those clones to the environmental conditions as well as stability across sites over environments is very limited. This report was aimed to address the understanding on the stability as well as the adaptation of 24 RRIV's *Hevea* clones in two different environmental conditions representing traditional (Southeast) and non-traditional (North Central Coast) rubber growing regions of Vietnam.

Materials and methods

Plant materials and experimental locations

A total of 24 RRIV's genotypes (clones) of *H. brasiliensis* along with 2 checks, of which the names and code numbers were given in Table 1, were brought into the study. These new clones have been considered as the promising clones, several of which have currently been recommended as planting materials for on-farm trials in all of rubber growing regions in Vietnam. Small Scale Clonal Trials (SSCT) of these clones were laid out in randomized completed block design with three replications in Binh Duong (traditional rubber growing region) and Nghe An (non-traditional rubber growing region) provinces of Vietnam (Figure 1, Table 2).

Measurements

Girth at opening and latex yield of each tree in the trials were measured. During the mature period or tapping phase, the trunk girth (in centimeter) was taken once a year in March or April at the height of 1 m above the ground level using a graded tape measure. Girth at opening was defined as the trunk girth measured before the tree was opened for tapping.

Normally after 6–8 years of planting, a genotype were opened for tapping when 50% of its trees reached a girth of 50.0 cm or more, the rest with girth of 42 cm or more were also opened for tapping. The rubber trees were opened for tapping at a height of 1.3 m above ground level for latex production. The widely standardized tapping system used to harvest the annual latex yield was S/2 d3 6d/7 10 m/y, that is, tapping in a half spiral (S/2) at three-day intervals (d3) for

Table 1. Origins and genealogies of *Hevea* clones tested at traditional and non-traditional rubber growing regions of Vietnam.

Code	Clones	Parentage (mother × father)	Origin
1	LH 82/182	RRIC 100 × PB 235	Vietnam
2	LH 91/579	RRIC 121 × GU 176	Vietnam
3	LH 94/105	PB 255 × LH 82/90	Vietnam
4	LH 94/359	RRIM 725 × RRIC 121	Vietnam
5	LH 94/374	LH 82/75 × RRIC 121	Vietnam
6	LH 94/475	IAN 710 × LH 82/198	Vietnam
7	LH 94/481	LH 82/173 × RRIC 121	Vietnam
8	LH 94/501	VQ 79 × LH 82/198	Vietnam
9	LH 94/612	Haiken 1 × LH 82/198	Vietnam
10	LH 94/62	PB 255 × LH 82/90	Vietnam
11	LH 95/208	RRIC 121 × FX 4425	Vietnam
12	LH 95/345	TU 45/525 × IAN 2978	Vietnam
13	LH 95/395	IRCA 117 × LH 82/173	Vietnam
14	LH 96/115	RRIC 102 × RRIC 132	Vietnam
15	LH 96/133	RRIC 102 × RRIC 132	Vietnam
16	LH 96/305	RRIC 102 × RRIC 132	Vietnam
17	LH 96/308	RRIC 102 × RRIC 132	Vietnam
18	LH 96/345	RRIC 102 × RRIC 132	Vietnam
19	LH 97/165	PB 260 × FX 3925	Vietnam
20	LH 97/646	PB 260 × RO 22/112	Vietnam
21	LH 97/647	PB 260 × FX 3925	Vietnam
22	LH 97/657	PB 260 × IAN 2903	Vietnam
23	LH 97/697	PB 255 × FX 2829	Vietnam
24	LH 98/444	RRIC 110 × AC 43/19	Vietnam
25	GT 1	Primary	Indonesia
26	PB 235	PB 5/51 × PB S/78	Malaysia

Note: AC – Acre (Brasil); FX – Ford Company; GT – Godang Tapen (Indonesia); GU – Guatemala; Haiken – South China Academy of Tropical Crops (China); IAN – Instituto Agronômico do Norte (Brasil); IRCA – Institut des Recherches sur le Couchouc (Côte d'Ivoire); LH – Lai Hoa (Rubber Research Institute of Vietnam); PB – Prang Besar (Malaysia); RO – Rondonia (Brasil); RRIC – Rubber Research Institute of Ceylon (Sri Lanka); RRIM – Rubber Research Institute of Malaysia; TU – Turrialba (Costa Rica); VQ – Van Hien Quan Loi (Vietnam).

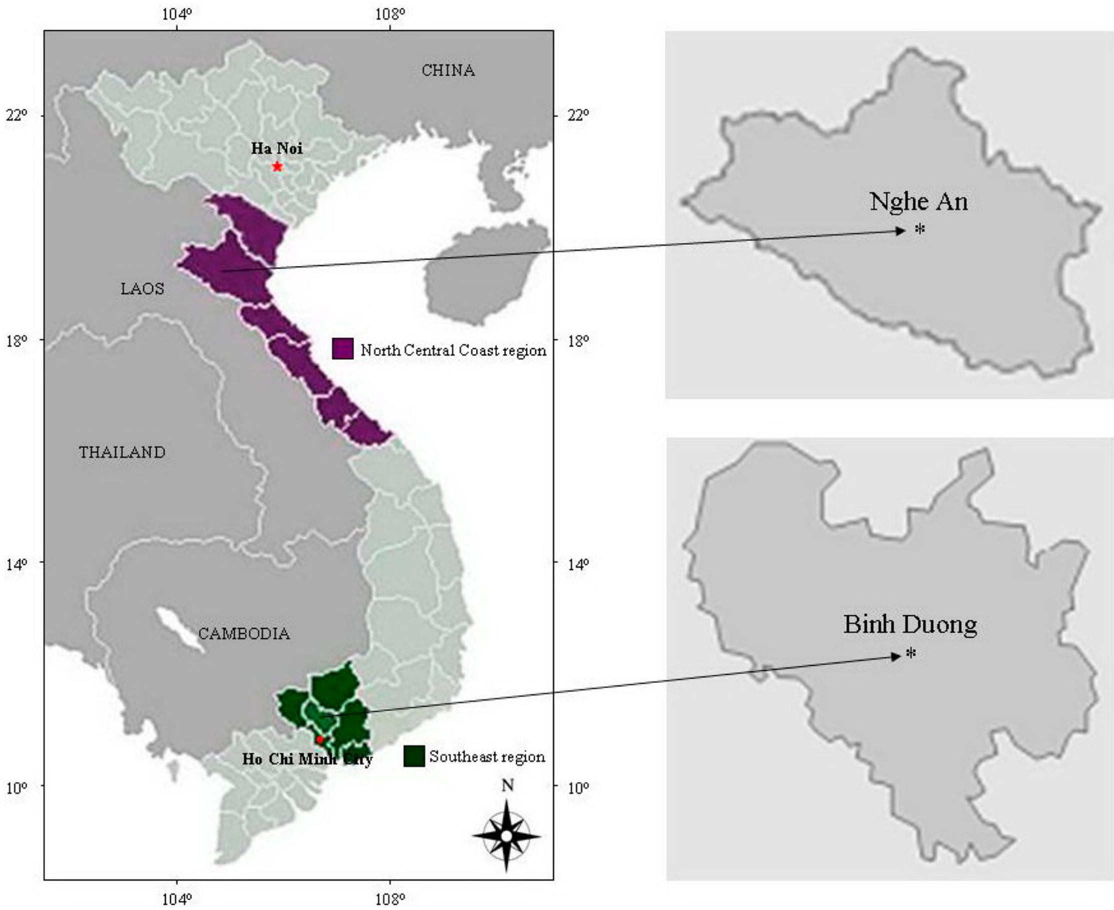

Figure 1. Location of the study sites.

10 months of the year (10 m/y). Latex yield was recorded by cup-coagulation method on normal tapping days. After tapping, latex was collected in plastic or ceramic cups provided for each tapping tree. Once the latex flow was stopped, rubber was coagulated in the cup itself by adding 2–3% acetic acid solution and stirring well. The coagulated rubber of each cup was then labeled, collected, air-dried for at least one month and the dry rubber content of each tree was then weighed and recorded as gram per tree per tapping (g/t/t).

Table 2. Details of the experimental trials and climate features of the study sites.

Remarks	Locations: Binh Duong	Nghe An
Year of planting	2003	2004
Year of opening	2010	2011
Spacing (m)	7.0 × 2.5	7.0 × 2.5
Planting density (trees/ha)	571	571
Numbers of trees × replications	8 × 3	8 × 3
Latitude (N)	11°12′	19°24′
Longitude (E)	106°36′	105°25′
Altitude (a.s.l.)	42	96
Soil type	Grey soil (Acrisols)	Red basaltic soil (Ferralsols)
Air temperature (°C)		
Annual mean	26.7	23.0
Highest month mean	33.0	34.1
Coldest month mean	23.0	13.3
Extreme maximum	39.3	41.6
Extreme minimum	18.0	−0.2
Annual precipitation (mm)	1900	1579
Annual evaporation (mm)	1200	835
Number of days with rain	159	137
Sunshine (h/year)	2508	1580

Statistical analysis

All statistical analyses were performed using SAS program (SAS Institute Inc 1999). The method described by Eberhart and Russell (1966) was used to characterize genotypic stability and adaptation. The following linear regression model was used:

$$Y_{ij} = m_i + b_i I_j + \delta_{ij}$$

where Y_{ij} is the mean of the clone ith at the location j, μ_i is the general mean of clone i, b_i is the regression coefficient (stability parameter) of the ith clone at the location index which measures the response of this clone to varying location, I_j is the environmental index which is defined as the mean deviation of all clones at a given location from the overall mean, δ_{ij} is the deviation from regression of the ith clone in the jth location.

Two stability parameters were calculated:

(a) The linear regression coefficient, which is the regression of the performance of each clone under different locations on the environment, means over all the genotypes. This is estimated according to Singh and Chaudhary (1979) as follows:

$$bi = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2},$$

where $\sum_{j\ ij} I_j$ is the sum of products and $\sum_j I_j^2$ is the sum of squares

(b) Mean square deviations from linear regression estimated according to Eberhart and Russell (1966) is as follows:

$$S^2\text{di} = \frac{\sum_j \delta_{ij}^2}{(E-2)} - \frac{S_e^2}{r},$$

where

$\sum_j \delta_{ij}^2 = \sum_j Y_{ij}^2 - \frac{\left(\sum_j Y_{ij}\right)^2}{E}$, S_e^2 is the estimate of pooled error and

$$S_e^2 = \frac{\sum_j \left(\text{d}f_E \times \text{MSe}_E\right)}{\sum_j \text{d}f_E},$$

and E is the number of environments. The coefficient of determination (R_i^2) was computed from individual linear regression analyses. The significance of the linear regression coefficient (i.e. bi $\neq 1$) and the grand means of latex yield were tested by employing the *t*-test. The significance of the mean square deviations from regression (i.e. $S^2\text{di} \neq 0$) were tested by employing the *F*-test.

The grand mean and regression coefficient were taken into account when the stability status of the genotypes was evaluated over nine different environments (Figure 2).

Results and discussion

Growth performance

The variation between environments in girth at opening of the RRIV's clones was significantly different ($p < .01$) (Table 3). In traditional environment (Binh Duong province), girth at opening varied from 47.38 cm (GT 1) to 55.61 cm (LH 94/501). Meanwhile, in non-traditional environment (Nghe An province), girth at opening ranged from 37.13 cm (LH 98/444) to 55.08 cm (LH 94/62). Several clones showed very good growth performance in both environmental conditions such as LH 94/501, LH 94/62, LH 97/697, LH 97/657, LH 97/647, LH 94/481, LH 96/345, LH 96/305 and LH 91/579. Indeed, the girth at opening of these clones was higher than that of the check clones in respective environmental condition, that is, up to 9.7% higher than that of PB 235 in traditional environment and up to 34.0% higher than that of GT 1 in non-traditional environment (Table 3). Among these clones, LH 94/62, LH 97/697, LH 97/647, LH 94/481, LH 96/345 and LH 91/579 exhibited good girth growth performance in both experimental conditions with their girth at opening greater than 50 cm (Table 4).

Latex yield performance

The variation between environments in latex yield of the studied clones was significant ($p < .01$) (Table 4). Mean latex yield over two years of tapping ranged from 19.50 g/t/t (LH 94/475) to 57.08 g/t/t (LH 94/359) in traditional rubber growing region (Binh Duong province) and 15.24 g/t/t (PB 235) to 50.75 g/t/t (LH 91/579) in non-traditional rubber growing region (Nghe An province). The results showed that 9 out of 24 tested clones showed very good yield performance in both environmental conditions, such as LH 94/359, LH 82/182, LH 94/481, LH 95/208, LH 97/165, LH 97/647, LH 96/133, LH 96/308 and LH 94/62. The mean latex yield over two years of tapping of these clones was significantly higher than that of the check clones in respective environmental condition with 7.0–51.9% higher than that of PB 235 in traditional environment and 66.7–204.6% higher than that of GT 1 in non-traditional environment (Table 4). Outstandingly, mean latex yields of all RRIV's clones in non-traditional environment (Nghe An province) were significantly higher than that of the check clone GT 1 which is recommended for this region. Among these clones, LH 91/579 and LH 94/481 were the best yielding clones in Nghe An province with mean latex yield over two years of tapping of 50.75 and 48.66 g/t/t, corresponding to 317.6% and 304.6% of that of the check clone GT 1, respectively (Table 4).

Analysis of variances for stability

Similar to previous studies on genotype × environment interactions in plants as well as in *H. brasiliensis*, the genotype ×

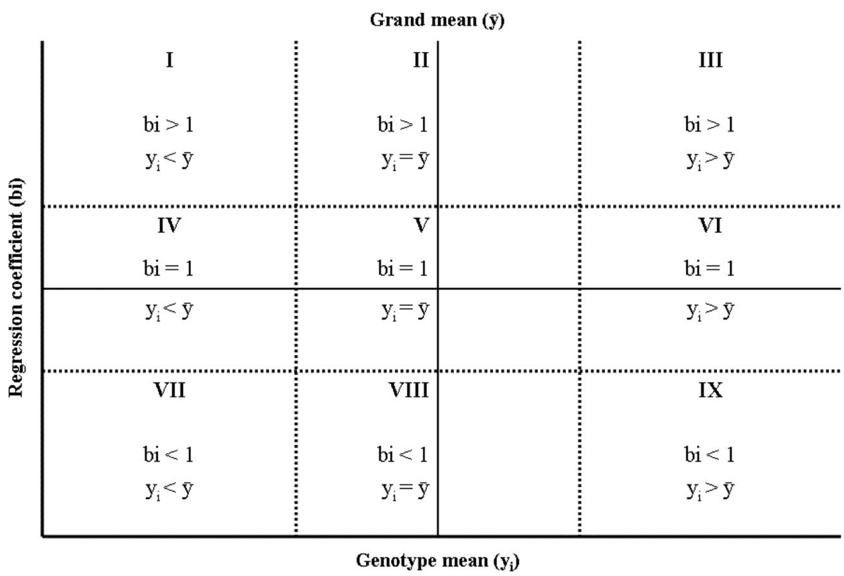

Figure 2. The mathematical explanation for environmental stability. I, II, III: Adaptability to favorable environmental conditions with low, average and high genotype mean, respectively. IV, V, VI: Adaptability to all environmental conditions with low, average and high genotype mean, respectively. VII, VIII, IX: Adaptability to unfavorable environmental conditions with low, average and high genotype mean, respectively.

Table 3. Girth at opening (cm) of the studied clones.

	Binh Duong						Nghe An					
Clones	Min	Max	Mean	%(1)	CV%	Rank	Min	Max	Mean	%(2)	CV%	Rank
LH 94/501	42.7	63.5	55.61[a]	109.7	11.4	1	22.5	61.8	45.71[d–g]	111.0	23.3	16
LH 94/62	44.0	59.7	54.43[ab]	107.2	6.6	2	36.0	69.0	55.08[a]	134.0	16.0	1
LH 97/697	40.8	60.3	53.36[a–c]	105.1	9.2	3	41.5	58.3	51.12[a–d]	124.1	10.8	5
LH 97/657	43.7	62.8	52.86[a–d]	104.2	11.3	4	21.5	65.2	46.90[b–g]	114.1	23.3	14
LH 97/647	43.5	66.2	52.31[a–d]	103.3	10.9	5	33.0	63.0	51.09[a–d]	123.6	17.9	6
LH 94/481	37.5	60.5	51.92[b–d]	102.4	11.2	6	37.2	63.5	50.29[a–d]	122.1	15.1	8
LH 96/345	42.5	63.1	51.20[b–e]	101.0	9.8	7	40.2	69.6	51.66[a–d]	125.5	15.1	4
LH 96/305	37.7	59.5	50.80[c–f]	100.2	10.0	8	25.5	61.0	47.19[b–g]	114.3	18.5	13
LH 91/579	33.6	61.0	50.75[c–f]	100.1	13.4	9	41.0	67.5	51.05[a–d]	124.0	13.1	7
LH 98/444	33.7	59.4	50.73[c–f]	99.7	12.0	10	20.3	49.0	37.13[h]	89.2	19.7	26
LH 95/208	41.3	56.0	50.58[c–f]	99.7	7.5	12	22.0	63.9	46.17[c–g]	111.9	25.0	15
LH 82/182	41.5	61.0	50.48[c–f]	99.7	10.8	13	26.4	70.7	42.76[e–h]	104.1	26.2	19
LH 95/395	40.6	59.7	50.08[c–f]	98.7	10.1	14	27.0	52.0	40.36[gh]	97.8	17.1	24
LH 94/612	41.8	55.8	49.78[c–f]	98.0	8.7	15	24.8	67.8	53.19[a–c]	128.1	20.7	3
LH 94/374	41.3	55.5	49.75[c–f]	98.1	8.4	16	39.0	59.0	47.79[b–f]	120.9	15.0	12
LH 94/475	37.0	58.5	49.72[c–f]	98.1	8.9	17	32.8	65.0	48.39[a–e]	116.9	16.7	9
LH 96/308	40.7	59.0	49.69[c–f]	98.0	10.7	18	25.3	70.3	53.73[ab]	129.4	18.0	2
LH 97/165	28.7	58.7	49.64[d–f]	97.9	13.1	19	17.0	56.0	37.81[h]	92.2	27.1	25
LH 96/115	36.0	60.0	49.47[d–f]	97.4	13.3	20	22.6	53.8	40.66[gh]	98.9	20.5	22
LH 96/133	35.5	58.7	49.42[d–f]	97.5	11.7	21	22.5	63.3	45.08[d–g]	109.2	22.2	17
LH 94/359	40.5	57.5	49.21[d–f]	97.1	9.0	22	23.0	61.0	48.32[a–e]	117.2	18.9	10
LH 97/646	40.5	55.3	48.20[ef]	94.8	10.2	23	37.0	60.5	48.29[a–e]	117.3	13.5	11
LH 94/105	37.0	55.5	47.86[ef]	94.3	9.6	24	32.5	50.5	41.83[e–h]	95.2	19.0	20
LH 95/345	38.2	54.8	47.56[ef]	93.8	9.2	25	29.4	51.0	40.48[gh]	98.1	13.7	23
GT 1	34.7	56.0	47.38[f]	93.4	12.2	26	23.0	54.3	41.18[f–h]	100.0	20.4	21
PB 235	41.5	59.5	50.62[c–f]	100.0	12.7	11	29.8	59.0	42.92[e–h]	104.2	20.3	18
I_j			1.87						−1.87			

(1) Compared to check clone PB 235 which was popularly cultivated in traditional region of Vietnam.
(2) Compared to check clone GT 1 which was popularly cultivated in non-traditional region of Vietnam.
a,b,c Means followed by the same letters within a column are not statistically different at the level of $p < .01$ for Duncan Range Test.
I_j is the environmental index.

environment interactions were found to be highly significant in terms of girth at opening as well as latex yield for 26 *Hevea* clones in this study. This meant that the girth at opening and the latex yield of all studied clones differed between locations. Indeed, analyses of variance for stability showed the significant differences ($p < .01$) for both girth at opening and latex yield among genotypes and environments. This revealed not only the genetic variability among the genotypes but also the variation due to the changes of environments. For both girth at opening and latex yield, significant F values were found for G × E interaction, indicating differences among the regression coefficients (Table 5).

Table 4. Latex yield (g/t/t) over two years of tapping of the studied clones.

	Binh Duong						Nghe An					
Clones	Min	Max	Mean	%(1)	CV%	Rank	Min	Max	Mean	%(2)	CV%	Rank
LH 94/359	37.20	85.76	57.08[a]	151.9	24.5	1	20.92	42.95	30.01[d–f]	187.8	19.7	8
LH 82/182	23.81	75.24	50.05[b]	133.2	30.5	2	22.95	39.68	30.58[d-f]	191.4	14.1	7
LH 94/481	13.89	84.48	46.59[bc]	124.0	40.9	3	39.81	59.38	48.66[a]	304.6	12.4	2
LH 95/208	26.21	57.85	42.59[cd]	113.4	20.4	4	36.71	51.98	42.33[b]	265.0	10.2	3
LH 97/165	13.47	64.42	42.57[cd]	113.3	31.3	5	22.06	32.70	26.64[f–i]	166.7	9.5	13
LH 97/647	13.02	70.96	41.60[c–e]	110.7	33.3	6	24.36	34.36	28.16[e–h]	176.3	10.3	12
LH 96/133	28.44	61.28	40.82[c–e]	108.7	21.7	7	22.40	36.46	28.22[e–h]	176.6	14.2	11
LH 96/308	17.42	62.94	40.78[c–e]	108.6	33.3	8	22.26	34.56	29.12[d–f]	182.2	12.5	9
LH 94/62	12.27	63.46	40.20[c–e]	107.0	30.7	9	26.23	42.74	37.44[c]	234.3	10.4	4
LH 96/345	13.54	54.96	35.67[d–g]	95.0	30.3	11	26.39	44.75	32.64[de]	204.3	13.3	6
LH 94/374	18.88	59.46	34.81[d–g]	92.6	26.4	12	18.68	24.75	21.97[ij]	137.5	8.8	19
LH 97/697	17.11	54.90	34.80[d–g]	92.6	30.0	13	19.34	27.66	23.22[h–j]	145.4	10.4	16
LH 95/395	11.72	50.23	34.03[e–g]	90.6	31.1	14	23.29	29.31	26.37[f–i]	165.0	7.4	14
LH 94/105	11.88	55.80	33.95[e–g]	90.4	35.8	15	16.02	27.73	21.83[ij]	136.6	26.8	21
LH 94/501	13.83	50.68	31.81[f–h]	84.7	35.2	16	14.50	27.37	20.18[jk]	126.3	16.8	23
LH 94/612	10.09	53.31	31.74[f–h]	84.5	30.6	17	21.50	40.23	28.40[e–g]	177.7	18.7	10
LH 95/345	19.48	43.53	31.22[f–h]	83.1	19.6	18	16.21	25.25	22.53[ij]	141.0	10.9	18
LH 91/579	14.88	51.61	30.82[f–h]	82.0	32.9	19	38.06	62.86	50.75[a]	317.6	11.9	1
LH 98/444	14.19	44.58	29.92[f–h]	79.7	28.2	20	18.60	28.29	22.73[ij]	142.2	14.6	17
LH 96/115	11.91	62.86	29.17[g–i]	77.6	39.5	21	17.52	35.38	23.56[g–j]	147.5	19.4	15
LH 97/657	8.56	53.93	28.59[g–i]	76.1	38.2	22	18.25	25.67	21.88[ij]	136.9	9.7	20
LH 97/646	10.30	39.11	25.78[h–g]	68.6	29.7	24	26.18	42.11	33.68[cd]	210.8	12.0	5
LH 96/305	7.63	36.82	22.14[ij]	58.9	30.6	25	14.20	23.43	18.30[j–l]	114.6	12.3	24
LH 94/475	7.79	36.99	19.50[j]	51.9	35.2	26	13.02	31.84	21.55[ij]	134.9	18.9	22
GT 1	14.48	45.12	27.84[g–i]	74.1	28.2	23	11.75	20.58	15.98[kl]	100.0	15.3	25
PB 235	18.91	71.67	37.57[d–f]	100.0	33.7	10	10.79	18.78	15.24[l]	95.4	17.2	26
I_j			4.03						−4.03			

(1) Compare to check clone PB 235 which was popularly cultivated in traditional region of Vietnam.
(2) Compare to check clone GT 1 which was popularly cultivated in non-traditional region of Vietnam.
a,b,c Means followed by same letters within a column are not statistically different at the level of $p < .01$ for Duncan Range Test.
I_j is the environmental index.

Table 5. Analysis of variance and variance components for stability parameters for girth at opening and latex yield of 26 *Hevea* clones in two different environmental conditions.

	Girth at opening				Latex yield			
Source of variation	df	Sum of square	Mean square	Explained (%)	df	Sum of square	Mean square	Explained (%)
Model	53	13,510.304	254.911**		53	2808.613	52.993**	
Genotypes (G)	25	7988.203	319.528**	58.6	25	1359.155	54.366**	49.0
Environments (E)	1	2255.099	2255.099**	16.5	1	642.154	642.154**	23.2
G × E interaction	25	3400.961	136.038**	24.9	25	771.963	30.879**	27.8
Pooled error	99	1451.116	14.658		97	741.144	7.641	
Corrected total	152	14,961.420		100.0	150	3549.758		100.0

**Significant at 0.01 probability level.

A pooled analysis of girth at opening of 26 *Hevea* clones tested at two different environmental conditions showed that 58.6% of variation was attributed to genotypic effects, meanwhile environmental and G × E interaction effects explained 16.5% and 24.9%, respectively. Similarly, a pooled analysis of latex yield of these clones across two different environments showed that 49.0% of variation in latex yield was attributed to genotypic effects, while environmental and G × E interaction effects explained 23.2% and 27.8%, respectively. The large environmental sum of squares of genotype for both girth at opening and latex yield indicated that genotypes were diverse with large differences causing most of the variations in girth growth and latex yield. Additionally, the sum of squares of G × E interaction values was larger than that of environments for both girth at opening and latex yield, indicating that there were substantial differences in genotypic response across the environments (Table 5).

Stability analysis for girth at opening

It was noted that both linear (bi) and non-linear (S^2di) components of genotype × environment (G × E) interactions are necessary for judging the stability of a genotype (Eberhart & Russell 1966). A wide adaptability genotype was defined as one with the regression coefficient (bi) approximating 1.0 (bi = 1) and high stability as one with the deviations from regressions (S^2di) of approximating zero ($S^2di = 0$). Regression values above 1.0 describe genotype with higher sensitivity to environmental change (below average stability) and greater specificity of adaptability to high yielding environments. A regression coefficient below 1.0 provides a measurement of greater resistance to environmental change (above average stability), and thus increases the specificity of adaptability to low yielding environments (Wachira et al. 2002). Regarding the coefficient of determination (R_i^2), Pinthus (1973) and Sayar et al. (2013) noted that R_i^2 was often considered better for measuring the validity of the linear regression (bi) than non-linear S^2di because its value ranges between zero and one; a greater R_i^2 value is desired because higher R_i^2 values indicate favorable responses to environmental changes. Additionally, a higher R_i^2 value also indicates a reliable stability (Pinthus 1973).

In the present study, the regression coefficient (bi) for girth at opening across two different environments (y_i) ranged from −0.307 (LH 94/612) to 2.403 (LH 98/444) (Table 6). This large variation reflects the different responses of different genotypes to environmental changes. With respect to clones with a regression coefficient equal to unity (bi = 1), the results showed that clones LH 94/481, LH 91/579, LH 97/657, LH 94/475, LH 96/305, LH 94/359, LH 94/374, LH 95/208, LH 96/133 and LH 82/182 had average girth growth and adaptability to all environmental conditions

Table 6. Estimates of stability and adaptability parameters of girth at opening (cm) for 26 *Hevea* clones across two different environmental conditions.

Code	Clones	Girth at opening (cm)	Regression coefficient (bi)	Deviation from regression (S^2di)	Coefficient of determination (R_i^2)
1	LH 82/182	46.62	1.418	0.928	0.382
2	LH 91/579	50.90	0.438	1.346	0.914
3	LH 94/105	44.85*	1.208	−1.845	0.420
4	LH 94/359	48.77	0.538	−0.710	0.838
5	LH 94/374	48.77	0.564	−2.515	0.154
6	LH 94/475	49.05	0.701	−1.323	0.364
7	LH 94/481	51.10	0.772	−0.664	0.785
8	LH 94/501	50.66	2.041*	1.419	0.990
9	LH 94/612	51.49	−0.307*	3.722	0.911
10	LH 94/62	54.75*	0.261*	1.545	0.783
11	LH 95/208	48.37	0.959	−2.376	0.966
12	LH 95/345	44.02*	1.549	−0.997	0.932
13	LH 95/395	45.22*	1.697*	2.918	0.976
14	LH 96/115	45.06*	1.646*	0.942	0.954
15	LH 96/133	47.25	0.947	−2.413	0.988
16	LH 96/305	49.00	0.872	−2.562	0.931
17	LH 96/308	51.71*	−0.248*	8.245*	0.954
18	LH 96/345	51.43	0.259*	2.369	0.921
19	LH 97/165	43.72*	2.139*	3.713	0.856
20	LH 97/646	48.24	0.279*	−0.479	0.434
21	LH 97/647	51.70*	0.829	−0.525	0.756
22	LH 97/657	49.88	1.369	−0.946	0.947
23	LH 97/697	52.24*	0.804	−1.821	0.909
24	LH 98/444	43.93*	2.403*	5.009*	0.982
25	GT 1	44.28*	1.165	−1.304	0.658
26	PB 235	46.77	1.697*	−0.833	0.065
Average ($\bar{y}$)	48.45	1.000			

*Significant at 0.05 probability level (bi ≠ 1 or $S^2di \neq 0$ or $y_i \neq \bar{y}$).

(bi = 1, $y_i = \bar{y}$) due to their y_i, bi and S^2di values were non-significantly different from the grand mean ($y_i = \bar{y}$), unity (bi = 1) and zero (S^2di = 0), respectively. Among these clones, however, the very low coefficient of determinations (R_i^2) value for girth at opening was recorded for LH 94/374, LH 94/475 and LH 82/182 clones with R_i^2 were 0.154, 0.364 and 0.382 respectively (Table 6), indicating these clones seemed to be unstable in terms of the girth growth. Clones LH 97/697 and LH 97/647 had high girth growth and adaptability to all environmental conditions (bi = 1, $y_i > \bar{y}$) due to their y_i were significant greater than the grand mean ($y_i > \bar{y}$), bi and S^2di values were non-significantly different from the unity (bi = 1) and zero (S^2di = 0), respectively. In contrast, due to the low y_i ($y_i < \bar{y}$), bi equal to unity (bi = 1) and small S^2di value, clones LH 94/105, LH 95/345 and GT 1 were considered as low girth growth and adaptability to all environmental conditions (bi = 1, $y_i < \bar{y}$).

Due to their high regression coefficient values (bi > 1) and small S^2di values (S^2di = 0), clones LH 97/165, LH 94/501, LH 95/395, LH 96/115 and PB 235 were considered as adaptability to favorable environmental condition (Table 6). Among these clones, LH 94/501 and PB 235 were accepted as average girth growth clones due to their y_i values equal to the grand mean ($y_i = \bar{y}$) (Figure 3). Meanwhile, the other clones were accepted as low girth growth due to its low y_i value compared to the grand mean ($y_i < \bar{y}$) (Figure 3).

With the low regression coefficient values (bi < 1) and small S^2di values (S^2di = 0), clones LH 97/646, LH 94/62, LH 96/345, LH 96/308 and LH 94/612 were regarded as adaptability to unfavorable environmental condition (Table 6). Among these clones, LH 94/612, LH 96/345 and LH 97/646 were considered as average girth growth clones due to their y_{ij} values equal to the grand mean ($y_i = \bar{y}$) (Figure 3). Meanwhile, due to the high y_i value compared to the grand mean ($y_i > \bar{y}$), clones LH 96/308 and particularly LH 94/62 were accepted as high girth growth and adaptability to unfavorable environmental condition (Figure 3). Therefore, in terms of girth growth, clones LH 94/62 can be recommended for cultivation under unfavorable conditions.

Stability analysis for latex yield

Regarding latex yield across two different environmental conditions (y_i), values for the regression coefficients (bi) ranged from −0.745 (LH 91/579) to 2.894 (LH 94/359) (Table 7). This large variation in regression coefficients reflects the different responses of different genotypes to environmental changes. The results showed that latex yield in clones LH 94/359, LH 97/647, LH 97/165, LH 82/182, LH 96/308, LH 96/133, LH 97/697, LH 98/444 and PB 235 had high regression coefficient values, significantly above unity (bi > 1) (Table 7, Figure 4). Accordingly, these clones can be said to be sensitive to environmental changes and to have greater specificity of adaptability to high-yield environment. Among those clones, LH 94/359, LH 82/182, LH 96/308 and LH 97/647 were accepted as high yielding clones having adaptability to favorable environmental condition due to their high y_i and bi values (bi > 1 and $y_i > \bar{y}$). Therefore, these clones can be recommended for cultivation under favorable conditions. Clones of LH 96/133, LH 97/165 and LH 97/697 were accepted as the average yielding clones having adaptability to favorable environmental condition due to their average latex yield and high bi values (bi > 1 and $y_i = \bar{y}$). Meanwhile, LH 98/444 and check clone PB 235 were considered as low yielding clones having adaptability to favorable environmental condition due to their low latex yield and high bi values (bi > 1 and $y_i < \bar{y}$).

Clones with a regression coefficient equal to unity (bi = 1) were LH 94/481, LH 95/395, LH 94/105, LH 94/374, LH 95/345, LH 96/115, LH 94/501, LH 97/657 and LH 96/305 (Table 7, Figure 4). These clones can be said to be adaptable to all environmental conditions. Among these, LH 94/481 was accepted as the clone of high yielding and adaptability to all environmental conditions (bi = 1 and $y_i > \bar{y}$) due to its highest

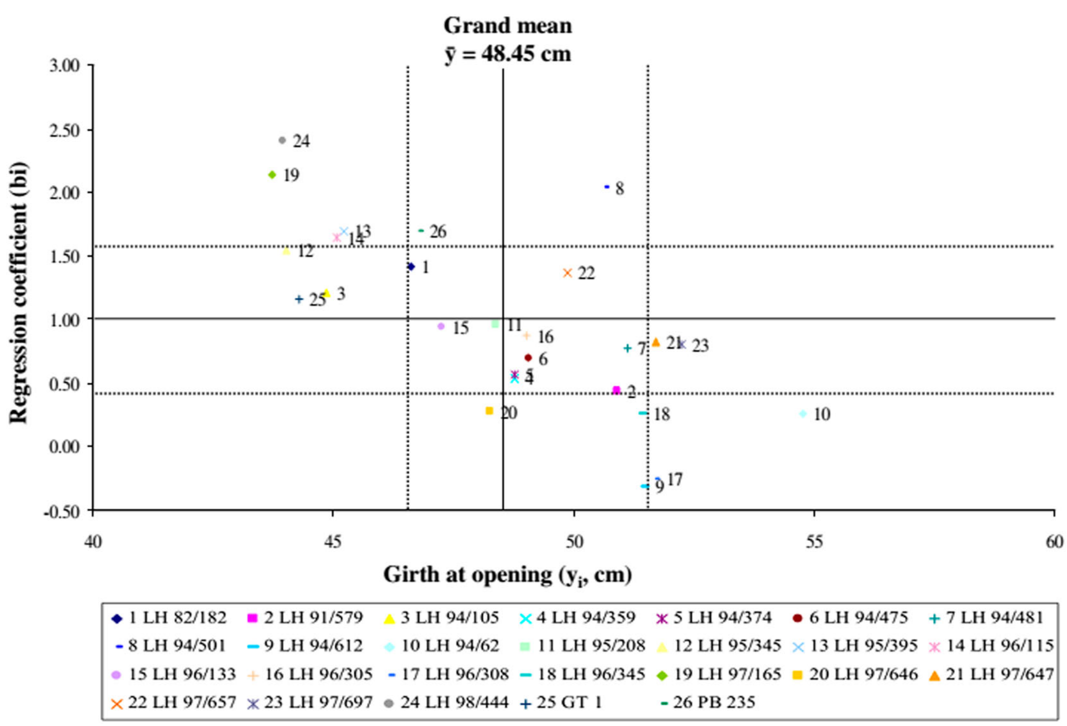

Figure 3. Relationship between the stability parameter (bi) and girth at opening (y_i, cm).

Table 7. Estimates of stability and adaptability parameters of latex yield (g/t/t) for 26 *Hevea* clones across two different environmental conditions.

Code	Clones	Latex yield (g/t/t)	Regression coefficient (bi)	Deviation from regression (S^2di)	Coefficient of determination (R_i^2)
1	LH 82/182	40.10**	1.605*	12.218*	0.921
2	LH 91/579	40.67**	−0.745**	35.729**	0.902
3	LH 94/105	29.61	1.018	189.775**	0.702
4	LH 94/359	42.77**	2.894**	21.188**	0.880
5	LH 94/374	28.44*	1.187	76.368**	0.926
6	LH 94/475	20.61**	0.330*	6.450	0.962
7	LH 94/481	47.63**	1.071	24.008**	0.755
8	LH 94/501	26.06*	1.221	91.768**	0.770
9	LH 94/612	29.88	0.611*	−1.145	0.992
10	LH 94/62	38.82*	0.490*	−1.879	0.959
11	LH 95/208	42.46**	0.164**	−3.023	0.897
12	LH 95/345	26.46*	1.018	−0.745	0.954
13	LH 95/395	30.25	0.998	−4.148	0.959
14	LH 96/115	26.19*	0.925	−2.053	0.980
15	LH 96/133	34.54	1.460*	−3.448	0.960
16	LH 96/305	20.41**	0.763	−0.264	0.999
17	LH 96/308	35.39*	1.494*	−1.229	0.982
18	LH 96/345	34.34	0.214**	−1.563	0.993
19	LH 97/165	34.39	1.650*	1.300	0.946
20	LH 97/646	29.74	−0.377**	18.174*	0.944
21	LH 97/647	34.88*	1.813**	14.308*	0.802
22	LH 97/657	25.48*	0.680	5.444	0.984
23	LH 97/697	29.30	1.438*	−2.576	0.950
24	LH 98/444	25.13*	1.343*	−1.583	0.992
25	GT1	22.32**	1.045	−2.777	0.984
26	PB 235	27.39*	1.689*	78.078**	0.849
Average	31.66	1.000			

*Significant at 0.05 probability level (bi ≠ 1 or S^2di ≠ 0 or $y_i \neq \bar{y}$).
**Significant at 0.01 probability level (bi ≠ 1 or S^2di ≠ 0 or $y_i \neq \bar{y}$).

latex yield and a regression coefficient that did not differ significantly from 1.0; LH 95/395 and LH 94/105 were considered as the average yielding and adaptable clones to all environmental conditions (bi = 1 and $y_i = \bar{y}$); and the remaining clones were considered as the low yielding and adaptable clones to all environmental conditions (bi = 1 and $y_i < \bar{y}$). The results also revealed that in addition to their low latex yield ($y_i < \bar{y}$) and very high R_i^2 values, clones of LH 95/395, LH 95/345, LH 96/115, LH 96/305, LH 97/657 and GT 1 had regression coefficients and regression deviations mean square that were not significantly different from 1.0 and zero (bi = 1.0 and S^2di = 0) respectively, thus these clones were considered as fair stability clones (Finlay & Wilkinson 1963; Eberhart & Russell 1966; Pinthus 1973).

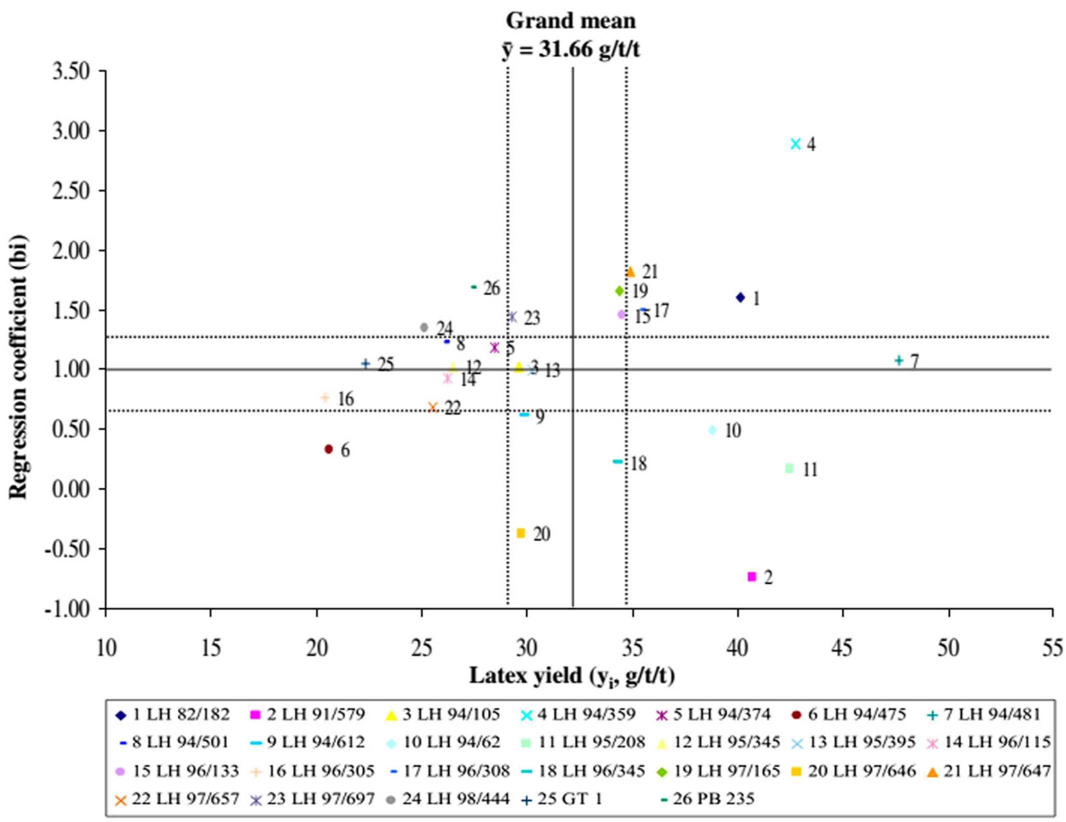

Figure 4. Relationship between the stability parameter (bi) and latex yield (y_i, g/t/t).

Clones LH 91/579, LH 97/646, LH 95/208, LH 96/345, LH 94/475, LH 94/62 and LH 94/612 had low regression coefficient values, significantly below unity (bi < 1) (Table 7, Figure 4). These clones can be said to be adaptable to unfavorable environmental conditions. Among these, LH 94/475 was considered as the clone of low yielding and adaptability to unfavorable environmental conditions (bi < 1 and $y_i < \bar{y}$) due to its lowest latex yield and low bi value. Meanwhile, LH 96/345, LH 94/612 and LH 94/646 clones were considered as the average yielding and adaptable clones to unfavorable environmental conditions (bi < 1 and $y_i = \bar{y}$) due to their latex yield did not differ significantly from grand mean latex yield. The other clones, LH 95/208, LH 94/62 and particularly LH 91/579 were accepted as the high yielding and adaptable clones to unfavorable environmental condition (bi < 1 and $y_i > \bar{y}$), these clones thus can be recommended for cultivation under unfavorable conditions.

Conclusions

In this study, the analysis on genotype × environment interactions of 26 *Hevea* clones was carried out after two year of tapping in two different environmental conditions represented for traditional (Southeast) and non-traditional (North Central Coast) rubber growing regions in Vietnam. The G × E interactions were found to be highly significant ($p < .01$) for both girth at opening and latex yield. The stability analysis for girth at opening among the studied clones indicated that LH 94/501 and LH 94/62 could be accepted as the most adaptable clones under traditional and non-traditional rubber growing regions of Vietnam, respectively. Meanwhile, LH 97/697 was considered as the best girth growth and the most adaptable clone for both rubber growing regions.

In terms of latex yield, the stability analysis in this study revealed that among the 26 clones, LH 94/359 was the best clone that can be recommended for cultivation under traditional rubber growing region. Meanwhile, clone LH 94/481 was the best clone that can be recommended for cultivation in both rubber growing regions. Clone LH 91/579 was the best clone that can be recommended for cultivation in the North Central Coast, which has considered as a non-traditional rubber growing region of Vietnam, where the prolong low temperature and low solar radiation in the winter are the major factors limiting the development and production of rubber tree. These clones were also accepted as the average girth growth and adaptability to both rubber growing regions of Vietnam.

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Disclosure statement

No potential conflict of interest was reported by the author.

References

Akçura M, Kaya Y, Taner S. 2005. Genotype-environment interaction and phenotypic stability analysis for grain yield of durum wheat in the Central Anatolian region. Turk J Agric For. 29:369–375.

Ali N, Javidfar F, Mirza Y. 2003. Selection of stable rapeseed (*Brassica napus* L.) genotypes through regression analysis. Pak J Bot. 35:175–183.

Becker HB, Leon J. 1988. Stability analysis in plant breeding. Plant Breeding. 101:1–23.

Correa AM, Gonçalves MC, Destro D, de Souza LCF, Sobrinho TA. 2003. Estimates of genetic parameters in common bean genotypes. Crop Breed Appl Biotechnol. 3:223–230.

Costa RBD, Resende MDVD, Araújo AJD, Gonçalves PDS, Martins ALM. 2000. Genotype-environmental interaction and the number of test locations for the genetic improvement of rubber tree (*Hevea*) in São Paulo State, Brazil. Genet Mol Biol. 23:179–187.

Crossa J. 1990. Statistical analysis of multilocation trials. Adv Agron. 44:55–85.

Daslin A, Bailaki A, Danakusuma TM, Haeruman MS. 1986. Genotypes × environment interaction in rubber and their implications in clonal selection. Bulletin Perkaretan. 4:23–28.

Eberhart SA, Russell WA. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36–40.

Farshadfar E, Sabaghpour SH, Zali H. 2012. Comparison of parametric and non-parametric stability statistics for selecting stable chickpea (*Cicer arietinum* L.) genotypes under diverse environments. Aust J Crop Sci. 6:514–524.

Finlay KW, Wilkinson GN. 1963. The analysis of adaptation in a plant-breeding programme. Aust J Agric Res. 14:742–754.

Gonçalves PDS, Bataglia OC, Santos ERD, Ortolani AA, Segnini JI, Shikasho EH. 1998. Growth trends, genotype × environment interaction and genetic gains in six year old rubber tree clones (*Hevea*) in São Paulo State. Genet Mol Biol. 21:115–122.

Gonçalves PDS, Bortoletto N, Martins ALM, Costa RBD, Gallo PB. 2003. Genotype-environment interaction and phenotypic stability for girth growth and rubber yield of *Hevea* clones in São Paulo State, Brazil. Genet Mol Biol. 26:441–448.

Gonçalves PDS, Cardoso M, Santos ICID, Martins ALM, Ortolani AA, Colombo CA. 1992. Selection of *Hevea* mother tree adapted to unpredictable annual climatic variability. Braz J Genet. 15:137–147.

Gonçalves PDS, Fujihara AK, Ortolani AA, Bataglia OC, Bortoletto N, Segnini JI. 1999. Phenotypic stability and genetic gains in six-year girth growth of *Hevea* clones. Pesq Agropec Bras. 34:1223–1232.

Gonçalves PDS, Moraes MLTD, Gouvêa LRL, Aguiar ATDE, Júnior EJS. 2008. Temporal stability for unpredictable annual climatic variability for *Hevea* genotype selection. Braz Arch Biol Technol. 51:11–18.

Gonçalves PDS, Moraes MLTD, Silva MDA, Gouvêa LRL, Aguiar ATDE, Costa RBD. 2009. Prediction of *Hevea* progeny performance in the presence of genotype-environment interaction. Braz Arch Biol Technol. 52:25–33.

Gouvêa LRL, Silva GAP, Verardi CK, Silva JQ, Junior EJS, Gonçalves PDS. 2012. Temporal stability of vigor in rubber tree genotypes in the pre- and post-tapping phases using different methods. Euphytica. 186:625–634.

Gurmu F, Mohammed H, Alemaw G. 2009. Genotype × environment interactions and stability of soybean for grain yield and nutrition quality. Afr Crop Sci J. 17:87–99.

Hebert Y, Plomion C, Harzic N. 1995. Genotypic × environment interaction for root traits in maize as analysed with factorial regression models. Euphytica. 81:85–92.

Jacob J, Annmalainathan K, Alam BM, Sathick MB, Thapaliyal AP, Devakumar AS. 1999. Physiological constraints for cultivation of *Hevea brasiliensis* in certain unfavourable agroclimatic regions of India. Indian J Nat Rubb Res. 12:1–16.

Jayasekera NEM. 1983. A basis for selecting *Hevea* clones stable to unpredictable agro-climate variability. Silvae Genet. 32:181–185.

Jayasekera NEM, Karunasekera KB, Kearsey MJ. 1994. Genetics of production traits in *Hevea brasiliensis* (rubber) I: changes in genetic control with age. Heredity. 73:650–656.

Lam LV, Thanh T, Trang LTT, Truong VV, Lam HB. 2012. Hevea germplasm in Vietnam: conservation, characterization, evaluation and utilization. In: Caliskan M, editor. Genetic diversity in plants. Rijeka: InTech Publisher; p. 433–456.

Lin CS, Binns MR, Lefkovitch LP. 1986. Stability analysis: where do we stand?. Crop Sci. 26:894–900.

Menattoor RJ, Vinod KK, Krushnakumar AK, Seturaj MR, Potty SN, Sinha RR. 1991. Clones × environmental interaction during early growth phase of *Hevea brasiliensis*: I. Clonal stability on girth. Indian J Nat Rubber Res. 4:51–58.

Omokhafe KO. 2004a. Clonal stability of tree dryness in *Hevea brasiliensis* Muell. Arg. Genet Mol Biol. 27:242–244.
Omokhafe KO. 2004b. Interaction between flowering pattern and latex yield in *Hevea brasiliensis* Müell. Arg Crop Breed Appl Biotechnol. 4:280–284.
Omokhafe KO, Alika JE. 2003. Clonal stability of latex yield in eleven clones of *Hevea brasiliensis* Muell. Arg Genet Mol Biol. 26:313–317.
Onokpise OU, Olapade O, Mekaki HU. 1986. Genotype × environment interaction in *Hevea brasiliensis* (Müell. Arg.). Ind J Genet. 46:506–511.
Piepho HP. 1998. Methods for comparing the yield stability of cropping system – a review. J Agron Crop Sci. 190:193–213.
Pinthus JM. 1973. Estimate of genotype value: a proposed method. Euphytica. 22:121–123.
Pushparajah E. 1983. Problems and potentials for establishing *Hevea* under difficult environmental conditions. Planter. 59:242–251.
Rao PS, Saraswathyamma CK, Sethuraj MR. 1998. Studies on the relationship between yield and meteorological parameters of Para rubber tree (*Hevea brasiliensis*). Agric For Meteorol. 90:235–245.
Romagosa I, Fox PN. 1993. Genotype-environment interactions and adaptation. In: Hayward MD, Bosenmark NO, Romagosa I, editor. Plant breeding: principles and prospects. London: Chapman and Hall; p. 373–390.
SAS Institute Inc. 1999. SAS/STAT user's guide, version 8.01. Cary, NC: SAS Institute.
Sayar MS, Anlarsal AE, Basbag M. 2013. Genotype-environment interactions and stability analysis for dry-matter yield and seed yield in Hungarian vetch (*Vicia pannonica* Crantz.). Turk J Field Crops. 18:238–246.
Silva GAP, Gouvêa LRL, Verardi CK, Oliveira ALBD, Gonçalves PDS. 2014. Annual growth increment and stability of rubber yield in the tapping phase in rubber tree clones: implications for early selection. Ind Crop Prod. 52:801–808.
Silva GAP, Gouvêa LRL, Verardi CK, Resende MDVD, Junior EJS, Gonçalves PDS. 2013. Genetic parameters and correlation in early measurement cycles in rubber trees. Euphytica. 189:343–350.
Singh RK, Chaudhary BD. 1979. Biometrical methods in quantitative genetic analysis. New Delhi: Kalyani publication.
Tan H. 1995. Genotype × environment interaction studies in rubber (*Hevea*) clones. J Nat Rubb Res. 10:63–76.
Tesemma T, Tsegaye S, Belay G, Bechere E, Mitiku D. 1998. Stability of performance of tetraploid wheat landraces in Ethiopian highland. Euphtytica. 102:301–308.
Truberg M, Huhn HG. 2000. Contributions to the analysis of genotype-environment interactions: comparison of different parametric and non-parametric tests for interaction. J Agron Crop Sci. 185:267–274.
Tuy LM, Truong VV, Vinh LD, Chien VV, Thanh T, Lam LV. 2012. "Performances of RRIV's clones in non-traditional rubber growing regions of Vietnam." Paper presented at international natural rubber conference, October 28–31; Kerala, India.
Wachira F, Wilson NG, Omolo J, Mamati G. 2002. Genotype × environment interactions for tea yields. Euphytica. 127:289–296.
Withanage SP, Attanayake DPSTG, Karunasekara KBA. 2005. Adaptability of recently recommended rubber clones for agro-climatic variability of Sri Lanka. J Rubb Res Inst Sri Lanka. 87:1–6.