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Genetic Diversity and Identification of Potential Cold Tolerant Ecotypes from the Brazilian *Hevea* Germplasm of International Rubber Research and Development Board Collection

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Hevea brasiliensis is a commercially cultivated species for its natural rubber (NR) latex in Southeast Asian countries and its genetic base is very narrow. India has received a share of the wild *Hevea* germplasm from the 1981 IRRDB collection of Brazil. To meet the ever-increasing demand, NR cultivation has been extended to non-traditional regions in India. Eighteen wild *Hevea* accessions along with two modern clones RRII 203 and PB 235 and two check clones RRIM 600 and Haiken 1 were evaluated in RBD at Nagrakata, West Bengal, the sub-Himalayan cold-prone region of India. In *Hevea*, low temperature causes reduction in plant growth, thereby increasing its uneconomical immaturity period. The genotypes exhibited highly significant clonal differences (P=0.05) for all the growth traits. The highest mean noted for the plant height 19.62 m (RO 2727); bark thickness 5 mm (MT 900); girth of plant in the 14^{th} year after planting 92.32 cm (MT 915); annual girth increment (cm/year) over seven years 5.61 cm (MT 915); winter girth increment (cm/year) over seven years 1.05 cm (MT 915). The 22 genotypes were grouped into 5 clusters, reflected the presence of considerable genetic diversity in the population. The top 30% of the potential accessions showing high growth vigour under cold stress were identified which could be used in reducing immaturity period in this crop. These ecotypes/selections have high potential value for the development of cold-tolerant clones to mitigate climate change for these regions and also in broadening the genetic base of the present-day cultivated rubber.

Key Words: Cold tolerance, Genetic diversity, Growth vigour, Natural rubber, Wild *Hevea brasiliensis*

Introduction

The *Hevea* rubber tree belongs to the family Euphorbiaceae and indigenous to the tropical rain forests of Central and South America. Among the ten species, *H. brasiliensis* is being cultivated in a plantation scale in the Southeast Asian countries, for its high quality natural rubber (NR) latex. NR obtained from the latex of the tree, which is harvested by tapping, is an industrial raw material and has enormous industrial applications. So commercially it is in high demand including a major automobile sector and globally short in supplies. Francois Fresneau was the first man to have set out on a carefully planned search for the tree and to have given a description of *H. brasiliensis* and of the methods of tapping and preparation of crude rubber (Schurer, 1951).

Several scientific works have contributed to a better understanding of the complex genetic composition of *Hevea*. Recently efforts have been made to understand the links between production capacity, the genetic makeup and the ecological factors. In this context, a two-pronged approaches have been made a) critical cytogeographic surveys by Baldwin (1947) and b) taxonomical studies by Seibert (1947). According to Seibert and Baldwin, everywhere, where two *Hevea* species grow in the vicinity of one another in their natural habitat, introgressive hybridization has taken place in the past and is still taking place at present. From these hybrids, geographic races have established themselves by ecotypical selection. These geographic races have a morphological stature and habit superficially identical to one of the parents, but geographically impregnated with germplasm of one or more of other *Hevea* species. Owing to this selection, they have adapted themselves to habitats different from those preferred by the parents. The geographical distribution of the genus *Hevea*, location of 1876 Wickham collection and the 1981 IRRDB collection in the Amazon rainforests of Brazil are depicted in Figure 1.

In 1876, Henry Wickham collected few seedlings from a minuscule of the genetic range of *Hevea brasiliensis* in Boim, near the Tapajos River in Brazil

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Fig. 1. Distribution, range of the genus *Hevea* and *H. brasiliensis* in Amazon forest of Brazil

(Wycherley, 1968). The entire developments in rubber of Southeast Asian countries came from these few seedlings and thus the resultant clones developed from these seedlings are popularly known as “Wickham clones”. Therefore, currently the genetic base of *Hevea* in the domesticated countries is narrow. In the initial stages of crop improvement, main emphasis was on the improvement of yield, i.e. unidirectional selection for yield alone. In *Hevea* cultivated regions, the genetic advance gained in the early breeding phases seems to have slowed down in the more recent phases of breeding (Tan, 1987) for which the narrow genetic base is considered to be the chief factor.

To protect the fast depleting genetic resources from their native region in Brazil (Wycherley, 1968) and also to broaden the narrow genetic base of cultivated rubber, a large collection of wild *Hevea* germplasm was made at its center of origin in the Amazon rainforests of Brazil, by the International Rubber Research and Development Board (IRRDB) - EMBERPA during 1981 (Ong *et al*., 1983). The IRRDB expedition collection resulted in 64,736 seeds and budwood of 194 high yielding, disease free ortets. The expedition area comprised three states in Brazil *viz*. Acre (AC), Rondonia (RO) and Mato Grosso (MT), therefore ecological differences between these provenances offered chances of selection of materials suitable for diverse situations. A share of these germplasm was distributed to member countries including India. Around 4,548 accessions are being conserved in source bush nurseries in India, and are under different stages of evaluation for identification of desirable genes.

Rubber is traditionally grown profitably in the states of Kerala and Kanyakumari district of Tamil Nadu, and Dakshin Kannada and Kodagu districts of Karnataka in south India. To meet the increasing global demand for natural rubber, and also due to limited scope of further expansion in traditional area, rubber cultivation has been expanded to non-traditional regions such as Konkan region of Goa and Maharashtra and parts of Andhra Pradesh, Madhya Pradesh, Odisha, West Bengal and Notheastern (NE) states in India. Now, the rubber cultivation is extended near to sub-Himalayan range of NE India comprises Tripura, Assam, Meghalaya, Arunachal Pradesh and northern part of West Bengal. These areas are often exposed to a wide range of various biotic and abiotic stresses, such as various diseases, wind, higher altitude, and most importantly drought and temperature extremes. Various phenotypic symptoms in response to cold stress include poor germination of seeds, stunted growth, in severe cases results in leaves turning yellow and growing tips dry up and further cold stress can lead to major crop losses. Among various stress factors, low temperatures in the winter, have strongly affected growth, development and latex production of rubber trees in South central China (Priyadarshan *et al*., 2005) and in Northern part of Vietnam (Tuy *et al*., 2012). Sethuraj *et al*. (1991) and Rao *et al*. (1993) reported that cold stress is a serious threat for growth and development of *Hevea* plants and to the sustainability of crop yields in the NE India.

Therefore, the present study aimed at identifying the location specific clones which could adapt to low temperature as-well-as good performance in the cold climate. However, the wild relatives of crops are important sources of resistance to biotic and abiotic constraints. Since no information is available on wild germplasm in the sub-Himalayan region of West Bengal, the present study was undertaken in a cold-prone region to evaluate the growth performance of wild germplasm accessions in the mature phase, to quantify the degree of diversity for various growth traits in the population and to identify genetically diverse clusters and potential cold tolerant genotypes for breeding programmes.

Materials and Methods

A set of 18 wild *Hevea* accessions, two modern clones PB 235 and RRII 203 along with two check clones RRIM 600 and Haiken 1, were planted in a field trial in randomized block design during 2000, with three replications at the Regional Experiment Station of the Rubber Research Institute of India, Nagrakata (Latitude 26º43'N, longitude 88º26'E and altitude 69 m MSL and annual rain fall 3661 mm) in Jalpaiguri district of West Bengal, sub-Himalayan region of India. The spacing adopted was 4.9 × 4.9 m with five plants per plot and the recommended cultural practices of Rubber Board were followed. Among the 18 wild germplasm accessions, five were from Acre (AC 3074, AC 3075, AC 3293, AC 3514, AC 3810), four from Mato Grosso (MT 900, MT 915, MT 1020, MT 2229) and nine from Rondonia provenance (RO 2638, RO 2727, RO 2886, RO 2901, RO 2908, RO 2948, RO 3043, RO 3169, RO 3197). On the basis of weather variables, the entire year in this sub-Himalayan region can be broadly classified into two groups/ halves *viz*., Weather Regime I and Weather Regime II (Rao and Kole, 2016). Weather Regime I comprising of non-winter period *i.e*. from April to September, mainly consisting of summer, monsoon and post monsoon seasons in this area. Mean temperature ranges from 23.3 to 32º C and 94 per cent of annual rainfall is received in this period. Weather Regime II comprising of winter period *i.e*. from October to March, mainly consisting of cool and cold winter season only. Mean temperature ranges from 13.7 to 27.7º C and it dips as low as 5º C during December to January.

Observations on the height of plant (m) were recorded by VL402 Vertex Laser-height measurer from the bud union to the tip of the tree. Bark thickness (mm) of the stem and girth (cm) of the plant was recorded at 125 cm height from the bud union. Growth during the winter cold stress period was taken as an indication of tolerance to cold. Winter growth was recorded as the girth increment (cm) of a plant during winter by computing the difference between pre- and post-winter girth, for seven consecutive years, from the seventh year after planting. Pre-winter girth was recorded in the month of September (last week) continuously from 2007 to 2013, while post-winter girth was recorded in the first week of April every year from 2007 to 2014. The post-winter girth recording commenced with the annual girth recording every year. The average annual girth increment (cm) per year over seven years was calculated using the annual girth data of seventh and fourteenth years.

The data were subjected to analysis of variance (ANOVA) for randomized block design (Panse and Sukhatme, 1989). In order to study genetic diversity, all the genotypes were clustered by hierarchical cluster analysis (SPSS, 1999; Romesburg, 2004) using six characters. The overall performance of all these accessions were assessed by rank sum method (Kang, 1988), using the traits plant height, bark thickness, annual girth in the seventh and fourteenth year after planting, mean annual girth increment (cm/year) over seven years and mean winter girth increment (cm/year) over seven years. Based on the mean value of a character, each accession was ranked, giving the highest rank to the best performer. Then the ranks across all the traits for each accession were pooled to give a rank sum. Hence the highest rank sum indicated the best performer (rank "1").

Results

The experimental site of the Nagrakata area gets an annual rainfall of 3,661 mm and about 94% of the annual rainfall is received between April and September. The maximum temperature rises as high as 32.6º C during August and the minimum temperature is as low as 8.8º C during January. From October to March, the temperature range between 20.3–15.4º C and the rainfall is less than 201 mm. In the present study, the growth behavior of different wild accessions under these environmental conditions was investigated. The genotypes exhibited highly significant clonal differences ($P = 0.05$) for all the six quantitative traits studied. The range and population mean values in comparison with the check clones for the six growth characters in the mature growth phase are depicted in Table 1.

Table 1. Mean and range of variability for various growth characters in wild *Hevea* germplasm

Characters	Wild accessions		General mean	Check clones		CD (0.05)
	Minimum	Maximum		RRIM 600	Haiken1	
Plant height (m)	14.70	19.62	17.20	16.75	16.67	1.81
Bark thickness (mm)	2.33	5.00	3.87	4.00	4.50	0.94
Annual girth (cm)- 7th year	22.38	53.12	43.44	46.83	50.02	5.81
Annual girth (cm)- 14th year	34.93	92.32	68.51	66.11	82.56	9.12
Annual girth increment (cm/year) over 7 years	1.22	5.61	3.58	2.75	4.65	0.94
Winter girth increment (cm/year) over 7 years	0.34	1.05	0.71	0.65	0.85	0.21

Plant Growth Traits

The height of the plants showed in Table 1, ranged from 14.70 m (RO 2948) to 19.62 m (RO 2727)), while the check clones-Chinese Haiken 1 and Malaysian RRIM 600 recorded height of 16.67 m and 16.75 m, respectively. Bark thickness of the tree ranged from 2.33 mm (AC 3293) to 5 mm (MT 900) with a general mean of 3.87 mm. The check clones had a bark thickness of 4-4.5 mm.

In the seventh year after planting, girth of plant ranged from 22.38 (AC 3293) to 53.12 cm (RO 2727) and the general mean was 43.32 cm. The girth of plant in the fourteenth year after planting ranged from 34.93 cm (AC 3074) to 92.32 cm (MT 915) while the best check clone Haiken 1 recorded a girth of 82.56 cm (Table 1). The wild accession MT 915 recorded the highest girth increment (5.61 cm/year) over seven years, while the check clones RRIM 600 and Haiken 1 recorded an increment of 2.75 cm and 4.65 cm, respectively.

Winter girth increment (cm/year) over seven years ranged from 0.34 cm a^{-1} (AC 3074) to 1.05 cm a^{-1} (MT 915). Certain tolerant wild accessions, namely MT 915, topped in winter girth increment rate (1.05 cm a^{-1}) closely followed by RO 2727 (0.95 cm a^{-1}) and RO 3197 (0.85 cm a^{-1}). The check clones RRIM 600 and Haiken 1 recorded a winter girth increment of 0.65 cm a^{-1} and 0.85 cm a^{-1}, respectively.

Genetic Diversity

The 22 *Hevea* genotypes were grouped into 5 clusters, in which one cluster was solitary in nature (contains only one genotype) while the other 4 were multiple-genotype clusters (Figure 2). The composition of clusters has been presented in Table 2. The similarity coefficient ranged between 0.634 and 22.295. Cluster III and IV had maximum number of 10 and 6 genotypes each followed by clusters I with 3 genotypes. Clusters II consists of 2 genotypes while clusters V was a solitary one. The accessions were ranked using the six main growth parameters *i.e.* plant height (m), bark thickness (mm), annual girth (cm) in the seventh year and fourteenth year, annual girth increment (cm a^{-1}) over seven years and winter girth increment (cm a^{-1}) over seven years for overall performance. The rank sum values ranged from 12 to 125 with a general mean of 68 (Table 3) and top 30% vigorous accessions could be identified in this study.

Discussion

In the present study, the growth behavior of different wild accessions under the environmental conditions of Nagrakata, a sub-Himalayan region of India was investigated. The genotypes exhibited highly significant clonal differences (P = 0.05) for all the six quantitative traits studied. The range and population mean values in comparison with the check clone for the six growth characters in the mature growth phase are depicted in Table 1 and discussed under three major grouping characters/heads. An insight into the magnitude of variability present in crop species is of utmost importance, as it provides the basis for effective selection.

Plant Growth Traits

Biological growth, which is regulated by genetics and environment, changes continuously with age, leading to an increase in volume, size, or shape of organism and *Hevea* plants are no exception to this. Apart from rubber yield, the other important aim is stand stability. The useful stand density, i.e. the number of trees tapped, tend to decrease with time in plantations. This is mostly due to damage caused by wind, uprooting and, especially trunk snapping. Wind damage could be linked to the shape of the trees, rather than to the physical properties of the wood. Plant height, also provides interesting architectural features. Wind susceptible architectures

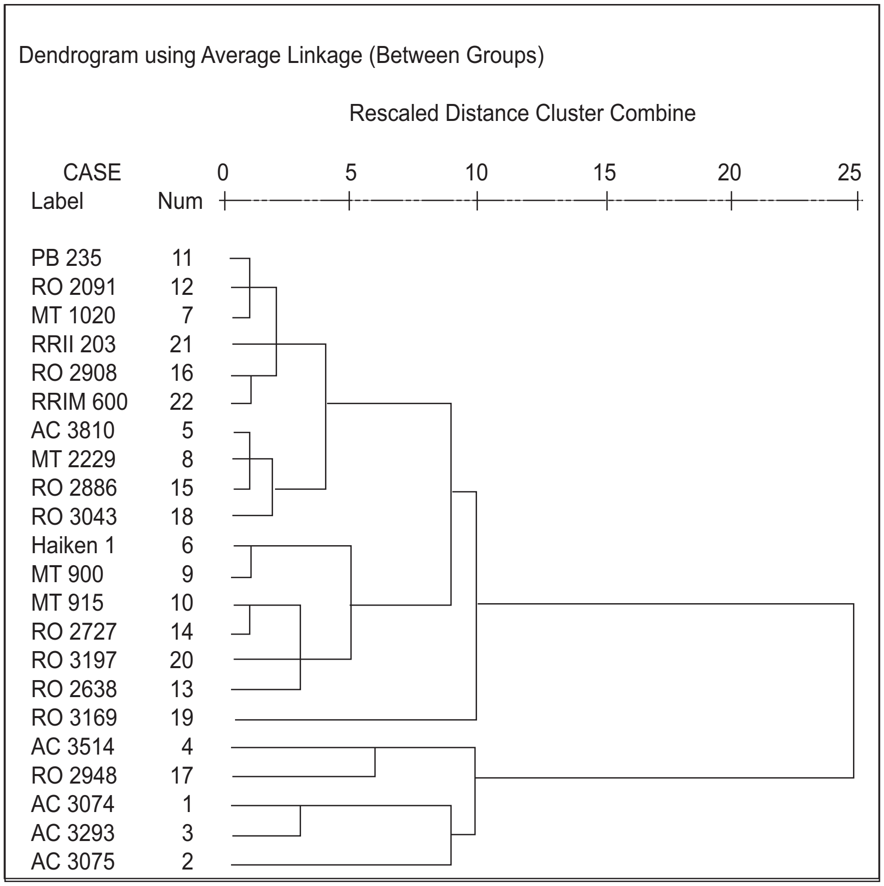

Fig. 2. Genetic distances among the wild *Hevea* germplasm and modern clones

Table 2. Distribution of 22 *Hevea* genotypes in five different clusters

Cluster No.	No. of genotypes	Name of genotype
I	3	AC 3074, AC 3075, AC 3293
II	2	AC 3514, RO 2948
III	10	AC 3810, MT 1020, MT 2229, RO2901, RO 2886, RO 2908, RO 3043, RRII 203, PB 235, RRIM 600
IV	6	Haiken 1, MT 900, MT 915, RO2638, RO 2727, RO 3197
V	1	RO 3169

are characterized by a greater trunk-crown imbalance in rubber. The wild accession RO 2727 (19.62 m) recorded the tallest plants followed by MT 915 and MT 900 (Table 1). While the popular check clones such as Chinese Haiken 1 and Malaysian RRIM 600 were extremely tall in height, and excellent in bark thickness with vigourous growth habit.

One of the main factors in the successful establishment of *Hevea* culture in the Far East was the discovery of the proper method of tapping, latex was extracted from the tree by means of cuts made through the bark. Bark consumption and thick bark is important because it minimizes wounding incidence, which is known to effect yield productivity on latter panels (Goncalves *et al*., 2006). Yield was found to be positively correlated with bark thickness and Girth. The trees of the accession MT 900 have highest bark thickness of 5 mm which is superior to the check clone Haiken 1 and RRIM 600. Bark thickness in *Hevea* is a clonal characteristics (Licy and Premakumari, 1988). Goncalves (1982) found in wild mother trees from 10 sites, pronounced difference in bark thickness between fast growing and slow growing trees in the Amazon valley basin. Similar wide variations in the bark thickness was also reported by Azwar *et al*., (1995) and Rao *et al*. (1999). Wide variations in the wild *Hevea* germplasm with reference to plant height and growth traits are reported in the traditional rubber growing regions in India (Rao *et al*., 1999; 2005; 2011; Rao and Varghese, 2011; Rao and Reghu, 2012 and Rao *et al*., 2013a).

In general, yield and vigour in *Hevea* are hardly separable (Simmonds, 1989). Girth and rate of girth increase are also used in experimental work to assess the growth performance of new planting materials. Even though in the seventh year after planting RO 2727 (53.12 cm) recorded the highest plant girth, MT 915 (92.32 cm) over took the growth of other genotypes in the fourteenth year after planting, and reached to the top position (Table 1). Girth values of this accession even significantly superior to the best check clone Haiken 1 (82.56 cm). Growth vigour in rubber tree is genetically controlled and there is a marked clonal variation with regard to girth increment under tapping and its effect on yield (Ferwerda, 1969).

The growth performance of a clone/accession can also be assessed on the basis of annual girth increment (GI) or growth rate and girth increment is seen around the year in the rubber plants (Rao and Kole, 2016). The genotype MT 915 recorded the highest girth increment (5.61 cm a^{-1}) over seven years, in comparison with the check clones RRIM 600 (2.75 cm a^{-1}) and Haiken 1 (4.65 cm a^{-1}). It is very important to note that the superiority observed in the mature phase of these accessions is in conformity with the best performance in the previous immature phase as well (Rao and Kole, 2016). Wide variations in the wild *Hevea* germplasm with respect to certain growth traits and growth-rate are reported in the traditional rubber growing regions in India (Rao *et al*., 2011; Rao and Varghese, 2011; Rao and Reghu, 2012 and Rao *et al*., 2013a) as well as in the non-traditional regions (Rao *et al*., 2006; Krishan *et al*., 2011; Rao and Kole, 2016). In general, during the non-winter season (Weather Regime I), all the wild accessions and clones under study attained maximum level of growth, as compared to the winter season (Weather Regime II).

Breeding experiments on *Hevea* always focus on genotypes with better performance in the cold climate, so as to identify the location specific clones which could adapt to low temperatures. In rubber, the threshold temperature for growth increment is believed to be in the range of 20º C (Jiang, 1988). Photosynthesis is impaired at 10º C (Huang and Zheng, 1983). The minimum temperature is as low as 5º C during December to January and the low winter temperature is conspicuous in the Nagrakata region as compared to the other rubber growing NE areas of India. So, low temperature is one of the major bottlenecks for rubber production in this region. It was reported that long durations of low temperatures affects the productivity and normal growth of *Hevea* plant (Alam *et al*., 2005). Among various stress factors, low temperatures in the winter, have strongly affected growth, development and latex production of rubber trees in South central China (Priyadarshan *et al*., 2005) and in the Northern part of Vietnam (Tuy *et al*., 2012).

The winter growth is indicative of a genotype's ability to continue its metabolic functions under stress and hence could be an indication of its tolerance to cold stress in the current study. Winter girth increment (cm/year) over seven years ranged from 0.34 cm a^{-1} (AC 3074) to 1.05 cm a^{-1} (MT 915). Certain tolerant wild accessions, namely MT 915, topped in winter girth increment rate (1.05 cm a^{-1}) closely followed by RO 2727 (0.95 cm a^{-1}), RO 3197 (0.85 cm a^{-1}) and MT 914 (0.80 cm a^{-1}) are on par with the check clones. The check clone of Malaysia- RRIM 600 and China-Haiken 1, which also reached higher growth, recorded a winter girth increment of 0.65 cm and 0.85 cm/year, respectively. These accessions which have reached high growth in the seventh year, not only performed better in low-temperature during winter period, but also showed a higher overall growth, indicating adaptability to cold stress. Similar observations were made in some wild *Hevea* accessions at immature phase (Rao and Kole, 2016). In the current study, growth of accessions during winter period was low as compared to the non-winter period and this is in agreement with an earlier report (Mondal *et al*., 1999; Das *et al*., 2011; Rao and Kole, 2016). Three wild accessions such as AC 3074, AC 3293, and AC 3075 showed negligible growth, an indication of high susceptibility to winter stress. Hence, winter growth is the critical criteria for the real assessment of a clone in terms of cold tolerance.

Genetic Diversity

The importance of cluster analysis to determine the extent of variability was reported earlier (Mahalanobis, 1936). D^2 statistics has been utilized extensively for estimating genetic diversity in a number of crop plants with diverse breeding systems (Murty and Arunachalam, 1966). Genetic diversity in germplasm lines is generally considered as an important criterion in deciding appropriate plant breeding methods for crop improvement. Precise information on the nature and magnitude of genetic diversity in the population helps the plant breeder in choosing the diverse parents for purposeful hybridization and to maximize expression of heterosis (Arunachalam, 1981; Samsuddin, 1985).

The 22 *Hevea* genotypes were grouped into 5 clusters (Figure 2) and the distribution pattern of genotypes in various clusters reflected the considerable genetic variability/diversity present in the population under study (Table 2). There were 4 multiple-genotype clusters, while one cluster was solitary in nature. Cluster III and IV had maximum number of 10 and 6 genotypes each followed by clusters I with 3 genotypes from Acre provenance. All the three Acre provenance accessions of clusters I were poor performers for most of the growth traits. Clusters II consists of 2 genotypes from each of Acre and Rondonia provenance, while cluster V was a solitary one from Rondonia provenance. Cluster III had maximum number of diverse genotypes from all three provenances (Acre, Rondonia and Mato Grosso) of Brazil and modern clones (RRIM 600, PB 235 and RRII 203) developed from Far East includes Malaysia and India with vigorous growth traits. Cluster IV had second largest in number, comprising of genotypes from two Brazilian provenances (Rondonia and Mato Grosso) and a modern cold tolerant Chinese clone Haiken 1 with highly vigorous growth traits. This indicates that the genetic uniqueness among different ecotypes of *Hevea brasiliensis* complex.

Murty and Arunachalam (1966) have opined that hybridization programmes should be formulated in such a way that the parents belonging to different clusters with maximum divergence should be utilized to get desirable transgressive segregants. The genotypes from the cluster III and IV with more plant height, bark thickness, and other growth attributes could be utilized in hybridization programme for getting desirable segregants and high heterotic response. Crossing between widely distinct heterozygous genotypes of rubber exposes very few common recessives, so that F_1 vigour is markedly enhanced above the average, resulting in heterosis (Simmonds, 1989). The high recovery of heterotic progeny from the parents of wide divergence in *Hevea* was reported earlier (Licy *et al*., 1992; Mydin and Gireesh, 20l6). Moreover, the identification and availability of specific genotypes for use in breeding programmes assumes much significance, since wide array of diverse wild accessions and species of *Hevea* are available only in the Amazon forests of Brazil, the centre of diversity of the genus.

It was observed that the genotypes of different geographical origin were grouped together and the genotypes with same origin were included in different clusters (Table 2). The clustering pattern of the accessions showed that geographical diversity was not related with genetic diversity. This lack of correspondence between genetic and geographical diversity has also been reported in other crops (Sridhar *et al*., 2002; Tyagi and Sethi, 2011), as well as in *Hevea* (Markose, 1984; Mydin, 1992; Abraham, 2001; Rao *et al*., 2005).

Performance

By utilizing the six main growth parameters *i.e*. plant height (m), bark thickness (mm), annual girth (cm) in the seventh year and fourteenth year, annual girth increment (cm/year) over seven years and winter girth increment (cm/year) over seven years, individual performance of each accession was assessed for overall performance (Table 3). The top 30% vigorous accessions such as RO 2727, MT 915, RO 2638, RO 3197, MT 900, RO 3169, MT 2229, RO 3043, MT 1020 and AC 3810 could be identified as potentially superior for various growth traits. Balasimha *et al*. (1988) in Cocoa and Mercy (2001),

Table 3. Ranking of wild *Hevea* accessions and clones based on growth parameters

Accession/ Clone	Rank sum	Rank
RO 2727	125	1
MT 915	122	2
RO 2638	100	3
RO 3197	100	3
Haiken 1	94	5
MT 900	93	6
RO 3169	83	7
MT 2229	79	8
RO 3043	76	9
PB 235	74	10
MT 1020	73	11
RRII 203	72	12
AC 3810	68	13
RO 2901	68	13
RRIM 600	53	15
RO 2886	47	16
RO 2908	43	17
AC 3514	37	18
AC 3075	36	19
RO 2948	27	20
AC 3293	14	21
AC 3074	12	22
General mean 68		

Rao *et al*. (2006, 2011), Rao and Varghese (2011), Rao and Reghu (2012) and Rao *et al*. (2013a) also reported similar rankings in wild *Hevea* accessions, respectively while evaluating the Brazilian germplasm in India.

The high vigour of Rondonian genotypes may be due to hybrid vigour since reports on the probable hybrids of *H. brasiliensis* and *H. guianensis* in Costa Marques of Rondonia provenance (Anon. 1982) are available. Chevalier (1988) and Krishan *et al*. (2010) also reported that the intermediate position of Rondonian genotypes compared to the other two provenances. Better performance of accessions from Mato Grosso provenance also in the current study was in accordance with the earlier reports (Clement-Damange *et al*., 1990; Rao *et al*., 1999; Abraham, 2001; Krishan *et al*., 2010; Rao *et al*., 2013b). Genotypes from Acre provenance performed poorly for most of the growth traits, which is in accordance with the earlier reports.

Conclusion

Clustering of genotypes will be useful to the *Hevea* breeder in assessing the genotypes for vigour and arranging them into groups with similar growth patterns for selection. The present study confirmed the presence of wide variability in the germplasm for various growth traits. A potential group of ten accessions were identified, majority from Mato Grosso and Rondonia provenance *viz*., RO 2727, MT 915, RO 2638, RO 3197, MT 900, RO 3169, MT 2229, RO 3043, MT 1020 and AC 3810, ranked top in the cold prone sub-Himalayan region. Attainment of highest mean girth in the early mature period, which led to early tappable stage of these accessions, could be explained by its high growth rate when compared with the other wild accessions. Apparently, these genotypes also possess high timber potential. In fast growing timber species, high girth and high crotch height are proportional to high wood volume and the beneficial influence of fast growth rate on volumetric growth of tree was well known. Good growth is important in sustaining yield in high yielding clones and also reducing wind damage losses through trunk snap (Tan, 1987).

The superior performance for growth indicated that these ecotypes may be physiologically better adapted to the subtropical climate. The superiority of these selections may be explained by their inherent genetic potential and the genetic variability among accessions may be due to factors like heterogenity, selection pressure under diverse environments, genetic drift and/or geographical origin. Moreover, ecological differences between these three states/provenances (AC, RO, MT) offered chances of selection of materials suitable for diverse situations. These selected ecotypes were useful to increase the growth rate in elite clones, which leads to early maturity of the crop. Since they are genetically diverse from the cultivated clones, transgressive segregation and heterosis can be expected on crossing these accessions with elite Wickham cultivars. These ecotypes/selections possess highly potential new genes/alleles for growth and adaptation, useful in the development of cold-tolerant clones for these stress prone regions to mitigate changing climate and also in broadening the genetic base of the present-day cultivated rubber.

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