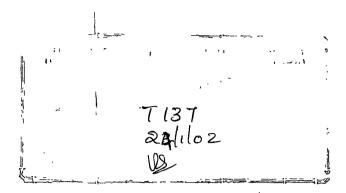# MULTIVARIATE ANALYSIS OF YOUNG AND MATURE CLONES IN PARA RUBBER (*Hevea brasiliensis* Muell. Arg.)

By

JAYASHREE MADHAVAN

THESIS
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DECLARATION

I hereby declare that this thesis entitled "**Multivariate analysis** of young and mature clones in para rubber (*Hevea brasiliensis* **Muell.Arg.**)" is a bona fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

JAYASHREE MADHAVAN

Vellayani,
11.06.2001.

CERTIFICATE

Certified that this thesis entitled **"Multivariate analysis of young and mature clones in para rubber (*Hevea brasiliensis* Muell.Arg.)"** is a record of research work done independently by **Smt. JAYASHREE MADHAVAN** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellayani,
11.06.2001.

Dr. S. G. SREEKUMAR
(Chairman, Advisory Committee)
Associate Professor,
Department of Plant Breeding and Genetics
College of Agriculture,
Vellayani, Thiruvananthapuram.

APPROVED BY

CHAIRMAN

        Dr. S.G.SREEKUMAR

CO- CHAIRMAN

        Dr. P.J.GEORGE

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        Dr. P. MANIKANTAN NAIR

        Dr. P. SARASWATHI

        Dr. K. RAJMOHAN

EXTERNAL EXAMINER

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INTRODUCTION

1. INTRODUCTION

Natural rubber, one of the most economically important agricultural commodities in India, is obtained almost exclusively from *Hevea brasiliensis* (Premakumari and Saraswathyamma, 2000), a tree indigenous to the tropical Amazon forests. A produce almost solely gathered by native South American tribals from the forests till the 1870s, it was first introduced into south east Asia for commercial cultivation only in 1876 by Sir Henry Wickham. *Hevea brasiliensis* is therefore one of the youngest of the major domesticated crops in the world. The original genetic material, referred to as the 'Wickham gene pool', was collected from a very small area near the confluence of the Tapajos and Amazon rivers in Brazil, and represents only a minuscule of the entire geographical range of distribution of the species in South America (Schultes, 1977). This stock forms the genetic base of most of the present day plantations in the east.

From the initial yields of around 200-300 kg ha^{-1} yr^{-1} in seedling plantations in the first few decades (Panikkar *et al.*, 1980), the production potential of the crop has been increased ten-fold to about 3500 kg ha^{-1} yr^{-1} in experimental holdings (Licy *et al.*, 1997) within a short span of 70 years. This is a remarkable achievement considering that the crop is a perennial tree with a long breeding cycle. The reason for this success has been partly the perfection of the budding technique which enabled planters to grow high yielding clones, and partly the great

strides made in the genetic improvement of the crop through systematic breeding and selection. However, a slowing down in genetic advance has been observed in recent years compared to the early phases of breeding, which has been attributed mainly to the narrowing down of the genetic base of rubber (Tan, 1987; Simmonds, 1989). The perennial nature of the crop, seasonal nature of flowering, low fruit set, long breeding and selection cycle of about 30 years, the heterozygous nature of the species, and lack of fully reliable early prediction parameters are serious constraints in *Hevea* breeding programmes. A wide gap still exists between the theoretical yield potential of 9.5 t.ha^{-1} (Templeton, 1969) and the actual productivity of 1.6 t ha^{-1} at the national level (Rubber Board, 2000).

Hevea is a cross pollinated crop. Introduction of proven cultivars from other countries, 'ortet selection' or selection of superior or 'plus trees' from seedling populations, and hybridization followed by clonal selection are some of the most important crop improvement methods in *Hevea*. The breeding method conventionally followed involves choice of parents, hybridization, selection of superior seedlings and their vegetative multiplication, evaluation, selection of superior clones and testing of clones for adaptation under different agroclimatic conditions. Generationwise assortative mating (GAM), in which the best clones are crossed in each cycle, is usually adopted in rubber. Another popular method is to make a few pairs of crosses, and to repeat those that produce superior types (Saraswathyamma and George, 1993). Evaluation of clones resultant from the crosses takes place in four stages. The first involves selection of two year old seedlings from crosses, usually on the basis of girth, number of latex vessel rings and testtap yield. Selections from these are put through small scale, large scale and block trials, with a reduction in the

number of clones in each successive stage (RRII, 2000). The perennial nature and long juvenile phase of the crop necessitates large area, manpower and time for the proper evaluation and selection of desirable clones. However, increasing economic constraints have prompted breeders to attempt to reduce this selection period, for which identification of early selection parameters seems indispensable.

Commercial exploitation of the tree begins when it is five to six years old and continues for the next twenty years during which at least four panels on the trunk are tapped – BO-1, BO-2 (the first and second panels of virgin bark), BI-1 and BI-2 (first and second panels of renewed bark). Each panel is tapped for about five years. Rubber yield that is obtained on tapping is a manifestation of various morphological, anatomical, physiological and biochemical characters of a tree, which are ultimately reflected in the volume of latex obtained on tapping and the quantum of rubber it contains (Pollinere, 1966). Assimilates from the source (leaves) are used for growth in the immature phase, and partitioned between the two sinks - girth increment and latex regeneration, once tapping commences. Rubber yield on any tapping day was defined by Sethuraj (1981) as a function of the average initial flow rate per cm of tapping cut during the first five minutes of tapping, the length of the cut, the dry rubber content of the latex and the rapidity of 'plugging' of the cut, as defined by the plugging index. The morphological, anatomical, physiological and biochemical subcomponents of these major components were in turn identified by Sethuraj (1992) as number of latex vessel rows, density, diameter and other anatomical features of latex vessels and turgor pressure at the time of tapping (influencing initial flow rate), average annual biomass increment which is a function of photosynthesis and translocation, as well as the

partitioning coefficient between growth and latex production (affecting girth of the tree and hence the length of tapping panel cut), biosynthetic capacity for polyisoprene synthesis (reflected in the dry rubber content) and stability of the rubber and lutoid particles, mineral composition of latex, etc. (influencing the rate of formation of flocs leading to plugging). Previous studies have usually dealt with only a few components at a time. However, yield is the result of a combination of all these factors, and hence a comprehensive study involving all these components simultaneously was envisaged in order to examine the relative importance of these factors during the immature and mature phases of the crop. Moreover, most of the studies to date have concentrated on the performance of the clones in the first panel of tapping, and a few on the second and third panels. Very little information is available on the performance of the crop for yield associated traits and the *inter se* relationships in the later stages of exploitation, even though the plant is economically exploited at this stage too. Many of the source and sink parameters vary with age as well as clone. There are reports that accountability of different sets of major factors in controlling rubber yield of *Hevea* clones vary at different growth phases (Bryce and Campbell, 1917; Gomez *et al.*, 1972; Ho, 1976). Hence, an understanding of these traits and their interrelationships in each of the four panels and in the immature phase, as well as the immature-mature correlations, will be extremely useful in assessing the overall yielding behaviour of the clones and will lead to a more judicious exploitation of these traits. With this in view, the present study was taken up in 25 Wickham clones in two stages of growth - the immature phase (first two years of growth) and the mature phase (the BI-2 panel) using a number of source and sink characters, in order to

- estimate the genetic variability for yield and other associated traits in the immature and mature phases

- estimate the genetic parameters of different attributes in the two phases

- study the direct and indirect effects of the various causal factors on yield in the two stages of growth

- examine the clustering patterns in young and mature clones

- determine the meaningful factors to explain the inter-correlations among given number of variables

- rank clones in the two stages, using discriminant function analysis, in order to see if the superiority in the young clones has been maintained in the mature phase also

- work out simple correlations of the young clones with the corresponding ones in the mature phase to identify the stable characters

- examine the possibility of prediction of mature yield of clones based on the immature attributes.

REVIEW OF
LITERATURE

2. REVIEW OF LITERATURE

Rubber yield is a very complex trait governed by a large number of major and minor components involving genetic and environmental factors and their interactions (Paardekooper, 1964; Jayasekara *et al.*, 1977). While there have been a number of studies on the variability and correlations for yield and yield contributing factors in rubber, path analyses and genetic divergen ve studies are scanty. Genetic studies on the biochemical parameters are also relatively few. The work carried out so far on all these aspects in rubber and similar studies in other crops are reviewed here.

2.1 Clonal variability for yield and associated traits

Varietal improvement in any crop depends on the extent of variability in the population. Considerable variablity has been recorded for both source and sink components in *Hevea*. The canopy of *Hevea*, as in any other crop, forms the source of photosynthates. Hence it is logical to expect that variability for leaf number, size, thickness, chlorophyll content and other anatomical parameters, will play a role in the total assimilatory capacity of the tree, which will ultimately be reflected in its yield. Duarte and Adams (1972) showed that leaf number and size in beans have highly significant effects upon yield. In coconut too, variability for leaf number of young plants and its correlation with yield have been recorded

(Liyanage, 1967; Nampoothiri *et al.*, 1975; Satyabalan *et al.*, 1975). Variations in leaf photosynthetic rate per unit area in rice and wheat have been correlated positively with leaf thickness (Ishii, 1998). In rubber, Senanayake and Samaranayake (1970) observed intraspecific variation for stomatal density per unit area in 25 clones. Gomez and Hamzah (1980) concluded that stomatal density, leaf thickness and palisade layer thickness were clonal characteristics. Clonal variations for stomatal density, cuticle thickness and leaf midrib width in ten clones were observed by Premakumari (1992). Abraham *et al.* (1992) and Madhavan *et al.* (1993) reported variation for leaf size and specific leaf weight in wild germplasm of *Hevea*.

Assimilates from the source are used for growth in the immature period of the tree. Once tapping commences, these assimilates are partitioned between girth increment and latex regeneration. According to Simmonds (1989), yield and vigour are hardly separable. Vigorous growth of the tree in the juvenile phase enables early commencement of tapping. It is also involved in increasing the laticifer area on tapping. However, under tapping, there is a decline in the girth increment rate due the diversion of assimilates for latex formation. The breeder's task therefore is to maximize latex yield in a tree which is still growing vigourously enough to sustain a rising yield trend for many years (Templeton, 1969; Wycherley, 1975;1976). Clonal variability has been recorded for girth and girth increment under tapping (Ramaer, 1929; Napitapulu, 1973; Ho, 1976; Mydin, 1992; Licy, 1997). However, Premakumari (1992) obtained clonal variation only for girth, and not for girth increment under tapping. Clonal variability for girth and girth increment in the immature phase has been reported by Licy *et al.* (1992) and Varghese *et al.* (1993; 1996), though Nazeer *et al.* (1992) did not obtain

significant variability for either girth in the third and fourth years of growth, or for girth increment in the same period.

Latex in *Hevea* is present in a system of vessels found in almost all parts of the tree except wood (Bobilioff, 1923). However, it is the latex in the bark which is harvested during tapping. The laticiferous system is both the storage region from which latex is released on tapping and the site of the final stages in rubber synthesis in *Hevea brasiliensis* (Dickenson, 1965; Southorn, 1966; Gomez, 1966). Its structure is therefore of direct relevance to productivity. Riches and Gooding (1952) have given a three dimensional representation of the structural organization of the bark of *Hevea*. Latex vessels are formed in longitudinal concentric mantles (called latex vessel rings) in the bark around the central trunk, sandwiched between rows of other phloem cells (the term 'bark' is used in popular sense and refers to all tissue outside the cambium). During growth, new rings are initiated by the cambium and the older ones are pushed outwards. The latex vessels within a layer are connected by anastomoses, while there are few or no connections between the latex vessels of the different layers. Variability for bark thickness, number of latex vessel rows, density and diameter of latex vessels will therefore be reflected in the quantum of laticiferous tissue. Gomez *et al.* (1972) formulated an index called the laticifer area index to quantify the laticiferous tissue in terms of crosssectional area that is being exploited at a given time. This index is believed to include all the major quantitative structural factors involved in latex production-girth, number of latex vessel rows, density and diameter of latex vessels. Bark thickness and number of latex vessel rings are reported to be clonal characters (Vischer, 1921, 1922; Bobilioff, 1923; Sanderson and Sutcliffe, 1929; Markose,

1984; Licy and Premakumari, 1988). Similar findings were made in the immature phase (Ho *et al.,* 1973; Narayanan *et al.,* 1974; Licy, 1997). However, Nazeer *et al.* (1992) obtained no significant variation for bark thickness and number of latex vessel rows in four year old plants planted in the Konkan region, which is a drought prone area. Laticifer diameter and density per unit length of ring were also found to be clonal characters (Gomez *et al.,* 1972; Premakumari *et al.,* 1985). Premkumari (1992) observed that number of latex vessel rows, density and diameter of latex vessels, girth and laticifer area index were clonal characters, but obtained no clonal variation for bark thickness.

During tapping, thin shavings of bark are removed along the tapping cut, which results in the opening of the vessels (Ridley, 1897). The latex in the vessels immediately begins to exude out and is collected. The rate of flow decreases after a period of time and ultimately stops. This is due to an inherent clotting mechanism within the vessels (Southorn, 1966) which is responsible for the plugging of the open ends of the vessels, in a manner akin to the clotting of blood in humans. Plugging occurs due to the flocculation of rubber particles, which is brought about by the bursting of the lutoid particles in the latex (Nair, 2000). Milford *et al.* (1969) proposed an index called the 'plugging index' to measure the rate of plugging in trees. Trees with a lower plugging index have a longer duration of flow and hence higher latex volume yield. Higher initial flow rate can also result in the lowering of the plugging index (Sethuraj *et al.,* 1974). The final yield of a tree therefore is a result of the final volume of latex (which in turn depends on the flow rate and plugging index) and its dry rubber content. Field latex usually contains 30 to 45 per cent rubber (Sethuraj and Nair, 1980). Plugging index has been

established as a clonal character (Sethuraj, 1968; Milford *et al.*, 1969). Saraswathyamma and Sethuraj (1975) and Sethuraj (1977) reported clonal variations for latex flow traits. Markose (1984), Mydin (1992), Premakumari (1992) and Licy (1997) also reported initial flow rate, plugging index and dry rubber content as clonal characteristics.

Various biochemical componenets of latex have also been found to influence latex yield flow and regeneration. Latex is a hydrosol and rubber occurs as discrete, dispersed particles (Bonner and Galston, 1947). Besides rubber, latex contains carbohydrates, proteins, resins, inorganic salts, *etc.* (Archer *et al.*, 1963). The total solids content (TSC), thiols, inorganic phosphorous, magnesium, sucrose, bursting index (BI), total acid phosphatase and latex pH have been identified as 'latex diagnosis' parameters which could be used to find out the factors involved in latex flow and regeneration (Bricard and Nicolas, 1989). Latex pH is involved in the regulation of several key enzymes, while lutoid BI affects plugging rate and hence flow of latex. These two parameters were established to be clonal characters by Esbach *et al.* (1984) and Jacob *et al.* (1986). TSC is an indicator of the *in situ* latex regeneration (Esbach *et al.*, 1984; Prevot *et al.*, 1984); however, very high TSC can decrease latex volume yield by increasing viscosity and hindering flow (Milford *et al.*, 1969; Brozozowska-Hanower *et al.*, 1979). Thiol groups (mainly glutathione) act as protectors of lutoid membranes by scavenging free radicals produced during cell metabolism and also activate key enzymes (Esbach *et al.*, 1984; Jacob *et al.*, 1989). Inorganic phosphorous is required for active metabolism (Jacob, 1970) and also contributes to the stability of latex (Sherief and Sethuraj, 1978). Sucrose is the precursor of the rubber molecule. However,

sucrose content is difficult to interpret as high sucrose could indicate either good supply to the laticifers or poor utilization (Tupy and Primot, 1976; Prevot *et al.*, 1986). Magnesium in the latex plays two opposing roles. It is necessary for the activation of certain key cytosol enzymes (Skilleter and Kekwick, 1971; Chrestin *et al.*, 1985) but also inhibits some others like invertase (Tupy and Primot, 1976). Magnesium in the lutoid serum also causes destabilization and coagulation of latex, thus stopping flow (Southorn and Yip, 1968). Bricard and Nicolas (1989) defined the conditions that are, *a priori*, favourable for high production: an active metabolism associated with 1) high inorganic phosphorous, thiols, total acid phosphatase and pH, 2) good sugar supply capacity 3) stable latex characterized by low magnesium and bursting index and high inorganic phosphorous and thiol content, 4) moderate TSC to ensure good flow. They obtained significant clonal variability for all the eight parameters in the juvenile phase in four trials, while clonal differences for pH and thiol groups became nonsignificant in some of the trials at the adult phase. Esbach *et al.* (1983; 1984), Jacob *et al.*(1989) and Licy (1997) also reported clonal variability for these parameters.

2.2. Genetic parameters

Information on the magnitude of genetic parameters like phenotypic and genotypic coefficients of variation, heritability and expected genetic advance under selection for yield and its components is essential in crop improvement programmes. Most of the characters of economic value to plant breeders are quantitative in nature (Falconer, 1960). Such traits show continuous variation and involve a number of genes whose individual effects are small. The theoretical basis of

quantitative or biometrical genetics, which deals with the analysis and interpretation of such variability, was established by the works of Fisher (1918), Wright (1921a) and Haldene (summarized in 1932).

An estimate of the genotypic variability for a metric character, obtained by partitioning the directly measurable total or phenotypic variance into its genetic and environmental components, is essential as it is *this* genotypic variability that is exploited by breeders. However, as the various traits are measured in different units, their variances cannot be compared directly. Expressing these estimates in terms of their coefficients of variation (by dividing the standard deviations of the traits by their respective means) renders them independent of the unit of measurement and hence amenable to comparison. The estimates of the coefficients of genotypic and phenotypic variability will give an idea of the relative magnitude of the diversity for the different traits. While selection acts on the genetic differences between individuals, its effectiveness depends on the heritability for the particular trait (Allard, 1960). Heritability is the proportion of the phenotypic variation that is due to its genetic makeup, and hence can be transmitted to the next generation. Lush (1937) differentiated two types of heritability - heritability in the broad sense ($H^2_{b.s.}$), and that in the narrow sense ($H^2_{n.s}$). While the former refers to the ratio of the total genotypic variance to its phenotypic variance, the latter is more specific and is the ratio of its additive genetic variance to the total phenotypic variance. High heritability estimates imply low influence of environment in the expression of the particular character. Genetic advance gives an estimate of the genetic gain that can be expected for a particular trait in the next generation, under a given intensity of selection. Burton and de Vane (1953) and Johnson *et al.* (1955) estimated the

genetic advance for a character as a product of its heritability, phenotypic standard deviation and selection differential for a given selection intensity. High genetic variability coupled with high heritability estimates are required for greater genetic advance. The earlier work on genetic parameters for different characters contributing to yield is presented below.

Simmonds (1968), using data on the progenies of a 1937 hand pollination programme (planted using North Carolina Design II), concluded that yield inheritance is mainly additive. Nga and Subramaniam (1974) obtained high genetic variance for yield and girth in the same progeny and found that additive gene action accounted for all the genetic variance observed for girth and yield. Narrow sense heritability estimates were around 50 per cent for these two traits. Gilbert et al. (1973) also concluded from progeny analysis of rubber that the inheritance of yield and girth was additive.

Tan et al. (1975) examined the contribution of male and female variances separately in a large number of progenies of different provenences for yield, girth, girth increment, and thickness of virgin and renewed bark, and reported that heritability based on female variance ratios were generally higher than those based on male variance ratios for most of the characters studied. They suggested the existence of dominance variance also in rubber. Tan (1979) obtained heritability estimates of 0.29 to 0.47 for yield over five years, 0.17 to 0.46 for virgin bark thickness and 0.27 to 0.28 for renewed bark thickness for progeny families of a single pair mating design.

Low broad sense heritability estimates were obtained by Liu et al. (1980) for yield while those for dry rubber content and plugging index were high.

Heritability estimates for girth and latex flow indices were medium. They found that genetic advance based on selection for yield alone was low, and suggested that this should be combined with girth and flow indices. Liang *et al.* (1980) reported a heritability of 0.42 for yield in seedling progenies of eight cross combinations. Low estimates of heritability for yield (21%), girth (2%), virgin and renewed bark thickness (30 and 29% respectively) were also reported from a single pair mating design study in Nigeria (RRIN, 1981). Alika (1982) obtained only a 0.21 heritability estimate for yield over four years. Alika and Onokpise (1982) observed negligible genotypic variability for girth, while heritability estimates were 0.30 for bark thickness, and 0.23, 0.24, 0.16 and 0.02 for dry rubber yield in the first four years of tapping.

High genotypic and phenotypic variability for dry rubber yield, volume of latex and number of latex vessel rows was obtained by Markose (1984), while bark thickness, girth and dry rubber content had a comparatively low GCV. Broad sense heritability was high for dry rubber yield (0.82), volume of latex (0.77), number of latex vessel rows (0.93) and virgin bark thickness (0.75). Alika (1985) reported a low genetic gain of 10.87 per cent over mean for yield at a selection intensity of 10 per cent. Premakumari *et al.* (1987) obtained low to medium PCV and GCV values for six anatomical parameters. All the traits except ray width exhibited high heritability. However, except for ray height, genetic advance for all the other traits was low or moderate, implying the involvement of non additive gene action in their expression. Liang *et al.* (1988) observed high variability in 14 clones for girth, girth increment, latex volume, dry rubber content and dry rubber yield. They also obtained a heritability of 0.89 for girth . Boock *et al.* (1995)

examined genetic variability, heritability and gain for yield and morphological characters in young progenies of rubber.

High genetic variability was reported by Mydin (1992) in a population of 40 clones of different provenences for dry rubber yield, latex flow rate and volume of latex. The variance for girth, dry rubber content, chlorophyll content and bark thickness was low. Similar results were obtained by Licy (1997), who reported high genetic variance in the progenies of a biparental cross for dry rubber yield, latex flow rate, volume of latex and girth increment rate. Low variance for girth, dry rubber content and bark thickness and moderate variance for number of latex vessel rows were observed. High genetic variance was also obtained for the latex biochemical parameters thiols, sucrose, magnesium and inorganic phosphorous (40.10 - 22.65%), while that for total solids content was only 6.16 per cent.

Moderate levels of genetic variability for yield, latex volume, initial flow rate and plugging index were recorded by Premakumari (1992) compared to the relatively higher levels of GCV for number of latex vessel rows and laticifer area index. Girth, density and diameter of latex vessels as well as dry rubber content showed only low genetic variability. However, all these parameters had high heritability. Density and diameter of latex vessels, girth and dry rubber content exhibited low genetic advance, initial flow rate and plugging index moderate, while dry rubber yield, volume of latex number of latex vessel rows and laticifer area index showed high estimates of genetic advance.

Mydin (1992) obtained moderate to high heritability coupled with high genetic advance for dry rubber yield, rate of latex flow, volume of latex, girth

increment under tapping, and average annual plugging index. Dry rubber content had high heritability with low genetic advance. Girth as well as virgin and renewed bark thickness had moderate to high heritability levels with low genetic advance. Chlorophyll content had very low estimates for all the four genetic parameters.

High heritability ranging from 48.39 to 79.46 per cent for yield, rate of latex flow, volume of latex, plugging index, number of latex vessel rows, dry rubber content and girth increment were reported by Licy (1997). Virgin bark thickness had the lowest heritability of 21.62 per cent. High heritability was also seen for the latex biochemical parameters thiols, sucrose, inorganic phosphorous and magnesium three years after opening. Genetic advance was high for yield, latex volume, initial flow rate, girth increment and biochemical traits except total solid content (71.19-34.75%), while number of latex vessel rows and plugging index had moderate values(35.55-23.12%). Dry rubber content, renewed and virgin bark thickness, girth and total solid content had low estimates of genetic advance (10.05-3.69%).

2.3 Interrelationships among characters

As yield is controlled by a number of morphological, structural and physiological parameters and is greatly influenced by environment, direct selection for yield is usually less effective than selection based on its component characters (Kronstad and Foote, 1964). Hence a knowledge of the correlations between yield and various traits affecting it is a prerequisite for any breeding programme. Selection for some of the contributing traits will result in simultaneous improvement

of the correlated traits including yield. Galton (1889) first proposed the concept of correlation, which was later elaborated by Fisher (1918). Burton (1952) explained the method of deriving the genotypic, phenotypic and environmental correlation coefficients. The association between characters that can be directly observed is the correlation between phenotypic values or the phenotypic correlation. In genetic studies, it is necessary to distinguish between the two causes of phenotypic correlation observed between characters, genetic and environmental. The genetic cause of correlation is chiefly pleiotropy, though linkage is a cause of transient correlations, particularly in populations derived from crosses between divergent strains (Falconer, 1960). Gallais (1984) has stated that genotypic correlations depend on the genotype frequencies in the population, and as these frequencies vary from population to population, the genotypic correlations also vary along with them. The environment is a cause of correlation insofar as two characters are influenced by the same differences of environmental conditions.

The method of path coefficient analysis in which the direct and indirect effects of several variables on a dependent variable are estimated, was proposed by Wright (1921b) and elaborated by Dewey and Lu (1959). Path coefficients are standardized partial regression coefficients. The dependent variable is the 'effect' (usually yield), while the component variables, which may or may not be interrelated, are the 'causes'. The total correlation of each cause with the effect is partitioned into the direct effect of the component variable on the dependent variable and the indirect effect of the component through its association with other component variables. The innumerable correlations between yield and its components in *Hevea* have been worked out by many, though path analysis studies are fewer.

Yield was reported to be positively correlated with girth, latex vessel rows and bark thickness by Narayanan *et al.* (1974), while Hamzah and Gomez (1982) and Markose (1984) obtained no significant correlation between yield and girth. Yield has been reported to be positively correlated with initial flow rate (Paardekooper and Samosorn 1969; Mydin, 1992) and negatively with plugging index (Sethuraj *et al.*, 1974). Paardekooper (1966) initially reported a positive correlation between initial flow rate and plugging index for 100 clones, but later Paardekooper and Samosorn (1969) found no significant correlation and speculated that this was due to delay in plugging in clones with high initial flow rate, as the small barriers to flow that are progressively formed within minutes after tapping are offset by the higher rate of flow. They also found that the correlation between plugging index and total yield is higher between clones, whereas that between initial flow rate and yield is higher within clones.

Ho (1972) and Narayanan *et al.* (1973) obtained significant correlations between girth, number of latex vessel rows and plugging index in mature rubber. Narayanan *et al.* (1973) found that girth and number of latex vessel rows were important in determining yield both within and between clones. Bark thickness was also positively correlated with yield but was linked to girth in its effect on yield. Density of latex vessels was only a minor factor for yield. They found that the positive correlation within clones between girth and yield changes to a non significant negative correlation between clones, probably due to the higher suppression of girth increment on tapping in high yielding clones. Napitapulu (1973) also found a positive correlation between yield and girth within clones but not between clones.

Narayanan and Ho (1973), in a nursery study involving 11-18 plants each of eighty clones, found that 23 to 98 per cent of the variation in yield was accounted for by its regression on girth (r= 0.48-0.99). They also found significant linear correlations between the regression coefficient and constant of the yield- girth relationship with number of latex vessel rows, bark thickness and distance between consecutive latex vessel rings, while those with diameter of sieve tubes, density and diameter of latex vessels were not significant.

Narayanan *et al*. (1974) observed that girth, number of latex vessel rows and plugging index are the important parameters determining the yield of young rubber plants. The average distance between latex vessel rings have varying associations with young nursery buddings. The major mineral constituents in latex (N,P,K) were related to yield through dry rubber content. Partial correlations indicated that girth , number of latex vessel rows and plugging index were not correlated with each other and contributed to yield of young buddings independently.

Sethuraj *et al*. (1974) examined the relationship between yield, initial flow rate and plugging index in the progeny of four crosses and found that initial flow rate was positively correlated with yield, while plugging index showed a negative correlation. A negative correlation was also obtained between plugging index and initial flow rate in three crosses out of four. Number of latex vessel rows was positively correlated with yield and initial flow rate. The effect of number of latex vessel rows on yield seemed to be effected through its relationship with initial flow rate.

Liu *et al.* (1980) obtained a high genetic correlation between yield and girth (r>0.7), while that between yield and dry rubber content was low (r<0.3). Nazeer *et al.* (1986) reported a negative correlation between yield and girth increment.

Premakumari *et al.* (1987) studied the genotypic and phenotypic correlations among certain anatomical yield attributes in *Hevea*, and found that density of the ray groups was negatively correlated with ray height and latex vessel diameter while the density of the latex vessels showed a negative correlation with ray width. Liang *et al.* (1988) studied 14 clones and reported high positive genotypic correlations between yield and yield index (0.9451), latex volume (0.9265) and girth (0.7094), while no significant correlation was obtained with dry rubber content (-0.022).

Hamzah and Gomez (1982) reported significant positive correlations of girth with bark thickness, latex vessel volume in the tapping panel, number of latex vessel rows and negative correlations with density of latex vessels. Bark thickness was significantly positively correlated with number of latex vessel rows (0.78), though not with latex vessels density. Yield recorded significant positive correlation with girth (0.56), bark thickness (0.521) and number of latex vessel rows(0.627).

Paiva (1982), Goncalves (1982) and Ribeiro (1984) reported that girth, bark thickness, number of latex vessel rows and density of latex vessels, are related to yield potential. Momoh and Alika (1987) found that height, girth and bark thickness at the age of 18 months were highly inter correlated (0.954 to 0.797). These correlations were retained at the age of 21 months, and height was also correlated with number of leaf whorls. However, girth showed no correlation with number of leaf whorls.

Samsuddin *et al.* (1987) found that photosynthetic rates of two-whorl buddings raised in a controlled growth chamber were positively correlated with mean yield over five years of the corresponding field grown plants. There was no correlation between photosynthetic rate and girth at opening, girth at the fifth year of tapping and girth increment. The correlation between mature yield and girth increment was negative. No correlation was found between girth and girth increment. Multiple regression studies of photosynthetic rate on yield, girth at opening, girth after five years and girth increment suggested that yield was the only dominant and significant factor accounting for 22 per cent variation in photosynthetic rate.

Onokpise *et al.* (1986) found that height, girth and plant vigour at 18 months were positively correlated. Licy and Premakumari (1988) obtained a significant positive relationship between plant height and girth, girth and bark thickness, bark thickness and number of latex vessel rows, and yield with all the four, at the age of 18 months. Olapade (1988) however obtained a negative correlation between girth and yield.

Rubber yield was found to be positively correlated with bark thickness and number of latex vessel rows (Gomez *et al.* 1972; Ho *et al.* 1973; Narayanan *et al.* 1974). Sethuraj *et al.* (1974) reported a positive correlation between initial flow rate and number of latex vessel rows.

Lavorenti *et al.* (1990) obtained significant simple correlations between dry rubber yield on testtapping and girth, bark thickness, number of latex vessel rows, diameter of latex vessels and density of latex vessels within a ring in young

rubber plants (0.61, 0.34, 0.28, 0.29 and 0.43 respectively). Those between girth and bark thickness, number of latex vessel rows, diameter and density of latex vessels were 0.65, 0.22, 0.37 and 0.33 respectively. Linear simple regression analysis of yield suggested that girth was the only important and significant parameter accounting for 36 per cent of the juvenile yield variation, while bark thickness accounted for 42 per cent of the variation in girth.

Nazeer *et al.* (1992) reported in four year old plants of 15 clones that girth was highly and positively correlated with girth increment, plant height, canopy height, number of branches and negatively with branching angle, but not with branching height, bark thickness or number of latex vessel rows. No correlations were obtained between bark thickness and number of latex vessel rows. Varghese *et al.* (1996) obtained significant positive correlations of girth with height, number of flushes and number of leaves at the age of 16 months. At 28 months, girth was significantly correlated with height, bark thickness, annual girth increment and canopy density, though not with number of branches and branching height.

The functional significance of stomata is related to photosynthesis, transpiration, adaptation to environmental constraints and disease occurrence (Premakumari, 1992). Changes in turgor pressure in laticiferous phloem tissue of *Hevea brasiliensis* have been shown to be negatively associated with stomatal opening (Buttery and Boatman, 1966). There is a lot of evidence on correlations between the stomatal number per unit leaf area and the performance characteristics of other crop cultivars. Earliness and stomatal density were found to be directly correlated in cherry (Kansima, 1965), while an inverse relationship has been found

between early maturity and stomatal density in potato (Meinl and Raenber, 1960) and cabbage (Gencev, 1964). Gadkari (1964) found varietal adaptability of cotton cultivars to ecological conditions was correlated to stomatal density differences. Meinl and Moller (1961) were able to forecast the proportion of early and late maturing seedlings of potatoes in five out of six hybrid populations based on their stomatal densities. Studies in *Hevea brasiliensis* however, are meagre. Gomez and Hamzah (1980) reported significant clonal differences for stomatal density in ten clones, while Premakumari (1992) did not obtain clonal differences for this character. Senanayake and Samaranayake (1970) reported intraspecific variation for stomatal density in 25 *Hevea* cultivars, but found no correlation between this trait and yield. Studies on the leaf anatomical characters of *Hevea* are also very scanty. Gomez and Hamzah (1980) recorded clonal differences for leaf thickness and palisade layer thickness in ten clones. Premakumari (1992) reported significant clonal differences for cuticle thickness and midrib width, while no significant clonal differences were detected for midrib thickness, lamina thickness and palisade layer thickness. No significant correlation of yield was obtained with stomatal density, midrib thickness or palisade layer thickness, though a negative correlation was seen with width of palisade cells.

Zhongyu *et al.* (1982) observed a high correlation (r=0.6) between net photosynthetic intensity and latex yield of petiolules of one year old seedlings. Nugawela and Aluthhewage (1985) found that single leaf area was positively but not significantly correlated with yield at 1½ years of age. Initial studies have shown that there is a tendency for clones with smaller leaf size to have a high CO_2 assimilation capacity per unit leaf area. Such observations are abundant in literature.

Elmore (1980) suggests that this is due to the photosynthetic apparatus getting diluted when leaf area is large. Hence clones with smaller leaf area but larger number to increase the total assimilatory area would form a canopy with a high CO_2 assimilatory capacity. Diffusive resistance to water vapour exchange was low in clones with a high stomatal density. Ishii (1998) is of the opinion that the morphological traits of a leaf like leaf thickness and leaf size are correlated with the physiological ones like photosynthetic rate per unit leaf area (LPS). In wheat and rice, the LPS has been found to be correlated with specific leaf weight (SLW), an indicator of leaf thickness. This is due to the fact that thick leaves have high nitrogen content per unit leaf area. Hence photosynthetic enzymes are diluted in thin and large leaves, leading to low LPS. Madhavan *et al.* (1996) obtained low but significant negative correlations between leaf size and yield (r=-0.2436[**]) and between size and specific leaf weight (r= -0.2281[**]).

Among the latex biochemical parameters, Bricard and Nicolas (1989) reported on *inter se* correlations among seven latex biochemical traits in the immature phase at the age of three years and the first mature production year at the age of five years, in four trials. They observed that thiol content was positively correlated with inorganic phosphorous and negatively with total solids content (TSC). Sucrose showed no significant correlations with other parameters in both stages except inorganic phosphorous in the juvenile phase in two cases out of four. Latex pH was also positively correlated with TSC and negatively with magnesium. The negative juvenile correlations of inorganic phosphorous with TSC and pH disappeared in the mature phase.

Very few path analyses for yield using different component traits have been carried out so far in *Hevea* (Markose, 1984; Liang *et al.*,1988; Mydin,

1992; Premakumari, 1992; Madhavan *et al.* 1996). Markose (1984) on an examination of twenty clones found that latex volume yield had the highest positive direct effect on yield. Number of latex vessel rows and bark thickness had low direct effects on yield and contributed to the latter through volume yield. Liang *et al.* (1988) obtained high direct effects for girth and latex volume on yield. In another study on 40 clones (Mydin, 1992), dry rubber yield under stress, annual mean volume of latex and latex flow rate during the peak period emerged as the important traits with high direct effect on annual dry rubber yield. Premakumari (1992) obtained high positive direct effects of laticifer area index and latex volume on dry rubber yield, though the direct effects of number of latex vessel rows, girth and diameter of latex vessels were negative. Studies in wild *Hevea* germplasm by Madhavan *et al.* (1996) showed that girth and number of latex vessel rows were the most important factors influencing yield.

2.4. Early selection

The conventional breeding and selection cycle in *Hevea* is elaborate and takes 30 to 34 years for the final release of a clone (Varghese and Mydin, 2000). Markose and Panikkar (1984) suggested the establishment of replicated field trials in the third year after hand pollination, and taskwise trials in the 12th year. This could reduce the breeding cycle to 24-25 years, which is still a very long period. Identification of reliable juvenile selection parameters is thus of paramount importance in *Hevea* breeding. Early workers examined a number of parameters for early yield prediction. Ashplant (1928) proposed the use of number of latex vessel rows for predicting mature yield. Since then a number of criteria have been

suggested. Girth, height, bark thickness, number of latex vessel rows, latex vessel and sieve tube diameter, rubber hydrocarbon in the bark and petiole have shown inconsistent results (Tan, 1987). Senanayake and Samaranayake (1970) suggested the use of stomatal density as a selection criterion. Ho (1976) used nursery yield and plugging index to predict mature yield and reported that girth, number of latex vessel rows and plugging index account for 75 per cent of the variation in nursery yield, but only 40 per cent of the mature yield. Huang *et al.* (1981) obtained significant association between number of latex vessel rows and number of lateral veins of young clones with mature yield. Nugawela and Aluthhewage (1985) suggested the use of gas exchange parameters for early selection. The possibility of using physiological criteria for early selection have been discussed by some workers (Nicolas, 1978; Ditinger *et al.*, 1981; Odier, 1983; Henon *et al.*, 1984). Among the methods tried so far, only girth, plugging index and number of latex vessel rows have shown a relatively greater degree of consistency and are being utilized at present.

Different methods of estimating of juvenile yield for early yield prediction have been attempted: the 'testatex' method proposed by Cramer (1938) using a special knife with four V-shaped blades, the perforated wheel method proposed by Meyer (1950), the needle prick test method of Waidyanatha and Fernando (1972), the modified Hamaker-Morris-Mann (HMM) method, and the test incision method developed by Varghese *et al.* (1989). Zhongyu *et al.* (1991) compared five different methods of nursery yield estimation, and found the petiolule latex yield to be the best indicator of mature yield. The modified Hamaker-Morris-Mann method is the most widely adopted one in which two to three year old

plants are test tapped on a few successive days and the latex yield quantified. Correlation of juvenile yield with mature yield is only low to moderate (Dijkman, 1951; Ong et al., 1985; Premakumari et al., 1988a), and is therefore not a very reliable indicator of mature yield. However, this test tap method is the best among the available methods and is used at present in conjunction with other juvenile traits like vigour and number of latex vessel rows, for the initial selection of hybrid progenies. Mydin et al. (1990) developed a performance index based on a yield and related juvenile traits at the age of two years, which was found to be a good method for selection of clones at an early age by Varghese et al. (1993).

2.5. Genetic divergence

A knowledge of the extent of genetic divergence in the available base population, and the grouping of the genotypes into clusters based on the degree of diversity between them, is an important step prior to the selection of parents in any hybridization programme as it has been established that there is a close and intense relationship between the extent of heterosis and the extent of divergence of the parents involved in the F_1 cross.

2.5.1 Genetic distances and clustering

Multivariate analysis utilizing Mahalonobis' D^2 statistic (Mahalonobis, 1936) to measure the genetic distance between two populations, coupled with principal components, are used to form homogenous clusters of large numbers of genotypes. Genotypes are clustered in such a way that the average genetic distance between the members of a cluster is less than the distance between clusters. The

most widely used methods of clustering are the Tocher's technique and the principal component analysis (Rao, 1952). These techniques have been useful in quantifying the degree of divergence in the germplasm collection of various crop plants. They have also been frequently utilized to assess the relative contributions of different components to the total divergence both at the inter- as well as intra- cluster levels. Mahalonobis' D^2 statistic computes the exact genetic distance between parents and helps in choosing divergent parents for an effective hybridization programme (Peter et al., 1977). This technique has been successfully employed in a number of tree crops like arecanut (Bavappa and Mathew, 1982) and coconut (Balakrishnan and Namboodiri, 1987), as well as in vegetatively propagated crops like banana (Valsalakumari, et al., 1985; Mercy and George, 1987; 1988) and sugarcane (Punia et al. 1983; Santhi, 1989). Wahi and Kher (1991) in gerbera and dahlia found another method of clustering, the iterative method developed by Friedman and Rubin (1967), to provide more homogenous clusters than the Tocher's and principal component analysis methods.

In *Hevea*, Markose (1984) clustered 20 Wickham clones into eight groups. He observed that girth, girth increment, dry rubber yield, dry rubber content, bark thickness, number of latex vessel rows and volume of latex contribute to genetic divergence. Since clones of Indian, Malaysian, Liberian and Brazilian origin fell in the same clusters, he concluded that there was no association between geographical diversity and genetic diversity. Paiva (1994) while clustering 100 Wickham clones into 14 clusters, Mydin (1992) while clustering 40 clones into eight clusters and Abraham et al. (1995) while clustering 100 wild germplasm accessions into eight clusters, also concluded that there was no correlation between genetic distance and geographical origin. However, Chevallier (1988), using isozymes, reported genetic divergence between material collected from geographically distinct locations in wild *Hevea* germplasm. Mydin (1992)

reported that the traits with the highest contribution to divergence were annual average volume of latex, plugging index in the peak season, latex volume in the peak season, while renewed bark thickness, height at forking, and girth increment contributed the least. The contribution of girth, girth increment and virgin bark thickness was relatively low, while that of plugging index and dry rubber content high.

2.5.2. Factor analysis

Factor analysis is a multivariate tool for reducing a large number of correlated variables to a small number of main factors. The variables with which the calculations begin consist of measurements of observable traits. The factors determined by the calculations are abstract hypothetical components (Burt and Banks, 1947). Factor analysis is a powerful tool for eliciting underlying multivariate structures (Walton, 1972) as it explains the dependence structure of a set of variables in terms of certain common factors. Spearman (1940) was the first to put forth the concept of factor analysis in psychological studies, where he identified three types of factors. The first was a single general underlying factor common to all the inter correlated variables, while the second type was common to some of the variables but not all. The third was specific to single variables and called specific factors. This technique was later developed and elucidated by Bart (1952), Fruchter (1954), Harman (1967), Joreskog (1971) and Lawley and Maxwell (1971). A number of studies have been carried out in other crops. Walton (1972), in a study on yield in spring wheat, condensed 14 correlated variables into four factor groups. Denis and Adams (1978) identified three developmental patterns in the structural characteristics of yield in dry beans : size, number and architecture. Sawant et al. (1982) grouped seven yield related variables in 90 strains of triticale into two factors. Factor analysis was applied in another vegetatively propagated crop,

sugarcane, by Santhi (1989), who concluded that the quality factor was the main factor of divergence.

In *Hevea*, Odier (1983) carried out a principal component analysis of physiological parameters in the juvenile and adult periods, and found similar results in both cases, with the synthetic variables grouping related parameters. Latex pH, magnesium and lutoid bursting index formed one synthetic factor, inorganic phosphorous, thiols and acid phophatases the second group, and sucrose and total solids the third. Chevallier (1988) used factor analysis in analysing allozyme frequencies in the old Wickham and newer wild germplasm of *Hevea*. Mydin (1992) applied factor analysis to two genetically diverse clusters of 15 and 11 clones, using 12 variables, and reported that dry rubber yield, volume of latex, initial flow rate, yield depression under stress and branching height were the most important contributors to the factors of genetic divergence. Abraham (2000) in a similar study in wild germplasm in the immature phase, resolved 33 morphological and anatomical variables including yield into 12 meaningful factors of divergence.

2.6. Selection index

When selection is applied to the improvement of crops, it is generally applied to several characters simultaneously and not just one. The optimal procedure for selection uses all the information available about each individual's value, combined into an index of merit. The method involves application of selection simultaneously to all component characters together, appropriate weights being given to each character according to its relative economic importance, its heritability, and the genotypic and phenotypic correlations between the different characters. The component characters therefore are combined to form a score or index, such that selection applied to the index as if the

index were a single character, will yield the most rapid improvement. The index is the best linear prediction of an individual's performance and takes the form of a multiple regression of the performance on all the relevant traits. The concept of selection index was first proposed by Smith (1936) based on the 'discriminant function' of Fisher (1936). This was further elaborated by Hazel and Lush (1942) and Robinson *et al.* (1951). Since then it has been used in a number of crops, mostly annuals (Brim *et al.*, 1959; Caldwell and Weber, 1965; Bavappa and Ramachander, 1967; Singh and Singh, 1972; Mital and Verma, 1991). In sugarcane, a crop similar to *Hevea* in the method of propagation (vegetative) and in the economic product (vegetative and not reproductive), Miller *et al.* (1978) constructed the first selection indices for cane yield and sucrose yield separately, in four populations of sugarcane.

In *Hevea*, Mydin (1992) ranked progenies of 20 clones on the basis of their performance for test tap yield, girth, number of latex vessel rows and number of leaf flushes. Growth indices were also computed by Varghese *et al.* (1996) for young Wickham clones based on girth, height, number of flushes and number of leaves at the age of 16 months and height, girth, girth increment, and canopy density at the age of 28 months. Abraham (2000) computed a performance index for 80 wild accessions and one control (RRII 105) in the juvenile stage, using 16 morphological and anatomical characters. Based on this ranking, eight superior accessions were identified.

Hence the present study was initiated in order to assess the variability, correlations and genetic divergence, to identify the factor groups, to formulate the performance index for the clones at the mature and immature stages. and to examine the possibility of prediction of mature yield based on immature attributes.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study was carried out from 1996-1998, using 25 clones from the germplasm collection being maintained by the Rubber Research Institute of India at its Central Experiment Station, Chetheckal. The trees had been planted in 1979 as a small scale evaluation trial adopting a randomized block design with 3 replications, and 5 trees per replication. At the time of the experiment, the trees were being tapped in the BI-2 panel. Simultaneously, these 25 clones were also multiplied in August 1996 by bud grafting and raised in polybags at RRII for recording the immature attributes in the first two years of growth. The polybags were raised in a RBD with three replications and five plants per replication. All cultural operations were carried out as per the recommendations of the Rubber Board. Table 1 gives the list of clones selected for the study.

The following observations were recorded in the two sets of plants:

3.1 Mature trees

Two trees were randomly selected from each replication for recording the following characters. For the leaf parameters, representative leaves were selected from the middle of the topmost mature whorl of a branch of each sample tree in May 1998, to ensure that all samples were at the same stage of physiological maturity.

Table 1. List of clones selected for the study

Sl. No	Clone	Parentage	Country of origin
1	RRIM 501	Pil A 44 x Lun N	Malaysia
2	RRIM 519	Pil A 44 x Pil B 16	Malaysia
3	RRIM 526	Pil B 84 x Pil D 65	Malaysia
4	RRIM 600	Tjir 1 x PB 86	Malaysia
5	RRIM 602	Tjir 1 x Gl 1	Malaysia
6	RRIM 603	PB 86 x Pil B 84	Malaysia
7	RRIM 604	Tjir 1 x PB 49	Malaysia
8	RRIM 605	Tjir 1 x PB 49	Malaysia
9	RRIM 607	Tjir 1 x PB 49	Malaysia
10	RRIM 610	RRIM 504 x Tjir 1	Malaysia
11	RRIM 611	RRIM 504 x Tjir 1	Malaysia
12	RRIM 612	AVROS 157 x PB 49	Malaysia
13	RRIM 615	RRIM 511 x Tjir 1	Malaysia
14	RRIM 620	RRIM 501 x RRIM 511	Malaysia
15	RRIM 622	Tjir 1 x Pil B 84	Malaysia
16	RRIM 628	Tjir 1 x RRIM 527	Malaysia
17	RRIM 636	_	Malaysia
18	RRIM 701	44/553 x RRIM 501	Malaysia
19	RRIM 703	RRIM 600 x RRIM 500	Malaysia
20	RRIM 704	RRIM 600 x RRIM 500	Malaysia
21	RRIM 705	RRIM 632 x RRIM 500	Malaysia
22	RRIM 706	RRIM 632 x RRIM 500	Malaysia
23	IAN 873	PB 86 x FA 1717	Brazil
24	RRII 105	Gl 1 x Tjir 1	India
25	Harbel 1	Primary clone	Liberia

3.1.1. Morphological traits

(i) Girth

Girth of the trunk was recorded in cm at a height of 160 cm from the bud union at the commencement of the experiment in November 1996, and at the end of the second year in November 1998.

(ii) Girth increment

Girth increment in percentage during the two year period was calculated from the above data.

$$\text{Girth increment} = \frac{\text{Girth (1998) - Girth (1996)}}{\text{Girth (1996)}} \times 100$$

(iii) Leaf parameters

a) Leaf size

Single leaf area was measured from the central leaflets of the sampled leaves, in order to obtain the characteristic leaf size for each clone. Area was recorded in cm^2 using a leaf area meter Li-Cor 3100.

b) Specific leaf weight

Leaf samples used for recording area were dried to constant weight, and the weight recorded. The dry weight per unit leaf area gave the specific leaf weight in $g\ cm^{-2}$.

c) Density of stomata

Sections of leaf from the central portion of each leaflet excluding the midrib were boiled in 60 per cent nitric acid with a pinch of potassium chlorate. The leaf epidermal peels thus obtained were washed and stained using 1 per cent Safranine. The number of stomata per mm^2 was recorded from six peels per leaf sample using a grid graticule in a stereo microscope.

3.1.2. Anatomical traits

3.1.2.1. Bark anatomy

Bark samples were collected at the end of the experiment in November 1998, at a height just below the tapping cut, using a bark sampler. The samples were preserved in FAA (formalin-acetic acid- alcohol in the ratio 90:5:5). Radial longitudinal and tangential sections were taken using a sledge microtome, stained in Sudan IV and mounted in glycerine. The following observations were recorded:

(i) Bark thickness

Bark thickness was recorded in mm from the bark samples collected.

(ii) Number of latex vessel rows

The total number of latex vessel rows was recorded from radial longitudinal sections 100 μm in thickness.

(iii) Density of latex vessels

The density of latex vessels per unit length of latex vessel row was recorded from 80 μm thick tangential cross sections of the bark sample, and expressed as number per unit mm.

(iv) Diameter of latex vessels

Diameter was recorded from the tangential cross sections and expressed in microns.

(v) Laticifer area index

The laticifer area index (LtAI) was computed using the formula proposed by Gomez *et al.* (1972) for a ½S d/2 system of tapping:

$$LtAI = 0.3 \ nfG\pi r^2 \ mm^2$$

where 'n' is the number of latex vessel rows, 'f' is the density of latex vessels in a row, 'G' is the girth of the plant and 'r' is the radius of the latex vessels.

3.1.2.2. Leaf anatomy

Anatomical traits were recorded using leaf samples collected as described above. To ensure uniformity, only the central region of the left leaflets were used. Thin hand sections were taken, stained in Sudan 1V, and measurements recorded from six sections for each sample using a simple microscope. The following observations were recorded for the leaf samples:

(i) Midrib thickness

The maximum vertical thickness of the midrib from six sections for each leaf sample was recorded in microns.

(ii) Lamina thickness

The thickness of the leaf lamina at a uniform distance of 3 mm from the midrib was recorded in microns.

(iii) Palisade thickess

The thickness of the palisade layer in microns, was recorded at a distance of 3 mm from the midrib.

3.1.3. Biochemical parameters

The biochemical parameters of latex were measured in the peak yielding season, during the month of November 1998. Latex samples were collected from each tree in

ice cooled beakers. An extract was prepared from a known quantity of latex (about 1g) using 2.5% trichloro acetic acid. This extract was used to determine the quantity of thiols, inorganic phosphorous, sucrose and magnesium in the latex sample. Chlorophyll content in leaves was determined from the samples collected as described above.

(i) Total solids content (TSC)

One g of fresh latex was dried to constant weight in an oven. The TSC was the dry weight of the sample expressed as a percentage of its fresh weight.

(ii) Thiols

This was measured using the method of Boyne and Ellmam (1972). 0.1ml DTNB-EDTA and 2ml TRIS were added to 2ml extract, and the absorbance at 412nm was recorded.

(iii) Inorganic phosphorous

Inorganic content of the latex samples was determined according to Taussky and Shorr (1953). Two ml of a reagent of ferrous sulphate and sulphomolybdic acid was added to 0.5 ml extract, and the absorbance read at 740nm.

(iv) Sucrose

Sucrose in latex was determined as per the method of Scott and Melvin (1953). 0.1ml extract was used to react with 3ml of the reagent anthrone, and the absorbance read at 740nm.

(v) Magnesium in latex

The concentration of magnesium in latex was estimated using atomic

absorption spectroscopy as suggested by RRIM (1973). From the extract, 0.1ml was used to react with 1.25ml of a reagent of strontium chloride. The absorbance was read at nm in an atomic absorption spectrophotometer model no GBC 902.

(vi) Chlorophyll content of leaves

Chloropyll was extracted from a known weight of leaf samples by keeping them overnight in a 1:1 solution of DMSO: acetone. The absorbance was then read at 645 and 663nm. Chlorophyll content was then calculated as follows:

$$\text{Chl. a} = \frac{[(12.7 \times OD \text{ at } 663nm) - (2.69 \times OD \text{ at } 663nm)] \times V}{W \times 1000} \text{ mg/g fresh leaf}$$

$$\text{Chl. b} = \frac{[(22.9 \times OD \text{ at } 645nm) - (4.68 \times OD \text{ at } 663nm)] \times V}{W \times 1000} \text{ mg/g fresh leaf}$$

$$\text{Tot. chl.} = \frac{[(20.2 \times OD \text{ at } 645nm) + (8.02 \times OD \text{ at } 663nm)] \times V}{W \times 1000} \text{ mg/g fresh leaf}$$

where V= volume in ml to which the extract is made up, and W= fresh weight of leaf sample used.

3.1.4. Physiological parameters

The physiological parameters associated with yield were recorded in the month of November 1998 as follows:

(i) Initial flow rate (IFR)

The quantity of latex obtained in the first five minutes of tapping was measured and the initial rate of latex flow per minute determined.

(ii) Total volume of latex (FV)

The total volume of latex obtained at each tapping was recorded in ml.

(iii) Plugging index (P.I.)

Plugging index was computed as per the formula of Milford *et al.* (1969):

$$P.I. = \frac{\text{mean initial flow rate (ml min}^{-1})}{\text{final volume (ml)}} \times 100$$

(iv)   Dry rubber content (d.r.c.)

Latex samples of a known volume (20 ml) from each tree were coagulated using 1% acetic acid. The coagulum was washed, pressed , dried at 55 °C in an oven for one week and weighed. The d.r.c was then computed as the percentage rubber content on a dry weight by volume basis (Sethuraj, 1981).

3.1.5. Dry rubber yield

The dry rubber yield per tree per tapping was recorded on all tapping days (144 days) from January to December 1998 by the cup coaglation method. Latex was coagulated in the collection cup using 1% acetic acid. The coagula were partially dried in the shade for a week, and then in the smoke house for one month. The weight of the dried lumps was recorded in g using a top pan balance. 10 per cent was deducted from this dry weight in order to compensate for residual moisture, as suggested by Markose (1984). The average yield was calculated as the mean of all the recordings, and expressed as g tree^{-1} tapping^{-1}.

3.2. Immature plants

The following observations were recorded on all the plants in the polybags:

3.2.1. Morphological parameters

The following parameters were recorded in the first year of growth:

(i) Time taken to sprout

Sprouting was monitored at weekly intervals in the polybags, to see if the time taken to sprout had any bearing on juvenile vigour and yield. The average time taken for each clone to sprout was recorded as weeks after planting.

(ii) Height

Total height of the plant from the bud union to the tip of the topmost whorl, was recorded in cm at the end of the first year in August 1997.

(iii) Scion diameter

The diameter of the scion at the end of the first year was recorded in mm at a height of 15 cm from the bud union.

(iv) Number of whorls retained

The number of whorls retained at the end of the first year (W1).

(v) Number of whorls shed

The number of whorls produced, but shed by the end of the first year (W2).

(vi) Total number of flushes

The total number of leaf flushes produced during the first year of growth was recorded (W3).

(vii) Number of leaves

The total number of leaves produced during the first year of growth was recorded.

The following parameters were recorded in the second year of growth:

(i) Scion diameter

The diameter of the scion at the end of the second year in August 1998 was recorded in mm at a height of 15 cm from the bud union. Diameter increment was computed as percentage over the first year's diameter.

(ii) Number of new leaf whorls produced on the main stem during the second year of growth (W4).

(iii) Number of new leaf whorls produced on the main stem as well as on side branches during the second year of growth (W5).

(iv) Number of new leaf whorls retained on the main stem at the end of the second year (W6).

(v) Number of new leaf whorls retained on the main stem as well as on side branches at the end of the second year (W7).

(vi) Total number of whorls produced on the main stem during the first and second years of growth (W8).

(vii) Leaf parameters:

For recording the leaf traits, two leaves per plant were collected from the middle of the topmost mature flush of each plant in April 1998 to ensure that all

samples were at the same stage of physiological maturity. Leaf size (single leaf area), specific leaf weight and number of stomata per unit area, were recorded as described in section 3.1.1.iii.

3.2.2 Anatomy

Bark samples of size 2cm x 2cm were collected at a height of 15 cm from the top of the bud union at the end of the experiment in November 1998, on the side opposite the test tapping panel, using a bark sampler. The samples were preserved in FAA (formalin-acetic acid- alcohol in the ratio 90:5:5). Bark thickness was also recorded from these samples. All the anatomical measurements were then made as described in section 3.1.2.1.

The leaf anatomical parameters lamina thickness, midrib thickness and palisade layer thickness, were recorded as in section 3.1.2.2.

3.2.3. Biochemical parameters

The biochemical parameters of latex were measured in the peak yielding season, during the month of November 1998, after the last test tap yield collection. Collection of latex samples, further processing and analyses of thiol, inorganic phosphorous, sucrose and magnesium were carried out as described in section 3.1.3 above. Chlorophyll content in leaves from the samples collected was determined as described in section 3.1.3.vi. Physiological parameters like plugging index and dry rubber content, as well as total solids content could not be recorded due to insufficient latex production at this age.

3.2.4 Immature yield

Test tapping was carried out at the end of two years from September to November 1998 at a height of 20 cm from the bud union. The plants were tapped once in three days, using a half spiral cut as in mature plants. Yield from the first ten tappings were not collected as the plants has to be given time to stabilize. Latex from the next ten tappings were collected, dried, weighed and the total weight expressed in grams per plant.

Statistical Analysis

The data collected at both phases of growth were subjected to statistical analysis. Genetic parameters and correlations were estimated for all the variables recorded in both stages of growth. However only 20 and 16 characters respectively in the mature and immature stages were utilized for estimating path coefficients, genetic divergence and performance index after excluding the less important attributes.

1. Variance-Covariance analysis (Dabholker, 1992)

Analysis of variance and covariance as per the standard procedure for a randomized block design with three replications, was carried out on the data collected in order to :

a) test for genotypic differences for the various traits among the clones in the two sets of plants.

b) estimate genetic parameters, *viz.* variance components, heritability (broad sense), and genetic advance as percentage over the mean.

c) compute the phenotypic, genotypic and environmental correlation coefficients among the parameters.

The significance of the variance ratio (F) v as tested using the standard 'F' table given by Fisher and Yates (1963). Table 2 gives the standard analysis of variance and covariance.

1.1 Variability estimates

The estimates of phenotypic, genotypic and env ronmental coefficients of variation were derived from their respective variance estin ates. The phenotypic variation ($\sigma^2_{p(x)}$) of any trait is the result of its genotypic ($\sigma^2_{g(x)}$) and environmental ($\sigma^2_{e(x)}$) variations.

The corresponding coefficients of variation are computed as follows

$$\text{Phenotypic coefficient of variation (PCV \%)} = \frac{\sigma_{p(x)}}{\bar{x}} \times 100$$

$$\text{Genotypic coefficient of variation (GCV \%)} = \frac{\sigma_{g(x)}}{\bar{x}} \times 100$$

where $\sigma_{p(x)}$ and $\sigma_{g(x)}$ are the phenotypic and genotypic standard deviations respectively, and $\bar{x}$ is the mean of the trait x.

1.2 Heritability

Heritability in the broad sense (H^2) is the fraction of the total variance that can be ascribed to the genotype, and is expressed as a percentage. It was calculated as follows:

$$H^2 \ (\%) = \frac{\sigma^2_{g(x)}}{\sigma^2_{p(x)}} \times 100$$

The heritability estimates were classified into high (> 60%), medium (30-60 %) and low (< 30%) as per Robinson *et al.* (1951).

Table 2. Analysis of variance and covariance for characters x and y, when t genotypes are raised in R.B.D. with r replications

Source	df	M.S. (x)	Expectation of M.S.(x)	M.P.(xy)	Expectation of M.P.(xy)	M.S. (y)	Expectation of M.S.(y)
Block	(r-1)	B_{xx}		B_{xy}		B_{yy}	
Clones	(t-1)	V_{xx}	$\sigma^2_{e(x)} + r\sigma^2_{g(x)}$	V_{xy}	$\sigma_{e(xy)} + r\sigma_{g(xy)}$	V_{yy}	$\sigma^2_{e(y)} + r\sigma^2_{g(y)}$
Error	(r-1)(t-1)	E_{xx}	$\sigma^2_{e(x)}$	E_{xy}	$\sigma_{e(xy)}$	E_{yy}	$\sigma^2_{e(y)}$
Total	(rt-1)	T_{xx}		T_{xy}		T_{yy}	

$\sigma^2_{g(x)}$ and $\sigma^2_{g(y)}$ are the genotypic variances of x and y respectively

$\sigma^2_{p(x)}$ and $\sigma^2_{p(y)}$ are the phenotyic variances of x and y respectively

$\sigma^2_{e(x)}$ and $\sigma^2_{e(y)}$ are the error variances of x and y respectively

$\sigma_{g(xy)}$, $\sigma_{p(xy)}$ and $\sigma_{e(xy)}$ are the genotypic, phenotypic and error covariances between x and y respectively

$$\sigma^2_{g(x)} = \frac{V_{xx} - E_{xx}}{r}$$

$$\sigma^2_{g(y)} = \frac{V_{yy} - E_{yy}}{r}$$

$$\sigma_{g(xy)} = \frac{V_{xy} - E_{xy}}{r}$$

$$\sigma^2_{e(x)} = E_{xx}$$

$$\sigma^2_{e(y)} = E_{yy}$$

$$\sigma_{e(xy)} = E_{xy}$$

$$\sigma^2_{p(x)} = \sigma^2_{g(x)} + \sigma^2_{e(x)}$$

$$\sigma^2_{p(y)} = \sigma^2_{g(y)} + \sigma^2_{e(y)}$$

$$\sigma_{p(xy)} = \sigma_{g(xy)} + \sigma_{e(xy)}$$

1.3. Genetic advance under selection

Genetic advance under selection (GA) is the gain in percentage in the next generation that can be expected under a given selection intensity. It was estimated as follows:

$$GA\ (\%) = \frac{kH^2\ \sigma_{p(x)}}{\overline{x}} \times 100$$

where k is the selection differential which is 2.06 at 5 % intensity of selection in large samples. The genetic advance estimates were classified into high (> 28%), medium (16-28 %) and low groups (< 16%).

1.4 Correlations

Phenotypic, genotypic and environmental correlations between two variables 'x' and 'y', were computed from their covariance values in the mature and immature sets of plants as follows.

$$r_{p(x,y)} = \frac{\sigma_{p(xy)}}{\sqrt{\sigma^2_{p(x)} \times \sigma^2_{p(y)}}}$$

$$r_{g(x,y)} = \frac{\sigma_{g(xy)}}{\sqrt{\sigma^2_{g(x)} \times \sigma^2_{g(y)}}}$$

$$r_{e(x,y)} = \frac{\sigma_{e(xy)}}{\sqrt{\sigma^2_{e(x)} \times \sigma^2_{e(y)}}}$$

The significance of the phenotypic and environmental correlations were tested, while no statistical tests are available to test the significance of the genotypic correlations.

1.5 Path Analysis

The direct and indirect effects of the various traits on yield were calculated from the genotypic correlation coefficient matrix. The path coefficients, which are standardized partial regression coefficients, were obtained' by solving the simultaneous equations of the type:

$$r_{x_iy} = r_{x_ix_1}P_1 + r_{x_ix_2}P_2 + \ldots\ldots + r_{x_ix_i}P_i + \ldots\ldots + r_{x_ix_k}P_k$$

where i = 1,2,3,...k,

r_{x_iy} = correlation between the $x_i{}^{th}$ independent variable with the dependent variable (y),

P_i = direct effect of x_i on y , and

$r_{x_ix_k}P_k$ = indirect effect of x_i via x_k on y.

The residue 'R' was calculated as

$$R^2 = (1 - \Sigma r_{x_iy}P_i)$$

2. Correlation and regression analysis

Simple correlation coefficients of all the traits in the mature phase with the corresponding traits in the immature phase were worked out according to Snedecor and Cochran (1968) to identify which traits remained relatively stable as the trees aged.

Multiple regression analysis was carried out to measure the regression of mature yield on immature attributes The stepwise regression technique as detailed in Gomez and Gomez (1984) was adopted. In this technique, only those terms

that contribute significantly to the variation in the dependent variable are included in the regression equation. This was achieved by systematically adding terms, one at a time, to the regression equation. The level of significance (α) of the correlation coefficient (r) of the Z regression terms with yield was fixed as 20% for inclusion in the equation.

3. Genetic divergence

Genetic divergence was assessed using the Mahalonobis' D^2 statistic (1936). The D^2 is defined as

$$D^2 = \sum_{i=1}^{k} d_i^2 = \left(y_i^l - y_i^m \right)^2, \qquad (l \neq m)$$

where y_i^l is the uncorrelated mean of the lth clone for the ith character. Grouping was done by the Tocher's method. The relative contribution of characters to divergence at the cluster level as well as the genotype level was assessed on the basis of the coefficients of variation of the individual traits (Sharma, 1998).

4. Factor analysis

Factor analysis was carried out as per Lawley and Maxwell (1971) in order to group the large number of characters into a few meaningful factors of divergence using principal component analysis. The communalities as well as the percentage contribution of each factor to the divergence observed in the population were computed.

5. Discriminant function analysis

The discrimnant function based on a number of variables was used for the formulation of performance indices for the 25 clones in the mature and immature phases of growth, in order to examine whether the superiority in the young phase was maintained in the mature phase too. The genetic worth of the plant is defined by Smith (1936) as

$$H = a_1 G_1 + a_2 G_2 + \ldots\ldots + a_n G_n,$$

where $G_1, G_2, \ldots\ldots, G_n$ are the genotypic values of the individual clones and a_1, $a_2, \ldots\ldots, a_n$ signify their relative importance. As G values are not measurable, another function I, which describes the phenotype of an individual, is expressed as

$$I = b_1 x_1 + b_2 x_2 \ldots + b_n x_n,$$

where $x_1, x_2 \ldots x_n$ are the n characters observed, and $b_1, b_2 \ldots b_n$ are the corresponding coefficients calculated. The correlation between H and I is maximum and the selection of phenotypes using I as the discriminant function gives maximum gain.

The genetic advance that can be expected at a selection intensity of 5 per cent was calculated as follows:

$$GA = \frac{i\underline{a}'\, \underline{G}\underline{b}}{\sqrt{\underline{b}'\, \underline{P}\underline{b}}}$$

where

$\underline{a}$ is the vector of weights attached to each character,

$\underline{b}$ is the vector of b-coefficients in the discriminant function,

G is the genotypic variance-covariance matrix,

P is the phenotypic variance-covariance matrix, and

i is the selection differential at a given selection intensity, which at 5% is 2.06.

The performance of the 25 clones at both stages was compared by working out the simple correlation between the performance indices at the two stages of growth, in order to see if the performance of the clones in the mature stage could be predicted based on immature performance indices.

RESULTS

4. RESULTS

Morphological, anatomical, physiological and biochemical parameters of twenty five clones of *Hevea* were examined in two stages of growth - mature and immature, in order to study the relationships in each phase, as well as to identify characters showing consistent trends in the two phases. The results of the present investigation are presented under three main headings:

1. Mature phase

2. Immature phase

3. Immature - mature relationships

4.1 MATURE PHASE

Morphological, anatomical, physiological and biochemical traits as well as dry rubber yield in the mature plants were used to assess the extent of genetic divergence in the given population. Variability and genetic parameters for the different traits, as well as the interrelationships among these characters were estimated using variance and covariance analyses. The direct and indirect effects of the various traits on yield were computed. Clones were grouped into clusters based on the degree of divergence between them and the factors of divergence identified. The large number of characters were reduced to fewer number of meaningful factors through factor analysis. Discriminant function analysis was used to formulate a performance index based on which the clones were ranked.

4.1.1. Mean performance and genetic variability

The mean performance of the 25 clones for the various traits are presented in Tables 3-6. The clones exhibited significant differences for all the traits except density and diameter of latex vessels and chlorophyll a:b ratio. The partitioning of this total variability into its heritable and non heritable components is essential in order to obtain an estimate of the actual usable genetic variability, separated from the influence of environment. The variability at the phenotypic, genotypic and environmental levels are presented in Tables 7 and 8. The clones showing the maximum and minimum values for the leaf and bark anatomical traits are shown in Plates 1-8.

4.1.1.1. Girth

Girth of the plants showed high significant clonal differences with a mean of 92.68cm. Mean girth of clones ranged from 69.59cm (RRIM 610) to 127.33cm (RRIM 612). Four clones were on par with RRIM 612. The popular clones RRIM 600 and RRII 105 exhibited only average girth. The phenotypic variance for this trait was 286.30cm while those at the genotypic and environmental levels were 167.20 cm and 119.11cm respectively.

4.1.1.2. Girth increment (%)

Girth increment over two years showed significant clonal differences only at the 5 per cent level. The mean values for the 25 clones ranged from 3.24 per cent for RRIM 628 to 11.12 per cent for RRIM 703. Variances at the phenotypic

Table 3. Mean performance of clones for mature morphological traits

Clone	X1	X2	X3	X4	X5
RRIM 501	79.50	5.66	50.83	0.74	395.83
RRIM 519	98.00	7.49	47.58	0.61	387.50
RRIM 526	92.17	9.29	55.39	0.72	363.89
RRIM 600	89.58	9.25	41.49	0.83	366.67
RRIM 602	123.22	8.29	60.25	0.58	408.33
RRIM 603	86.17	6.64	69.17	0.84	358.33
RRIM 604	103.65	7.84	64.39	0.80	479.17
RRIM 605	99.28	6.62	63.68	0.72	387.50
RRIM 607	112.90	8.41	39.37	0.72	420.83
RRIM 610	69.59	3.76	40.26	0.84	406.67
RRIM 611	89.67	6.98	64.43	0.67	466.67
RRIM 612	127.33	10.05	66.13	0.68	325.00
RRIM 615	79.43	3.43	51.09	0.96	406.67
RRIM 620	84.45	3.96	50.34	0.92	354.17
RRIM 622	102.28	4.94	63.50	0.68	416.67
RRIM 628	72.94	3.24	58.03	0.71	391.67
RRIM 636	85.58	5.43	69.52	0.60	370.83
RRIM 701	91.25	5.95	48.30	0.86	420.83
RRIM 703	86.61	11.12	59.79	0.71	402.78
RRIM 704	76.75	3.52	59.58	0.76	383.33
RRIM 705	92.65	7.10	38.49	0.95	429.17
RRIM 706	109.75	8.64	43.90	0.84	366.67
IAN 873	89.67	6.98	54.28	0.88	425.00
RRII 105	83.08	7.43	43.70	0.81	387.50
HAR 1	91.37	3.95	79.47	0.76	404.17
Mean	92.68	6.64	55.32	0.77	397.03
$F_{24,48}$	5.21**	2.14*	2.67**	2.86**	4.91**
SE_m	6.30	1.52	6.68	0.06	15.40
CD	17.465	4.219	18.504	0.173	42.683

* and** : Clonal differences significant at P = 0.05 and 0.01 respectively

X1 = Girth (cm)
X3 = Leaf size (cm^2)
X5 = Stomatal density (no. mm^{-2})

X2 = Girth increment (%)
X4 = Specific leaf weight (g cm^{-2})

Table 4. Mean performance of clones for mature anatomical traits

Clone	X6	X7	X8	X9	X10	X11	X12	X13
RRIM 501	9.08	32.67	25.84	20.94	72.01	879.04	125.73	47.01
RRIM 519	9.25	37.17	24.52	20.06	87.53	659.28	111.52	36.08
RRIM 526	8.86	37.22	26.19	19.15	78.12	789.02	130.11	41.91
RRIM 600	9.83	29.00	24.41	19.39	54.86	724.88	121.36	36.08
RRIM 602	11.58	39.44	24.83	18.87	103.36	678.60	111.88	45.56
RRIM 603	7.92	31.00	24.72	21.85	74.80	920.59	111.52	47.01
RRIM 604	9.93	35.11	24.36	17.91	68.14	785.01	155.98	57.22
RRIM 605	10.42	35.67	24.34	18.14	65.59	839.68	132.29	51.68
RRIM 607	8.67	43.67	24.66	19.45	108.65	748.93	110.43	46.47
RRIM 610	7.25	30.67	25.83	20.45	49.94	820.33	155.06	46.69
RRIM 611	8.42	30.17	24.96	20.48	69.00	853.89	147.60	48.11
RRIM 612	11.42	39.83	24.90	20.99	136.99	770.80	125.73	55.76
RRIM 615	8.02	25.00	23.21	21.85	48.44	716.95	160.06	55.02
RRIM 620	8.58	29.50	26.27	20.69	67.37	947.92	147.60	51.39
RRIM 622	8.17	31.33	27.79	18.35	70.57	758.77	110.43	42.64
RRIM 628	9.44	31.67	25.01	19.59	52.19	833.85	115.89	41.91
RRIM 636	8.75	27.50	26.24	19.27	54.30	828.75	153.07	47.01
RRIM 701	9.75	37.00	26.06	21.03	92.12	846.24	121.36	39.36
RRIM 703	10.11	40.78	23.80	20.36	86.01	826.56	142.13	48.84
RRIM 704	8.17	29.17	24.89	18.36	45.06	752.21	124.64	39.36
RRIM 705	8.25	31.83	27.49	21.41	83.92	981.87	131.72	46.69
RRIM 706	10.42	32.67	27.10	19.59	88.74	672.40	142.13	44.83
IAN 873	8.67	32.17	23.23	21.52	73.96	725.97	138.85	47.01
RRII 105	10.50	43.33	25.35	21.66	109.35	743.47	141.04	51.39
HAR 1	11.29	39.83	23.25	21.08	91.89	912.93	154.16	55.21
Mean	9.31	34.14	25.17	20.10	77.32	800.72	132.89	46.81
$F_{24,48}$	4.13**	2.45**	1.43	1.70	3.19**	6.78**	3.94**	5.99**
SE_m	0.58	3.21	1.04	0.93	12.42	33.07	8.25	2.37
CD	1.604	8.906	-	-	34.424	91.664	22.859	6.580

* and** : Clonal differences significant at P = 0.05 and 0.01 respectively

X6 = Bark thickness (mm)
X7 = No. of latex vessel rows
X8 = Density of latex vessels (no. mm^{-1})
X9 = Diameter of latex vessels (μ)

X10 = Laticifer area index (mm^{-2})
X11 = Leaf midrib thickness (μ)
X12 = Leaf lamina thickness (μ)
X13 = Palisade layer thickness (μ)

Table 5. Mean performance for physiological traits in the mature stage

Clone	X14	X15	X16	X17
RRIM 501	4.97	115.67	4.59	29.81
RRIM 519	4.60	144.17	3.28	37.22
RRIM 526	6.90	191.83	3.57	32.10
RRIM 600	8.33	196.83	4.03	30.07
RRIM 602	7.80	164.44	4.70	36.72
RRIM 603	4.90	193.67	2.49	29.65
RRIM 604	7.53	185.39	4.12	32.51
RRIM 605	5.00	213.17	2.35	35.15
RRIM 607	11.57	295.00	3.89	33.75
RRIM 610	1.98	61.27	3.23	31.18
RRIM 611	4.37	108.33	4.16	34.07
RRIM 612	8.57	273.83	3.12	34.83
RRIM 615	2.33	83.33	2.76	35.58
RRIM 620	2.87	80.83	3.65	35.15
RRIM 622	6.60	201.33	3.37	30.69
RRIM 628	1.64	56.89	2.88	30.55
RRIM 636	4.73	155.17	3.12	31.03
RRIM 701	3.80	179.50	2.10	36.81
RRIM 703	4.36	208.78	2.10	32.29
RRIM 704	5.73	176.50	3.37	31.82
RRIM 705	4.53	129.37	3.49	35.24
RRIM 706	6.87	266.67	2.56	34.71
IAN 873	3.57	94.00	3.81	34.91
RRII 105	7.93	267.00	3.00	34.39
HAR 1	3.43	105.50	3.65	31.53
Mean	5.40	165.94	3.34	33.27
$F_{24,48}$	4.28**	5.71**	3.48**	3.40**
SE_m	1.15	28.41	0.38	1.27
CD	3.183	78.752	1.056	3.531

* and** : Clonal differences significant at P = 0.05 and 0.01 respectively

X14 = Initial flow rate (ml min⁻¹)   X15 = Final volume (latex volume yield) (ml)

X16 = Plugging index   X17 = Dry rubber content (%)

Table 6. Mean performance of clones for mature biochemical traits and yield

Clone	X18	X19	X20	X21	X22	X23	X24	X25	X26	X27
RRIM 501	36.04	13.03	71.26	720.86	350.92	1.89	1.39	3.29	1.46	51.80
RRIM 519	39.94	6.00	68.92	843.60	650.12	3.07	1.55	4.68	2.58	66.76
RRIM 526	37.69	7.14	45.91	478.77	1081.67	2.23	1.76	3.90	1.27	74.25
RRIM 600	36.24	8.41	54.33	750.69	1541.03	2.15	1.65	3.80	1.40	65.82
RRIM 602	41.79	11.59	38.74	699.95	970.92	2.51	1.98	4.48	1.31	61.99
RRIM 603	35.89	7.33	54.84	600.76	787.53	1.36	0.67	2.00	2.03	50.74
RRIM 604	38.95	7.00	54.09	496.67	927.94	1.77	1.26	3.03	1.68	73.64
RRIM 605	41.94	10.67	71.16	496.33	1279.83	2.67	1.99	4.66	1.35	89.53
RRIM 607	39.49	17.97	86.01	954.90	668.75	2.57	1.65	4.22	1.61	102.82
RRIM 610	36.08	9.85	70.49	398.65	1313.33	2.97	2.18	5.14	1.40	26.38
RRIM 611	41.71	8.95	54.55	550.53	927.08	2.87	2.14	5.01	1.37	52.04
RRIM 612	41.62	11.70	36.79	1123.88	336.67	1.86	1.92	3.84	0.97	67.58
RRIM 615	40.18	7.82	74.73	500.55	1192.77	2.06	1.62	3.67	1.30	31.16
RRIM 620	37.90	11.11	41.97	315.78	1077.92	2.09	1.43	3.53	1.46	49.71
RRIM 622	37.06	6.30	65.41	260.45	1058.33	2.02	2.11	4.12	1.01	78.12
RRIM 628	38.15	10.60	78.69	727.98	794.94	1.76	1.85	3.63	0.98	27.42
RRIM 636	37.13	9.92	49.63	605.11	842.50	3.18	2.12	5.39	1.52	55.91
RRIM 701	40.98	11.34	68.34	462.10	444.17	1.99	2.06	4.05	1.20	71.77
RRIM 703	37.10	9.90	89.79	301.53	747.78	2.23	1.85	4.08	1.22	93.72
RRIM 704	37.53	9.32	63.65	670.09	1091.25	2.70	1.82	4.60	1.47	48.62
RRIM 705	39.84	5.78	89.27	997.84	987.92	2.19	1.26	3.47	1.76	60.77
RRIM 706	38.07	10.73	87.65	365.21	443.08	2.21	1.63	3.84	1.33	96.91
IAN 873	41.85	8.30	48.29	684.10	589.62	1.66	1.05	2.71	1.76	46.36
RRII 105	41.12	9.35	84.65	716.33	1108.08	2.64	1.99	4.65	1.39	90.11
HAR 1	37.40	11.24	79.23	289.89	694.58	2.10	2.24	4.34	0.95	55.00
Mean	38.87	9.65	65.14	600.50	876.35	2.27	1.73	4.00	1.43	63.56
$F_{24,48}$	2.10*	4.06**	4.99**	7.19**	3.21**	2.51**	3.87**	4.14**	1.61	4.35**
SE_m	1.44	1.30	7.37	85.16	173.58	0.29	0.20	0.38	0.28	10.03
CD	4.000	3.609	20.430	236.060	481.140	0.816	0.546	1.051	-	27.800

* and** : Clonal differences significant at P = 0.05 and 0.01 respectively

X18 = Total solids content of latex (%)

X19 = Latex thiol content (mg 100g⁻¹ latex)

X19 = Latex thiol content (mg $100g^{-1}$ latex)

X20 = Inorganic phosphorous (mg $100g^{-1}$ latex)

X21 = Sucrose in latex (mg $100g^{-1}$ latex)

X22 = Magnesium content ($\mu g\ g^{-1}$ latex)

X23 = Chlorophyll a (mg g^{-1} fresh leaf)

X24 = Chlorophyll b (mg g^{-1} fresh leaf)

X25 = Total chlorophyll (mg g^{-1} fresh leaf)

X26 = Chlorophyll a :b ratio

X27 = Dry rubber yield (g tree⁻¹ tap⁻¹)

Table 7. Variability components for mature morphological and anatomical traits

Sl. No.	Trait	Phenotypic variance	Genotypic variance	Environmental variance
1	Girth (cm)	286.30	167.20	119.11
2	Girth increment (%)	9.58	2.63	6.95
3	Leaf size (cm^2)	208.28	74.58	133.70
4	Specific leaf weight ($g\,cm^{-2}$)	0.02	0.01	0.01
5	Stomatal frequency (no. mm^{-2})	1639.60	928.25	711.35
6	Bark thickness (mm)	2.05	1.05	1.01
7	Number of latex vessel rings	45.98	15.01	30.79
8	Density of latex vessels (no. mm^{-1})	3.74	0.47	3.27
9	Diameter of latex vessels (μ)	3.22	0.61	2.61
10	Laticifer area index (mm^2)	800.28	337.58	462.70
11	Leaf midrib thickness (μm)	9604.80	6324.00	3280.80
12	Leaf lamina thickness (μm)	403.81	199.78	204.03
13	Palisade layer thickness (μm)	45.04	28.13	16.90

Table 8. Variability components for mature physiological and biochemical traits, and yield.

Sl. No.	Trait	Phenotypic variance	Genotypic variance	Environmental variance
1	Initial flow rate (ml min^{-1})	8.28	4.32	3.96
2	Latex volume yield (ml)	6221.20	3799.50	2421.60
3	Plugging index	0.80	0.36	0.44
4	Dry rubber content (%)	8.77	3.90	4.87
5	Total solid content (%)	8.52	2.28	6.24
6	Thiol content (mg 100g^{-1} latex)	10.26	5.18	5.08
7	Inorganic phosphorous (mg 100g^{-1} latex)	379.71	216.73	162.98
8	Sucrose (mg 100 g^{-1} latex)	66661.00	44902.00	21759.00
9	Magnesium in latex (µg g^{-1} latex)	156996.00	66605.00	90391.00
10	Chlorophyll a (mg g^{-1} fresh leaf)	0.39	0.13	0.26
11	Chlorophyll b (mg g^{-1} fresh leaf)	0.23	0.11	0.12
12	Total chlorophyll (mg g^{-1} fresh leaf)	0.88	0.45	0.43
13	Chlorophyll a:b ratio.	0.28	0.05	0.23
14	Dry rubber yield (g tree^{-1} tap^{-1})	638.53	336.79	301.74

and genotypic levels were 9.58 and 2.63 per cent respectively. A high environmental variance of 6.95 per cent was observed for this trait.The general mean for this trait was 6.64 per cent, with 12 clones including the popular cultivars RRIM 600 and RRII 105 being on par with the highest clone.

4.1.1.3. Leaf size

Leaf size ranged from 38.49 cm^2 for RRIM 705 to 79.47 cm^2 for Har 1, with the variance at the genotypic and phenotypic levels being 74.58 and 208.28 cm^2 respectively. A high environmental variance of 133.70 cm^2 was observed for this trait. The population average for this trait was 55.31 cm^2. The clones RRIM 600 and RRII 105 had small leaves on par with that of the lowest.

4.1.1.4. Specific leaf weight

The specific leaf weight of the plants showed highly significant clonal differences, with values varying from 0.58 g cm^{-2} (RRIM 602) to 0.96 g cm^{-2} (RRIM 615). The phenotypic variance for this trait was 0.02g while that at the genotypic and environmental levels were 0.01 g cm^{-2} each. A general mean of 0.77 g cm^{-2} was observed for this trait, with 10 clones including the popular cultivars being on par with RRIM 615.

4.1.1.5. Number of stomata per unit area of leaf

High significant clonal differences were recorded for stomatal density per mm^2. The values ranged from 325 (RRIM 612) to 479.17 per mm^2 (RRIM 604),

with a general mean of 397.03 mm^{-2}. The variances at the phenotypic, genotypic and environmental levels were 1639.60, 928.25 and 711.35 mm^{-2} respectively. The popular clones exhibited average density of stomata.

4.1.1.6. Bark thickness

This trait had highly significant clonal differences. The mean values ranged from 7.25mm (RRIM 610) to 11.58mm (RRIM 602), with a general mean of 9.31mm. At the phenotypic, genotypic and environmental levels, the variances were 2.05, 1.05 and 1.01 respectively. RRIM 600 had an average bark thickness while that of RRII 105 was on par with the highest.

4.1.1.7. Number of latex vessel rows

High significant clonal differences were observed for this trait. The average number of latex vessel rows for the 25 clones ranged from 25 for RRIM 615 to 43.67 for RRIM 607, with a general mean of 34.14. RRII 105 was on par with the clone having the highest number of latex vessel rows, while RRIM 600 had a very low latex vessel count. The variance at the phenotypic level was 45.98, while those at the genotypic and environmental levels were 15.01 and 30.79 respectively.

4.1.1.8. Density of latex vessels

Clonal differences for this trait were not statistically significant. The individual values ranged from 23.21 mm^{-1} for RRIM 615 to 27.79 mm^{-1} for RRIM 622 with a general average of 25.17 mm^{-1}. The genetic variance was also very low (0.47) compared to its environmental variance (3.27).

4.1.1.9. Diameter of latex vessels

This trait also did not differ significantly among clones. The diameter ranged from 17.91µm (RRIM 604) to 21.85µm (RRIM 615), with a general average of 20.10µm. The genetic variance for this trait too was also very low (0.61 µm) compared to its environmental variance (2.61 µm).

4.1.1.10. Laticifer area index

Highly significant clonal differences were observed for this trait, with clonal average values ranging from 45.06 mm^2 (RRIM 704) to 136.99 mm^2 (RRIM 612). The population mean was 77.32 mm^2. RRII 105 was on par with the clone with the highest laticifer area index (RRIM 612), while RRIM 600 was one among the clones showing the lowest values for this trait. The variability at the genotypic level was 337.58 mm^2 while that at the phenotypic level was 800.28 mm^2.

4.1.1.11. Leaf midrib thickness

The clones showed high significant differences for this character. The mean values ranged from 659.28µm (RRIM 519) to 981.87µm (RRIM 705), with a general mean of 800.72µm. RRIM 600 and RRII 105 had average midrib thickness. The phenotypic and genotypic variances were 9604.80µm and 6324.00µm respectively.

4.1.1.12. Leaf lamina thickness

Clonal differences were significant for this trait. The thickness varied from 110.43µm for RRIM 622 to 160.06µm for RRIM 615, with a population mean of

132.89µm. The variances at the phenotypic, genotypic and environmental levels were 403.81µm, 199.78µm and 204.03µm respectively. The lamina thickness of RRII 105 was on par with the highest, while that of RRIM 600 was only average.

4.1.1.13. Palisade layer thickness

Significant clonal differences were recorded for this trait. The clones had an average thickness of 46.81µm with individual clones showing values ranging from 36.08µm (RRIM 519) to 57.22µm (RRIM 604). The variances at the phenotypic, genotypic and environmental levels were 45.04µm, 28.13µm and 16.90µm respectively.

4.1.1.14. Initial flow rate

Clonal differences were highly significant for this trait. The initial flow rate ranged from 1.64 ml min^{-1} (RRIM 628) to 11.57 ml min^{-1} (RRIM 607), with a general average of 26.98 ml min^{-1}. RRIM 600 was the only other clone on par with RRIM 607, though RRII 105 also showed a fairly high value for this trait. The genotypic variance was 4.32 ml min^{-1}, though at the phenotypic level it was 8.28 ml min^{-1}, with the environmental variance being 3.96 ml min^{-1}.

4.1.1.15. Final latex volume yield

Final latex volume obtained on each tapping day exhibited considerable differences among the clones, with values ranging from 56.89 ml (RRIM 628) to 295 ml (RRIM 607). The population mean was 165.94 ml. Three clones including RRII 105 were on par with RRIM 607. RRIM 600 recorded only an average

value for this character. The phenotypic, genotypic and environmental variances were 6221.20, 3799.5 and 2421.60 respectively.

4.1.1.16. Plugging index

Plugging indices for the 25 clones were significantly different, ranging from 2.10 (RRIM 706) to 4.70 (RRIM 602). The mean value was 3.34. Seven clones including RRIM 600 had very high plugging index on par with the highest, while nine clones including RRII 105 were on par with the lowest plugging index value. The variance for this trait was 0.80 at the phenotypic level while it was 0.36 and 0.44 at the genotypic and environmental levels.

4.1.1.17. Dry rubber content

The dry rubber content of the 25 clones exhibited significant clonal differences with values ranging from 29.65 (RRIM 603) to 37:22 per cent (RRIM 519). The general mean of the clones was 33.27 per cent. 12 clones including RRII 105 were on par with RRIM 519. RRIM 600 had only an average dry rubber content. Variance at the phenotypic level was 8.77 per cent while those at the genotypic and environmental levels were 3.90 and 4.87 per cent respectively.

4.1.1.18. Total solids content

Significant clonal differences for total solids content in the latex were observed. The individual clones showed mean values ranging from 35.89 per cent (RRIM 603) to 41.94 per cent (RRIM 605), with an average of 38.87 per cent.

14 clones including RRII 105 were on par with RRIM 605 for this trait. The phenotypic variance was 8.52 per cent while at the genotypic level, it was 2.28 per cent. A very high environmental component of 6.24 per cent was observed or this trait.

4.1.1.19. Thiols

The latex thiol content showed high clonal differences with mean values for the different clones ranging from 5.78 mg (RRIM 705) to 17.97 mg 100g^{-1} latex (RRIM 607). The population mean was 9.65 mg. No other clone was on par with RRIM 607. Clones RRIM 600 and RRII 105 showed average levels of thiol content. The variance at the phenotypic level was 10.26 mg, with the genotypic and environmental components being equally high (5.08 and 5.18 mg respectively).

4.1.1.20. Inorganic phosphorous

The 25 clones showed highly significant differences among themselves for inorganic phosphorous content of latex. The general mean for this trait was 65.14 mg 100g^{-1} latex. The mean clonal values ranged from 36.79 mg (RRIM 612) to 89.79 mg (RRIM 703). 14 clones including RRII 105 were on par with RRIM 703 for this trait. RRIM 600 had only an average inorganic phosphorous content. The phenotypic variance was 379.71 mg 100g^{-1} latex. The variance at the genotypic level was also relatively high at 216.73 mg 100g^{-1} latex, with the environmental variance being 162.98 mg.

4.1.1.21. Sucrose

The 25 clones showed high significant differences for sucrose content in the latex. The population averaged 600.50 mg sucrose 100 g^{-1} latex, with clones

ranging from 260.45 mg (RRIM 622) to 1123.88 mg (RRIM 612). RRIM 607 and RRIM 705 were found to be on par with RRIM 612. RRII 105 showed a mean equal to the population mean. The variances at the genotypic and phenotypic levels were found to be extremely high at 66661 and 44902 mg 100g^{-1} latex respectively, with a comparatively lower environmental component of 21759 mg.

4.1.1.22. Magnesium content in latex

Significant overall clonal differences were observed for magnesium content in latex, with clones ranging from 336.67 µg g^{-1} latex (RRIM 612) to 1541.03 µg g^{-1} latex (RRIM 600). RRIM 526, RRIM 605, RRIM 610 and RRII 105 were on par with RRIM 600. The overall mean was 876.35 µg g^{-1} latex. Variance at the phenotypic level was also found to be very high at 156996 µg g^{-1} latex, while that at the genotypic level was 66605 µg. The environmental variance was 90391 µg g^{-1} latex.

4.1.1.23. Chlorophyll content in leaves

High significant differences were recorded for chlorophyll a, b and total chlorophyll. However, clonal differences were not detected for chlorophyll a:b ratio. The maximum chlorophyll a content was recorded for RRIM 636 (3.18 mg g^{-1} fresh leaf weight) and the minimum for RRIM 603 (1.36mg). The population mean was 2.27 mg g^{-1} fresh leaf weight. Nine clones including RRII 105 had a high chlorophyll a content on par with RRIM 636, while 11 clones had low values on par with RRIM 603. The variances at the phenotypic and genotypic levels were 0.39 and 0.13 mg respectively. The environmental component for this trait was relatively high at 0.26 mg.

The chlorophyll b content ranged from 0.67 mg g^{-1} fresh leaf weight (RRIM 603) to 2.23 mg (Har 1), with a general mean of 1.73 mg. RRIM 600 had average chlorophyll b content, while RRII 105 was on par with Har 1. The variance at the genotypic level was only 0.11 mg g^{-1} fresh leaf weight while that at the phenotypic level was 0.23mg.

Total chlorophyll content ranged from 2.00 mg g^{-1} fresh leaf weight in RRIM 603 to 5.39 mg in RRIM 636. The population mean was 4.00 mg. RRIM 600 recorded average levels of total chlorophyll. RRIM 610, RRIM 611, RRIM 519, RRIM 602, RRIM 605, RRIM 704 and RRII 105 were on par with RRIM 636. The phenotypic and genotypic variances were 0.88 and 0.45 mg respectively.

Chlorophyll a:b ratio ranged from 0.95 (Har 1) to 2.58 (RRIM 519), with a general average of 1.43. The genotypic variance was only 0.05 while the phenotypic variance was 0.28.

4.1.1.24. Dry rubber yield

The average annual dry rubber yield per tree per tapping showed high significant clonal differences. The highest yield was recorded in RRIM 607 (102.82 g $tree^{-1}tap^{-1}$) while the lowest was seen in RRIM 610 (26.38 g). RRIM 706, RRIM 703, RRII 105, RRIM 605 and RRIM 622 were on par with the highest yielder, with mean yields ranging from 78.12 g to 96.91g. The yield of RRIM 600 was only 65.82 g which was on par with the population average of 63.56 g $tree^{-1}tap^{-1}$ at this age. The variances at the phenotypic and genotypic levels at this age were 638.53 g and 336.79 g respectively, with the environmental component being 301.74 g.

4.1.2. Genetic parameters

The genetic parameters like genotypic and phenotypic coefficients of variation (GCV and PCV), broad sense heritability (H^2) and genetic advance as percentage of mean, based on a selection intensity of 5 per cent (GA) for all the characters are given in Table 9 and 10. Figures 1-2 depict the genetic parameters for the different traits.

The phenotypic coefficients of variation ranged from 7.51 per cent for total solid content to 53.32 per cent for initial flow rate. Among the morphological traits, relatively high PCV was recorded for girth increment (46.63%) and leaf size (26.09%). All the other morphological traits had moderate estimates of PCV Laticifer area index displayed relatively high PCV among the anatomical traits. The remaining bark anatomical traits, viz. bark thickness and number of latex vessel rows had moderate levels, while density and diameter of latex vessels showed extremely low PCV (7.69 and 8.96% respectively). Leaf midrib, lamina, and palisade layer thickness displayed medium PCV. The latex physiological traits initial flow rate, final volume of latex and plugging index had high PCV, while dry rubber content had very low PCV (8.9%). All the leaf and latex biochemical parameters had relatively high PCV (23.46 - 45.21%) except total solids content (7.51%).

Similar trends were seen for GCV. Initial flow rate showed the highest estimate of variation at the genotypic level too (38.52%), followed by latex volume yield (37.15%) and sucrose content of latex (35.29%). Girth increment and laticifer area index exhibited relatively high levels of GCV (24.43% and 23.76% respectively). All the other morphological and anatomical parameters had moderate

Figure 1. Genetic parameters for mature morphological and anatomical traits

X1	Girth
X2	Girth increment
X3	Leaf size
X4	Specific leaf weight
X5	No. of stomata per unit leaf area
X6	Bark thickness
X7	Number of latex vessel rows
X8	Density of latex vessels
X9	Diameter of latex vessels
X10	Laticifer area index
X11	Leaf midrib thickness
X12	Leaf lamina thickness
X13	Leaf palisade layer thickness

Figure 1. Genetic parameters for mature morphological and anatomical traits

Figure 2. Genetic parameters for mature physiological and biochemical traits

X14	Initial flow rate
X15	Final volume of latex
X16	Plugging index
X17	Dry rubber content
X18	Total solids content
X19	Thiol concentration in latex
X20	Inorganic phosphorous in latex
X21	Sucrose concentration in latex
X22	Magnesium concentration in latex
X23	Chlorophyll a in leaves
X24	Chlorophyll b in leaves
X25	Total chlorophyll in leaves
X26	Chlorophyll a:b ratio
X27	Dry rubber yield

Figure 2. Genetic parameters for mature physiological and biochemical traits and yield

P.C.V.   G.C.V. H^2 G.A. (% over mean)

Table 9. Estimates of genetic parameters for mature morphological and anatomical traits

Sl. No.	Traits	PCV (%)	GCV (%)	H^2 (%)	GA (% over mean)
1	Girth (cm)	18.26	13.95	58.40	21.96
2	Girth increment (%)	46.63	24.43	27.45	26.37
3	Leaf size (cm^2)	26.09	15.61	35.81	19.24
4	Specific leaf weight (g cm^{-2})	17.91	11.08	38.25	14.11
5	Stomatal frequency (no. mm^{-2})	10.20	7.67	56.61	11.89
6	Bark thickness (mm)	15.40	11.00	51.09	16.20
7	Number of latex vessel rings	19.86	11.35	32.64	13.36
8	Density of latex vessels (no. mm^{-1})	7.69	2.72	12.53	1.98
9	Diameter of latex vessels (μm)	8.93	3.89	18.96	3.49
10	Laticifer area index (mm^2)	38.59	23.76	42.18	31.79
11	Leaf midrib thickness (μm)	12.24	9.93	65.84	16.60
12	Leaf lamina thickness (μm)	15.12	10.64	49.47	15.41
13	Palisade layer thickness (μm)	14.34	11.33	62.46	18.45

Table 10. Estimates of genetic parameters for mature physiological and biochemical traits, and yield

Sl. No.	Traits	PCV (%)	GCV (%)	H^2 (%)	GA (% over mean)
1	Initial flow rate (ml min^{-1})	53.32	38.52	52.20	57.34
2	Latex volume yield (ml)	47.53	37.15	61.07	59.80
3	Plugging index	26.73	17.99	45.30	24.95
4	Dry rubber content (%)	8.90	5.93	44.48	8.15
5	Total solid content (%)	7.51	3.88	26.78	4.14
6	Thiol content (mg 100g^{-1} latex)	33.19	23.58	50.48	34.51
7	Inorganic phosphorous (mg 100g^{-1}latex)	29.92	22.60	57.08	35.18
8	Sucrose (mg 100 g^{-1} latex)	43.00	35.29	67.39	59.66
9	Magnesium in latex (µg g^{-1} latex)	45.21	29.45	42.42	39.51
10	Chlorophyll a (mg g^{-1} fresh leaf)	27.55	15.95	33.53	19.03
11	Chlorophyll b (mg g^{-1} fresh leaf)	27.65	19.33	48.90	27.85
12	Total chlorophyll (mg g^{-1} fresh leaf)	23.46	16.78	51.18	24.71
13	Chlorophyll a:b ratio.	37.00	15.25	16.99	12.95
14	Dry rubber yield (g tree^{-1} tap^{-1})	39.76	28.87	52.74	43.19

GCV, except for stomatal density, leaf midrib thickness, density and diameter of latex vessels (7.67, 9.93, 2.72 and 3.89% respectively). Apart from initial flow rate and final volume of latex, relatively high GCV was exhibited by latex thiols, inorganic phosphorous, sucrose and magnesium (35.29 - 22.60%) and yield (28.87%). Dry rubber content and total solids content had very low GCV (5.93 and 3.88%), while plugging index, chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a:b ratio had moderate GCV.

Heritability for the various characters studied ranged from 12.53 per cent for density of latex vessels to 67.39 per cent for sucrose content of latex. Among the morphological characters, all the traits recorded moderate heritability (30-60 per cent), except girth increment which had only a low value. Of the anatomical traits, leaf midrib thickness and palisade layer thickness showed high heritability, while bark thickness, leaf lamina thickness, laticifer area index and number of latex vessel rows recorded moderate heritability estimates. Density and diameter of latex vessels showed very low estimates (12.53 and 18.96% respectively) indicating the influence of environment for these traits. High heritability for latex volume yield was observed, while this estimate was moderate for the remaining three physiological parameters. Moderate heritability was recorded for all the biochemical parameters except sucrose content, which had a high estimate, and chlorophyll a:b ratio which had a very low estimate. Dry rubber yield showed moderate levels of heritability.

Estimates of genetic advance at 5 per cent selection intensity ranged from 1.98 per cent for density of latex vessels to 59.80 per cent for latex volume yield. All the morphological traits showed low (<16%) to medium (16-28%) estimates of genetic advance. Among the leaf and bark anatomical traits, only laticifer area

index showed relatively high genetic advance (31.79%), while bark thickness, leaf midrib and palisade layer thickness exhibited medium values. All other anatomical traits had only low estimates of genetic advance. The physiological parameters initial flow rate, final latex volume and plugging index had high estimates of genetic advance (>28%), while that for dry rubber content was low (8%). Of the biochemical traits, only total solids content and chlorophyll a:b ratio had low estimates of genetic advance, while the estimates of chlorophyll a, b and total chlorophyll were moderate. All the other biochemical parameters showed high estimates of genetic advance. Yield also recorded a high genetic advance of 43.19%.

4.1.3 Association between characters

The phenotypic, genotypic and environmental correlations of mature yield and other morphological, anatomical, physiological and biochemical parameters are presented below. The correlation coefficient values for all the variables at the phenotypic, genotypic and environmental levels are shown separately in Appendices A, B and C respectively.

4.1.3.1. Correlations between yield and other parameters

Table 11 gives the phenotypic, genotypic and environmental correlations of yield with all the other parameters. Final volume of latex was found to have the highest phenotypic correlation with yield (r= 0.8179**), followed by initial flow rate (r= 0.6344**). Girth (r= 0.5966**), girth increment (r= 0.5317**), laticifer area index (r= 0.4908**), number of latex vessel rows (r= 0.4862**), bark

Table 11. Phenotypic, genotypic and environmental correlations between yield and 26 other variables at the mature stage

Trait		Correlation coefficients		
		Phenotypic	Genotypic	Environmental
Girth	X1	0.5966**	0.5623	0.6418**
Girth increment	X2	0.5317**	0.9222	0.3088*
Leaf size	X3	-0.1091	-0.1529	-0.0774
Specific leaf weight	X4	-0.1369	-0.3008	-0.0034
Stomatal density	X5	-0.0344	0.0025	-0.0789
Bark thickness	X6	0.3529**	0.5357	0.1557
No.latex vessel rows	X7	0.4862**	0.8610	0.2287
Density of latex vessels	X8	0.0996	0.3002	0.0349
Diameter of latex vessel	X9	-0.2113	-0.4980	-0.0870
Laticifer area index	X10	0.4908**	0.6479	0.3542*
Midrib thickness	X11	-0.1971	-0.3084	-0.0383
Lamina thickness	X12	-0.0781	-0.3623	0.2189
Palisade layer thickness	X13	0.0554	-0.0441	0.1917
Initial flow rate of latex	X14	0.6344**	0.7766	0.4775**
Final latex volume	X15	0.8179**	0.9112	0.7011**
Plugging index	X16	-0.2142	-0.1553	-0.2720
Dry rubber content	X17	0.1783	0.2757	0.0874
Total solid content	X18	0.0673	0.3581	-0.1144
Latex thiols	X19	0.2124	0.2578	0.1640
Inorganic phosphorous	X20	0.2895**	0.2828	0.2983*
Latex sucrose	X21	-0.0345	0.0341	-0.1395
Latex magnesium	X22	-0.1498	-0.1843	-0.1200
Chlorophyll a	X23	0.0523	0.1965	-0.0540
Chlorophyll b	X24	0.0388	0.1527	-0.0789
Total chlorophyll	X25	0.0475	0.1742	-0.0893
Chlorophyll a:b ratio	X26	-0.0170	0.0103	-0.0321

.0441 0.1917

thickness (r= 0.3529**) and inorganic phosphorous (r= 2895**) were also found to be phenotypically correlated with yield. Plugging index and diameter of latex vessels were negatively correlated (r= -0.2142) while thiols showed a positive phenotypic correlation with yield (r= 0.2124). However, these two correlations were not statistically significant.

At the genotypic level, the highest correlation of yield was observed with girth increment (r= 0.9222) followed by final volume (r= 0.9112), number of latex vessel rows (r= 0.8610), initial flow rate (r= 0.7766) and laticifer area index (r= 0.6479). Positive correlations at the genotypic level were also detected with girth, bark thickness, density of latex vessels, total solid content, dry rubber content, inorganic phosphorous, and thiol content, with values ranging from 0.5623 to 0.2578. Negative genotypic correlations of yield were recorded with diameter of latex vessels, lamina thicknes, midrib thickness and specific leaf weight (r= - 0.4958, -0.3623, -0.3084 and -0.3008 respectively).

Significant positive environmental correlations between yield and final latex volume, girth, initial flow rate, girth increment, laticifer area index and inorganic phosphorous, indicate that environment affected the expression of these traits in a similar manner. Non significant environmental correlations of yield with the remaining traits showed that the environment played no role in the correlations between these traits.

4.1.3.2. Associations between morphological traits

The *inter se* correlations among the mature morphological traits at the phenotypic, genotypic and environmental levels are shown in Table 12. The highest positive phenotypic correlation was recorded between girth and girth increment

Table 12. Phenotypic, genotypic and environmental correlations among five mature morphological traits

Trait			X2	X3	X4	X5
Girth	X1	P	0.4720**	0.1383	-0.2783*	-0.0948
		G	0.8036	0.1138	-0.4735	-0.0131
		E	0.2735	0.1669	-0.1076	-0.2055
Girth increment	X2	P		-0.0821	-0.0070	-0.0989
		G		-0.1860	-0.5980	-0.0936
		E		-0.0348	0.2790	-0.1105
Leaf size	X3	P			-0.4100**	-0.0394
		G			-0.5023**	0.0011
		E			-0.3560	-0.0756
Specific leaf weight	X4	P				0.0514
		G				0.0954
		E				0.0134
Stomatal density	X5	P				
		G				
		E				

* : Significant at 5% level of significance

** : Significant at 1% level of significance

(r= 0.4720**), and negative correlation between leaf size and specific leaf weight (r= -0.4100**). Significant negative phenotypic correlation was detected between girth and specific leaf weight (r= -0.2783*). All other morphological correlations were not significant. Similar results were obtained at the genotypic level too, with the highest correlation being recorded between girth and girth increment (r= 0.8036). Negative genotypic correlations were also recorded for specific leaf weight with leaf size (r= -0.5023) and girth (-0.4735). In addition, specific leaf weight also showed a high genotypic correlation with girth increment (r= -0.5980), though this relationship was negligible at the phenotypic level. The only significant environmental correlation was between leaf size and specific leaf weight (r= -0.3560**) indicating that these traits were affected in opposing ways by the environment.

4.1.3.3. Associations between anatomical traits

The correlations among the eight anatomical bark and leaf parameters recorded in the mature plants at the phenotypic, genotypic and environmental levels, are presented in Table 13.

The highest correlation at the phenotypic level was recorded between laticifer area index and number of latex vessel rows (r= 0.7930**), followed by bark thickness and diameter of latex vessels (r= 0.5632** and 0.3288** respectively). Bark thickness was also correlated positively with number of latex vessel rows (r= 5631**), and negatively with density of latex vessels (r= -0.2931**) at the phenotypic level. Leaf lamina thickness and palisade layer thickness were phenotypically positively correlated (r= 0.4936**). All other phenotypic anatomical correlations were not significant.

Table 13. Phenotypic, genotypic and environmental correlations among eight mature anatomical traits

Traits			X7	X8	X9	X10	X11	X12	X13
Bark	X6	P	0.5631**	-0.2931**	-0.0519	0.5632**	-0.1325	0.0295	0.1682
thickness		G	0.7235	-0.2120	-0.2645	0.6846	-0.3231	-0.1507	0.3215
		E	0.4663**	-0.3661**	0.0483	0.4614**	0.1343	0.2118	-0.0313
Number of	X7	P		-0.1372	-0.0088	0.7930**	-0.0369	-0.1248	0.1222
latex vessel		G		-0.2806	0.0012	0.8620	-0.2861	-0.4373	0.1950
rows		E		-0.1048	-0.0115	0.7581**	0.1996	0.0873	0.0678
Density of	X8	P			-0.1855	0.0211	0.0993	-0.1497	-0.1924
latex vessels		G			-0.1081	-0.0071	0.4532	-0.2874	-0.5630
		E			-0.2006	0.0320	-0.0564	-0.1214	-0.0609
Diameter of	X9	P				0.3288**	0.1445	0.0502	0.1765
latex vessels		G				0.1074	0.613	0.4584	0.3582
		E				0.4360**	-0.1371	-0.1409	0.0966
Laticifer	X10	P					-0.0565	-0.1637	0.1872
area index		G					-0.2177	-0.4163	0.2749
		E					0.1310	0.0489	0.0991
Leaf midrib	X11	P						0.2300*	0.1974
thickness		G						0.1658	0.3502
		E						0.3257*	-0.0759
Leaf lamina	X12	P							0.4936**
thickness		G							0.7410
		E							0.1876
Palisade	X13	P							
layer		G							
thickness		E							

* : Significant at 5% level of significance
**: Significant at 1% level of significance

At the genotypic level also, the highest correlation was obtained between number of latex vessel rows and laticifer area index (r= 0.8620). The genotypic correlations of bark thickness with number of latex vessel rows (r= 0.7235), and laticifer area index (r= 0.6846) were also high. The significant positive phenotypic correlation between diameter and laticifer area index was not retained at the genotypic level. The relationship between leaf lamina thickness and palisade layer thickness at the genotypic level was also positive and high (r= 0.7410).

Fairly high genotypic correlations were also obtained between the leaf and bark anatomical traits, though these were not significant at the phenotypic level. Bark thickness had a negative genotypic correlation with leaf midrib thickness and a positive correlation with palisade layer thickness (r= -0.3231 and 0.3215 respectively). Number of latex vessel rows had a negative correlation with leaf midrib thickness and lamina thickness (r= -0.2861 and -0.4373 respectively). Density of latex vessels showed a relatively high negative correlation with palisade layer thickness (r= -0.5630) and a positive correlation with midrib thickness (r= 0.4532). Diameter of latex vessels showed genotypic correlations of 0.6130, 0.4584 and 0.3582 respectively with leaf midrib, lamina and palisade layer thickness. Laticifer area was negatively correlated with lamina thickness (r= -0.4163).

Relatively high positive environmental influence was observed in the correlation between bark thickness and number of latex vessel rows, density of latex vessels and laticifer area index as evidenced by their significant environmental correlations. Significant environmental correlations were also seen between laticifer area index with number of latex vessel rows and diameter of latex vessels. All other environmental correlations were not significant.

4.1.3.4. Associations between physiological traits

The phenotypic, genotypic and environmental correlations among the four physiological traits are given in Table 14. Initial flow rate was found to have high positive phenotypic correlations with final volume of latex, and a relatively lower correlation with plugging index (r= 0.8238** and 0.3490** respectively). These correlations were also influenced by the environment in a similar manner as indicated by their high positive environmental correlations. Final latex volume was found to have a negative but statistically non significant phenotypic correlation with plugging index (r= -0.1987). At the genotypic level too, the correlation was negative (r= -0.2273). Environment had a negative influence on the correlation between these two traits.

4.1.3.5. Associations between biochemical traits

Table 15 gives the phenotypic, genotypic and environmental correlations among the nine latex and leaf biochemical traits. At the phenotypic level, the only significant correlation that could be detected among the latex biochemical traits was that between latex thiols and magnesium (r= -0.2310*). However, at the genotypic level, total solids content was correlated with sucrose (r= 0.5276), thiols with magnesium (r= -0.5052) and sucrose with magnesium (r= -0.3273), while the corresponding environmental correlations were very low. High positive phenotypic and genotypic correlations were observed amongst the three leaf traits-leaf chlorophyll a, b and total chlorophyll. Chlorophyll a:b ratio showed a positive phenotypic correlation with chlorophyll a (r= 0.3539**), while its correlation with chlorophyll b was negative (r= -0.5936**). At the genotypic level, the correlation

Table 14. Phenotypic, genotypic and environmental correlations among four mature physiological traits

Trait			X19	X20	X21
Initial flow rate	X18	P	0.8238**	0.3490**	0.0580
		G	0.8707	0.2619	0.0075
		E	0.7701**	0.4335**	0.1055
Final latex volume	X19	P		-0.1987	0.0896
		G		-0.2273	0.1059
		E		-0.1716	0.0740
Plugging index	X20	P			-0.0278
		G			-0.1912
		E			0.1053
Dry rubber content	X21	P			
		G			
		E			

* : Significant at 5% level of significance

** : Significant at 1% level of significance

Table 15. Phenotypic, genotypic and environmental correlations among nine
mature latex and leaf biochemical traits

Traits			X19	X20	X21	X22	X23	X24	X25	X26
TSC	X18	P	0.0388	-0.1257	0.2241	-0.1015	0.0688	0.1588	0.1289	-0.0772
		G	0.1192	-0.1352	0.5276	-0.2057	0.2214	0.0904	0.1680	0.2561
		E	-0.0083	-0.1298	0.0000	-0.0495	0.0035	0.2062	0.1115	-0.1691
Thiols	X19	P		0.1955	0.0910	-0.2310*	0.1548	0.2323*	0.2213	-0.1547
		G		0.0786	0.2178	-0.5052	-0.0010	0.2733	0.1438	-0.6413
		E		0.3324*	-0.0897	0.0053	0.2704	0.1918	0.3014*	0.0516
In. Phos	X20	P			-0.0496	-0.0110	0.0704	0.1096	0.1004	-0.0360
		G			-0.1138	-0.1448	0.1462	0.0965	0.1277	-0.0273
		E			0.0559	0.1213	0.0122	0.1251	0.0686	-0.0461
Sucrose	X21	P				-0.1031	-0.0572	-0.1993	-0.1216	0.1502
		G				-0.3273	0.1331	-0.2940	-0.0562	0.6096
		E				0.1658	-0.2585	-0.0748	-0.2219	-0.1076
Mg.	X22	P					0.1553	0.1175	0.1537	-0.0287
		G					0.4980	0.2085	0.3636	-0.0551
		E					-0.0525	0.0416	-0.0295	-0.0201
Chl a	X23	P						0.4059**	0.8831**	0.3539**
		G						0.7911	0.9589	-0.1545
		E						0.1469	0.8529**	0.5261**
Chl b	X24	P							0.7832**	-0.5936**
		G							0.9331	-0.7339
		E							0.6336**	-0.5866**
Tot. chl	X25	P								-0.0640
		G								-0.4278
		E								0.0975
Chl a:b	X26	P								
		G								
		E								

* : Significant at 5% level of significance   ** : Significant at 1% level of significance

TSC – Total solids content ; In. Phos- Inorganic phosphorous ; Mg. – Magnesium in latex ;
Chl a – Leaf chlorophyll a ; Chl b-chlorophyll b ; Tot. chl – total chlorophyll ;
Chl a:b - chlorophyll a:b ratio

of chlorophyll a:b ratio with chlorophyll a was non significant, while those with chlorophyll b and total chlorophyll were relatively high (r= -0.7339 and -0.4278 respectively).

Correlations between leaf and latex biochemical parameters were also detected. At the phenotypic level, a significant positive correlation was observed between latex thiols and chlorophyll b in the leaf (r= 0.2323*). At the genotypic level, this correlation was 0.2733. Thiol content was also found to have a high negative genotypic correlation with chlorophyll a:b ratio (r= -0.6413), while a low positive correlation was detected between total solid content and chlorophyll a:b ratio (r= 0.2561). Sucrose showed a relatively low negative genotypic correlation with chlorophyll b, and a high positive correlation with chlorophyll a:b ratio. Latex magnesium was found to be genotypically correlated with chlorophyll a and total chlorophyll (r= 0.4980 and 0.3636 respectively), with the corresponding environmental correlations being negligible.

4.1.3.6. Associations between morphological, anatomical, physiological and biochemical traits

Apart from the correlations discussed above, correlations between the morphological, anatomical, physiological and biochemical traits were also observed (Appendices A, B and C).

Significant positive phenotypic correlations were obtained between girth and anatomical traits bark thickness, number of latex vessel rows, and laticifer area index (r= 0.4980** to 0.6789**), while a negative correlation was recorded with leaf midrib thickness (r= -0.2307*). At the genotypic level too, girth was

positively correlated with bark thickness, number of latex vessel rows and laticifer area index (r= 0.5812 to 0.7796), and negatively with leaf midrib and lamina thickness (r= -0.4851 and -0.5107 respectively). The environmental correlations of girth with bark thickness, number of latex vessel rows and laticifer area index were also positive and high (r= 0.5021** to 0.5987**). Girth increment was highly correlated with bark thickness, number of latex vessel rows and laticifer area index (r=0.7080 to 1.1210) at the genotypic level. A low positive correlation was observed between leaf size and bark thickness at the phenotypic (r= 0.2306*) and genotypic (r= 0.3278) levels, while the environmental correlation between these traits was not significant. A similar relationship was observed between leaf size and palisade layer thickness. Leaf size also showed relatively high negative genotypic correlations with density and diameter of latex vessels (r= -0.6973 and -0.6225), though these correlations were not significant at the phenotypic level. On the other hand, specific leaf weight showed high negative genotypic correlations with bark thickness and number of latex vessel rows (r= -0.4480 and -0.5174), and positive correlations with diameter of latex vessels and lamina thickness (r= 0.9994 and 0.5146 respectively). The influence of environment on these correlations was found to be negligible.

Girth showed significant positive correlations with the physiological and biochemical parameters such as initial flow rate, final volume, dry rubber content and total solids content (r= 0.6678**, 0.6632**, 0.4129** and 0.3840** respectively), while its relationship with magnesium was negative (r= -0.2515*). These correlations showed a similar trend at the genotypic level also. Girth was genotypically correlated with thiols and sucrose, while it was negatively with

inorganic phosphorous. Girth increment was phenotypically correlated with initial flow rate, final volume, dry rubber content and sucrose (r= 0.4845** to 0.2377*). This trend was observed at the genotypic level also.

Leaf size showed a positive phenotypic correlation with chlorophyll b (r= 0.3052**), and negative correlations with inorganic phosphorous, sucrose and chlorophyll a:b ratio (r= -0.2427*, -0.2625* and -0.2913** respectively). The genotypic correlations of leaf size with initial flow rate, dry rubber content, inorganic phosphorous, sucrose and magnesium were also negative, with correlation values ranging from -0.2409 to -0.5207. Specific leaf weight was phenotypically and negatively correlated only with chlorophyll a, b and total chlorophyll (r= -0.3785** to -0.4702**). Genotypically, apart from chlorophyll content, specific leaf weight was also correlated negatively with initial flow rate, final volume and plugging index (r= -0.3053 to -0.4128). Environment was found to play a significant negative role in the correlations of specific leaf weight with latex magnesium and chlorophyll a and b (r= -0.2994* to -0.4117**) only. Number of stomata per unit area showed a weak but significant phenotypic correlation with final volume of latex (r= -0.2586*). The same level of correlation was seen at the genotypic level too. Environment had a low negative influence on this correlation, as evidenced by its low environmental correlation.

The correlations of the anatomical characters with the physiological and biochemical traits were also examined. Bark thickness was found to have a significant positive phenotypic correlation with initial flow rate (r= 0.3620**), final volume (0.3959**), dry rubber content (0.2869**) and total solids content (0.3371**).

At the genotypic level, it was also correlated positively with thiols and chlorophyll b, and negatively with magnesium and chlorophyll a:b ratio (r= -0.4164 to -0.6270). Similar trends were in general observed for the correlations of number of latex vessel rows, density of latex vessels and laticifer area index with the biochemical characters. However, diameter of latex vessels showed a different correlation pattern. Diameter was not correlated with any of the physiological and biochemical characters at the phenotypic level. At the genotypic level though, it showed a high negative correlation with initial flow rate, final volume, plugging index, magnesium, chlorophyll a, chlorophyll b and total chlorophyll (r= -0.6374, -0.4294, -0.3008, -0.6264, -0.4874, -0.7469 and -0.6460 respectively) and positive correlations with dry rubber content and chlorophyll a:b ratio (r= 0.3307 and 0.8275 respectively). The environmental correlations were significant only in the case of the relationship of diameter with chlorophyll b (r= 0.3294*) and chlorophyll a:b ratio (r= -0.3551*).

Leaf midrib thickness had negative phenotypic correlations with initial flow rate and final latex volume (r= -0.3144** and -0.2572*). Leaf lamina was correlated negatively only with sucrose content (r= -0.4035**). At the genotypic level too, relatively high negative correlations were observed between leaf midrib thickness and initial flow rate, final volume of latex, dry rubber content and total solids content (r= -0.3239 to -0.5257). Lamina thickness had a high negative correlation with initial flow rate, final volume of latex, sucrose and chlorophyll a:b ratio (r= -0.6762 to -0.4786). Palisade layer thickness appeared to be uncorrelated with any of the characters except chlorophyll a and chlorophyll a:b ratio (r= -0.3041 and -0.4271 respectively). Environment was found to play a

significant role only in the correlations between leaf midrib thickness and thiol content (r= -0.3188*) and those between lamina thickness with initial flow rate, final volume of latex and sucrose(r= 0.4747**, 0.4752** and -0.3133* respectively).

Correlations between the physiological and biochemical traits were observed. Significant phenotypic correlations were found only between initial flow rate and latex sucrose content (r= 0.2622*), plugging index and inorganic phosphorous (r= -0.3293**) and dry rubber content with total solid content (r= 0.7573**). At the genotypic level, a relatively higher correlation was obtained for initial flow rate with thiols and sucrose (r= 0.4472 and 0.5464). Final volume of latex too had a relatively high correlation with thiols and sucrose (r= 0.3503 and 0.3021 respectively). Plugging index had a negative genotypic correlation with inorganic phosphorous and positive correlation with sucrose (r= -0.4694 and 0.3601 respectively). Dry rubber content was highly correlated at the genotypic level with total solids content, sucrose, chlorophyll a, total chlorophyll and chlorophyll a:b ratio (r= 0.9297 to 0.2462). Effect of environment on most of these correlations was negligible, as shown by their corresponding environmental correlations. However, the environmental correlation between dry rubber content and total solids content was positive and high (r= 0.6845**).

4.1.4 Direct and indirect effects on mature yield

The direct and indirect effects of the various morphological, anatomical, physiological and biochemical traits on yield at the mature phase were computed. The characters included in the analysis were girth, girth increment, leaf size, specific

leaf weight, bark thickness, number of latex vessel rows, density and diameter of latex vessels, midrib thickness, lamina thickness, initial flow rate, final volume of latex, plugging index, dry rubber content, total solid content, thiols, inorganic phosphorous content of latex, and chlorophyll a and b content. The results are presented in Table 16.

The highest positive direct effect on yield was exerted by initial flow rate (0.9605) followed by bark thickness (0.8125), chlorophyll a (0.8090), specific leaf weight (0.5221), inorganic phosphorous (0.4819) and midrib thickness (0.4800). Moderate positive direct effect on yield was exerted by leaf size, while thiol content, number of latex vessel rows and chlorophyll b had negative direct effects (0.2941, -0.3413, -0.2837 and -0.2628 respectively).

Most of the correlation observed between initial flow rate and yield was accounted for by its high positive direct effect (0.9605). This was further supported by the cumulative positive indirect effects through girth, chlorophyll a, lamina thickness, bark thickness and final volume of latex (0.1027 to 0.2861). This high positive effect of initial flow rate was reduced to some extent by its negative indirect effects through specific leaf weight (-0.2155), midrib thickness (-0.2523), number of latex vessel rows (-0.2067) and thiols (-0.1526), though its net genotypic correlation with yield was still positive and high (r= 0.7766). Final volume of latex had only a low positive direct effect on yield. Its final high positive correlation with yield (r= 9112) was effected mainly through its positive indirect influence via initial flow rate (0.8363) and bark thickness (0.3519), and its relatively low negative indirect effects through specific leaf weight (-0.1594), midrib thickness (-0.2088), number of latex vessel rows (-0.2098) and thiol content (-0.1197).

Table 16. Direct and indirect effects of 19 morphological, anatomical, physiological and biochemical traits on yield

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Genotypic correlation with yield
Girth	1	0.1504	-0.0138	0.0335	-0.2472	0.4722	-0.1509	-0.0201	-0.0047	-0.2328	0.0858	0.6911	0.1172	0.0257	-0.0314	0.0227	-0.1144	-0.1634	-0.0545	-0.0032	0.5623
Gl%	2	0.1208	-0.0171	-0.0547	-0.3122	0.5752	-0.3180	0.0059	-0.0020	-0.2000	0.0562	0.8388	0.1777	-0.0121	-0.0087	0.0089	0.0368	-0.0761	0.0404	0.0625	0.9222
Lf size	3	0.0171	0.0032	0.2941	-0.2622	0.2664	0.0110	0.0722	-0.0069	0.1171	-0.0231	-0.2314	-0.0135	-0.0169	0.0319	-0.0063	0.0472	-0.2509	-0.2001	-0.0021	-0.1529
SLW	4	-0.0712	0.0102	-0.1477	0.5221	-0.3640	0.1468	0.0060	0.0110	0.1934	-0.0864	-0.3965	-0.0578	-0.0392	-0.0137	0.0005	0.0845	0.1915	-0.4217	0.1315	-0.3008
BT	5	0.0874	-0.0121	0.0964	-0.2339	0.8125	-0.2052	0.0219	-0.0029	-0.1551	0.0253	0.3382	0.0821	-0.0049	-0.0188	0.0163	-0.1420	-0.0370	-0.0285	-0.1041	0.5357
NLV	6	0.0800	-0.0192	-0.0114	-0.2701	0.5879	-0.2837	0.0290	0.0000	-0.1373	0.0735	0.6998	0.1401	0.0002	-0.0154	0.0150	-0.2453	0.1292	0.1570	-0.0663	0.8609
Den	7	0.0292	0.0010	-0.2051	-0.0301	-0.1722	0.0796	-0.1035	-0.0012	0.2175	0.0466	0.3133	0.0773	-0.0042	0.0075	-0.0079	0.1340	0.1132	-0.1321	-0.0625	0.3002
Dia	8	-0.0646	0.0031	-0.1831	0.5218	-0.2149	0.0003	0.0112	0.0111	0.2942	-0.0770	-0.6122	-0.0813	-0.0379	-0.0225	0.0074	0.0581	0.0864	-0.3943	0.1963	-0.4980
Md.thk	9	-0.0729	0.0071	0.0718	0.2103	-0.2625	0.0812	-0.0469	0.0068	0.4800	-0.0279	-0.5049	-0.0824	-0.0129	0.0257	-0.0128	-0.0298	0.0373	-0.2187	0.0432	-0.3084
L.thk	10	-0.0768	0.0057	0.0404	0.2686	-0.1225	0.1241	0.0287	0.0051	0.0796	-0.1680	-0.6494	-0.1058	-0.0127	-0.0006	-0.0006	0.0450	0.0560	0.1959	-0.0751	-0.3623
IFR	11	0.1082	-0.0150	-0.0709	-0.2155	0.2861	-0.2067	-0.0338	-0.0070	-0.2523	0.1136	0.9605	0.1650	0.0330	-0.0005	0.0067	-0.1526	-0.0466	0.1027	0.0017	0.7766
FLV	12	0.0930	-0.0161	-0.0209	-0.1594	0.3519	-0.2098	-0.0423	-0.0047	-0.2088	0.0938	0.8363	0.1895	-0.0286	-0.0072	0.0094	-0.1197	0.0647	0.1135	-0.0232	0.9112
PI	13	0.0307	0.0016	-0.0394	-0.1626	-0.0317	-0.0005	0.0034	-0.0033	-0.0492	0.0170	0.2516	-0.0431	0.1260	0.0130	-0.0056	-0.0594	-0.2262	-0.0270	0.0494	-0.1553
DRC	14	0.0693	-0.0022	-0.1382	0.1056	0.2248	-0.0645	0.0115	0.0037	-0.1812	-0.0015	0.0072	0.0201	-0.0241	-0.0680	0.0366	-0.0395	-0.0280	0.3567	-0.0127	0.2757
TSC	15	0.0866	-0.0039	-0.0467	0.0070	0.3362	-0.1080	0.0208	0.0021	-0.1555	0.0025	0.1639	0.0451	-0.0180	-0.0632	0.0394	-0.0407	-0.0652	0.1791	-0.0238	0.3580
Thiols	16	0.0504	0.0018	-0.0407	-0.1292	0.3380	-0.2039	0.0406	-0.0019	0.0419	0.0222	0.4295	0.0664	0.0219	-0.0079	0.0047	-0.3413	0.0379	-0.0008	-0.0718	0.2578
IP	17	-0.0510	0.0027	-0.1532	0.2075	-0.0624	-0.0761	-0.0243	0.0020	0.0371	-0.0195	-0.0929	0.0254	-0.0591	0.0039	-0.0053	-0.0268	0.4819	0.1182	-0.0254	0.2828
ChlA	18	-0.0101	-0.0009	-0.0728	-0.2721	-0.0286	-0.0551	0.0169	-0.0054	-0.1298	-0.0407	0.1219	0.0266	-0.0042	-0.0300	0.0087	0.0003	0.0704	0.8090	-0.2079	0.1965
ChlB	19	0.0018	0.0041	0.0023	-0.2613	0.3219	-0.0737	-0.0246	-0.0083	-0.0790	-0.0480	-0.0063	0.0167	-0.0237	-0.0033	0.0036	-0.0933	0.0465	0.6400	-0.2628	0.1527

Residue = 0.0672

Gl%: Girth increment	Md. thk: Midrib thickness	TSC: Total solids content
Lf size: Leaf size	BT: Bark thickness	In. P: Inorganic phosphorous
SLW: Specific leaf weight	NLV: no. of latex vessel rows	
ChlA: Chlorophyll a	Den: Density of latex vessels	FLV: Final latex volume
ChlB: Chlorophyll b	Dia: Diameter of latex vessels	PI: Plugging index
L.thk: Lamina thickness	IFR: Initial flow rate	DRC: Dry rubber content

In addition to its high positive direct effect on yield (0.8125), bark thickness exerted a relatively high positive indirect effect through initial flow rate (0.3382). However, its negative influence on yield through specific leaf weight (-0.2339), chlorophyll b (-0.1041), midrib thickness (-0.1551) and number of latex vessel rows (-0.2052) brought down its total genotypic correlation with yield to 0.5357.

The high direct effect of chlorophyll a on yield (0.8090) was supplemented further by its positive indirect effect through initial flow rate (0.1219). However its relatively high negative effect through specific leaf weight (-0.2721), chlorophyll b (-0.2079) and midrib thickness (-0.1298) considerably reduced its total correlation with yield to 0.1965. On the other hand, the negative effect of chlorophyll b on yield through its moderate direct effect (-0.2628) and indirect effect through specific leaf weight (-0.2613), was completely offset by its positive association through chlorophyll a (0.6400) and bark thickness (0.3219), resulting finally in a low but positive genotypic correlation with yield (r= 0.1527).

The relatively high positive direct effect of specific leaf weight on yield (0.5221) was further increased by low but positive effects through chlorophyll b (0.1315), midrib thickness (0.1934), number of latex vessel rows (0.1468) and inorganic phosphorous (0.1915). However, the high negative indirect effect of this trait through initial flow rate (-0.3965), bark thickness (-0.3640), chlorophyll a (-0.4217) and leaf size (-0.1477) resulted in a negative genotypic correlation of specific leaf weight with yield (r= -0.3008).

Inorganic phosphorous had a high positive direct effect on yield (0.4819). Its indirect effect via specific leaf weight and chlorophyll a was also positive (0.2075 and 0.1182 respectively). However, this trait had a negative indirect effect on yield through a number of other traits, the most prominent being leaf size. Though the individual effects through these traits were small (-0.0254 to -0.1532) their cumulative negative indirect effect brought down the ultimate correlation of inorganic phosphorous with yield to 0.2828.

The relatively high positive direct effect of midrib thickness on yield (0.4800) was supplemented by its positive indirect effect through specific leaf weight (0.2103). However, the higher negative indirect influence of this trait through initial flow rate (-0.5049), bark thickness (-0.2625) and chlorophyll a (-0.2187) resulted in its negative correlation with yield (r= -0.3084). In the case of lamina thickness, the low negative direct effect (-0.1680) was considerably enhanced by its indirect influence via initial flow rate (-0.6494), bark thickness (-0.1225) and final volume of latex (-0.1058). Its positive effect through specific leaf weight (0.2686), chlorophyll a (0.1959) and number of latex vessel rows (0.1241) reduced the negative effect to some extent, ultimately resulting in a moderate negative correlation with yield (r= -0.3623).

Thiol content was found to have a negative direct effect on yield (-0.3413). This effect, combined with its negative indirect effects through specific leaf weight (-0.1292) and number of latex vessel rows (-0.2039), was completely offset by its positive influence via bark thickness (0.3380), and initial flow rate (0.4295), to give a low but positive correlation with yield (r= 0.2578).

Number of latex vessel rows exerted a moderate negative direct effect on yield (-0.2837). This was further supported by its indirect influence through specific leaf weight (-0.2701), midrib thickness (-0.1373) and thiol content (-0.2453). However, its extremely high positive indirect influence on yield via initial flow rate (0.6998), bark thickness (0.5879), chlorophyll a (0.1570), final volume of latex (0.1401) and inorganic phosphorous (0.1292) served to make its net effect on yield high and positive (r= 0.8609).

Though leaf size had a moderate positive direct effect on yield (0.2941), which was further enhanced by its positive indirect effect through midrib and bark thickness (0.1171 and 0.2664 respectively), its relatively higher indirect negative effects through specific leaf weight (-0.2622), chlorophyll a (-0.2001), initial flow rate (-0.2314) and inorganic phosphorous (-0.2509) resulted in a negative though low genotypic correlation with yield (-0.1529).

The indirect effect of girth increment on yield was very high. Inspite of its negligible direct effect on yield (-0.0171) as well as its relatively higher negative influence through number of latex vessel rows (-0.3180), specific leaf weight (-0.3122) and midrib thickness (0.2000), this component had a very high net correlation with yield (r= 0.9222) due to its extremely high positive indirect effects through initial flow rate (0.8388), bark thickness (0.5752), final volume of latex (0.1777) and girth (0.1208). Similarly, the low direct effect of girth on yield (0.1504) and its negative indirect effects through specific leaf weight (-0.2472), number of latex vessel rows (-0.1509), midrib thickness (-0.2472), thiols (-0.114) and inorganic phosphorous (-0.1634) were counterbalanced by its positive indirect

effects via bark thickness (0.4722), initial flow rate (0.6911) and final volume of latex (0.1172), giving a relatively high positive correlation between girth and yield (0.5623).

Dry rubber content and total solids content also had negligible direct effects on yield. However, the relatively higher indirect influence of these traits via others caused a positive genotypic correlation with yield (r= 0.2757 and 0.3580 respectively). Dry rubber content had a positive indirect influence on yield through specific leaf weight a (0.3567) and bark thickness (0.2248), while its effect was negative via leaf size (-0.1382) and midrib thickness (-0.1812). Similarly, the indirect effects of total solid content were positive through chlorophyll a (0.1791), bark thickness (0.3362) and initial flow rate (0.1639), and negative through midrib thickness (-0.1555) and number of latex vessel rows (-0.1080).

Density and diameter of latex vessels were found to have negligible direct effects on yield (-0.1035 and 0.0111 respectively). Density also showed a negative indirect effect on yield through leaf size (-0.2051), chlorophyll a (-0.1321) and bark thickness (-0.1722), while its indirect effect was positive through midrib thickness (0.2175), initial flow rate (0.3133), thiols (0.1340) and inorganic phosphorous (0.1132). The net correlation of density with yield was therefore positive (r= 0.3002). On the other hand, the positive indirect effect of diameter of latex vessels on yield through specific leaf weight (0.5218), chlorophyll b (0.1963) and midrib thickness (0.2942) was outweighed by its indirect effect through leaf size (-0.1831), chlorophyll a (-0.3943), bark thickness (-0.2149) initial flow rate (-0.6122) to give a high net genotypic correlation between diameter and yield (r= -0.4980).
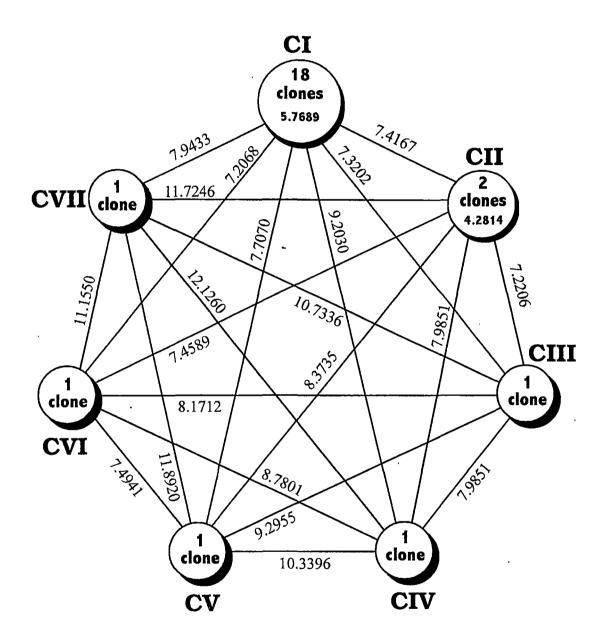
The 19 variables included in the analysis explained almost all the variation in yield (93.28 %), as evidenced by the very low residue obtained (0.0672).

4.1.5 Genetic divergence among clones at the mature stage

The genetic distances between the 25 clones were computed using 19 variables. The D^2 values for the 300 clone combinations, presented in Appendix D, ranged from 8.06 (between RRIM 611 and RRIM 636) to 147.04 (RRIM 607 and RRII 105).

Seven groups of clones were identified using the Tocher's method of clustering. The critical D^2 value used for initiating new clusters was 49.63. The clustering pattern of the 25 clones is given in Table 17. Cluster I was the single largest cluster comprising of 18 clones : RRIM 501, RRIM 519, RRIM 526, RRIM 600, RRIM 604, RRIM 605, RRIM 610, RRIM 611, RRIM 622, RRIM 628, RRIM 636, RRIM 701, RRIM 703, RRIM 704, RRIM 705, RRIM 706, IAN 873 and Har 1. Cluster II comprised of only two clones (RRIM 602 and RRIM 612). Clones RRIM 603, RRIM 607, RRIM 615, RRIM 620 and RRII 105 were distributed in independent clusters (Clusters III to VII). The cluster diagram of the 25 mature clones is given in Figure 3.

The mean inter and intra cluster distances are given in Table 18. Clusters CI and CII had an average intra cluster distances (D) of 5.77 and 4.28 respectively. The least inter cluster distance was recorded between clusters C I and C III (7.22), while the maximum distance was observed between C IV and C VII (12.13).

CI
18
clones
5.7689

CII
2
clones
4.2814

CVII
1
clone

CIII
1
clone

CVI
1
clone

CV
1
clone

CIV
1
clone

7.9433
7.2068
7.3202
7.4167
11.7246
7.7070
9.2030
12.1260
10.7336
7.4589
8.3735
7.9851
11.1550
8.1712
7.2206
7.4941
11.8920
8.7801
9.2955
7.9851
10.3396

Bold - Intra cluster distances
Normal - Inter cluster distances

Figure 3. Clustering of clones at the mature stage

Table 17. Clustering pattern of mature clones

Cluster	No. of clones	Clones included
C I	18	RRIM 501, RRIM 519, RRIM 526, RRIM 600, RRIM 604, RRIM 605, RRIM 610, RRIM 611, RRIM 622, RRIM 628, RRIM 636, RRIM 701, RRIM 703, RRIM 704, RRIM 705, RRIM 706, IAN 873, Har 1.
C II	2	RRIM 602, RRIM 612.
C III	1	RRIM 603.
C IV	1	RRIM 607.
C V	1	RRIM 615
C VI	1	RRIM 620.
C VII	1	RRII 105.

Table 18. Average inter- and intra cluster distances (D) among the mature clones

	CI	CII	CIII	CIV	CV	CVI	CVII
C I	**5.7689**	7.4167	7.2206	9.2030	7.7670	7.2668	7.9433
C II		**4.2814**	7.3202	7.2941	8.3735	7.4589	11.7246
C III			**0.0000**	7.9851	9.2955	8.1712	10.7336
C IV				**0.0000**	10.3396	8.7801	12.1260
C V					**0.0000**	7.4941	11.8920
C VI						**0.0000**	11.1550
C VII							**0.0000**

Diagonal elements (bold) are the intra cluster distances, while off diagonal elements are the inter cluster distances

Table 19 gives the cluster means for the 19 traits and contribution of the variables to genetic divergence at the cluster and genotypic levels. Cluster I, with the maximum number of clones, did not show superiority for any of the traits. Cluster II, comprising of clones RRIM 602 and RRIM 612, showed superiority for five traits viz. girth (with a cluster mean of 125.28 cm), girth increment (9.17%), bark thickness (11.50mm), dry rubber content (35.78%) and total solid content (41.71%). Cluster III (RRIM 603) had the largest diameter of latex vessels (21.85m) and the lowest plugging index (2.49). Cluster IV (RRIM 607) showed superiority for the maximum number of traits: number of latex vessel rows (43.67), initial flow rate (57.83 ml min^{-1}), final volume of latex (295 ml), thiol content (17.97 mg 100g^{-1} latex), inorganic phosphorous (86.01 mg 100g^{-1} latex), and yield (102.82 g tree^{-1} tap^{-1}). It also had the lowest diameter of latex vessels (19.45m). Cluster V (RRIM 615) had the maximum specific leaf weight (0.96 g cm^{-2}), diameter of latex vessels (21.85m) and lamina thickness (160.06m). Cluster VI, comprising the clone RRIM 620, had the highest density of latex vessels (26.27 mm^{-1} latex vessel ring) and maximum midrib thickness (947.92m). Cluster VII (RRII 105) had the maximum values only for chlorophyll a and chlorophyll b (2.64 and 1.99 mg g^{-1} fresh leaf weight).

The relative contribution of the different characters to genetic divergence, both at the cluster level as well as the genotypic level are also given in Table 19. The relative contribution at the cluster and genotypic levels was assessed using the respective coefficients of variation. At the cluster level, initial flow rate was found to contribute the maximum to genetic divergence among clones at the mature stage. This was followed by final volume of latex, yield, thiol content, girth

Table 19. Contribution of mature traits to genetic divergence

Cluster	No. of clones	Cluster means								
		Girth	Girth increment	Specific leaf weight	Bark thickness	No. of vessel rows	Density of latex vessels	Diameter of latex vessels	Midrib thickness	Lamina thickness
I	18	90.02	6.54	0.76	9.23	33.42	25.30	19.84	805.04	134.11
II	2	125.28	9.17	0.63	11.50	39.64	24.86	19.93	724.70	118.81
III	1	86.17	6.64	0.84	7.92	31.00	24.72	21.85	920.59	111.52
IV	1	112.90	8.41	0.72	8.67	43.67	24.66	19.45	748.93	110.43
V	1	79.43	3.43	0.96	8.02	25.00	23.21	21.85	716.95	160.06
VI	1	84.45	3.96	0.92	8.58	29.50	26.27	20.69	947.92	147.60
VII	1	83.08	7.43	0.81	10.50	43.33	25.35	21.66	743.47	141.04
Mean		94.47	6.51	0.80	9.20	35.08	24.91	20.75	801.09	131.94
SD		17.48	2.14	0.11	1.33	7.24	0.93	1.04	95.58	19.04
CV% (Cluster level)		18.51	32.91	14.09	14.51	20.65	3.74	4.99	11.93	14.43
CV% (Genotypic level)		11.78	39.72	14.08	10.77	16.30	7.19	8.04	7.15	10.75

Table 19 (Contd....)

Cluster	No. of clones	Cluster means									
		Initial flow rate	Final latex volume	Plugging index	Dry rubber content	Total solids content	Thiol content	Inorganic phosph.	Chl.a	Chl.b	Dry rubber yield
I	18	24.71	155.02	3.32	32.87	38.54	9.14	67.26	2.31	1.77	63.05
II	2	40.92	219.14	3.91	35.78	41.71	11.64	37.76	2.18	1.95	64.79
III	1	24.50	193.67	2.49	29.65	35.89	7.33	54.84	1.36	0.67	50.74
IV	1	57.83	295.00	3.89	33.75	39.49	17.97	86.01	2.57	1.65	102.82
V	1	11.67	83.33	2.76	35.58	40.18	7.82	74.73	2.06	1.62	31.16
VI	1	14.33	80.83	3.65	35.15	37.90	11.11	41.97	2.09	1.43	49.71
VII	1	39.67	267.00	3.00	34.39	41.12	9.35	84.65	2.64	1.99	90.11
Mean		30.52	184.86	3.29	33.88	39.26	10.62	63.89	2.17	1.58	64.63
SD		16.46	83.82	0.56	2.13	2.00	3.60	19.55	0.42	0.45	24.65
CV% (Cluster level)		53.93	45.34	17.00	6.29	5.10	33.92	30.60	19.47	28.22	38.15
CV% (Genotypic level)		36.86	29.66	19.77	6.63	6.43	23.35	19.60	22.46	19.76	27.33

increment, inorganic phosphorous, chlorophyll b, number of latex vessel rows, chlorophyll a, girth, plugging index, bark thickness, lamina thickness, specific leaf weight, midrib thickness, dry rubber content and total solid content. Density and diameter of latex vessels were found to contribute the least to genetic divergence.

At the genotype level too, a similar trend was observed, with only slight changes in the order of importance to divergence. Initial flow rate contributed the maximum to divergence in this case too. This was followed by final volume of latex, girth increment, yield, thiols, inorganic phosphorous, chlorophyll b, plugging index, chlorophyll a, girth, number of latex vessel rows, specific leaf weight, bark thickness, lamina thickness, midrib thickness, dry rubber content, diameter of latex vessels, total solid content and density of latex vessels.

4.1.6 Factor analysis

Factor analysis was carried out for the 25 clones using all the 27 morphological, anatomical, physiological and biochemical variables. The environment correlation matrix used is given in Appendix C. The principal component analysis method was applied and ten factors were extracted. The factor loadings were rotated using the varimax method with Kaiser normalization. 16 iterations were required for convergence. The results are summarized in Table 20. The characters constituting the factor groups are listed in Table 21.

The first factor accounted for 25.33 per cent of the variability in the population, and was associated with the variables girth, girth increment, leaf size, specific leaf weight, density and diameter of latex vessels, final volume of latex,

Table 20. Factor loadings of 27 variables on 10 principal factors at the mature stage

Sl. No.	Variable	Factor loadings										Communality
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	
1	Girth	0.957	0.098	0.058	0.046	-0.070	0.046	-0.117	0.078	0.079	0.050	0.980
2	Girth increment	0.930	0.026	-0.024	0.061	0.075	0.014	-0.138	-0.091	0.049	0.003	0.879
3	Leaf size	0.626	-0.088	0.459	0.107	-0.110	-0.307	0.357	0.131	-0.062	0.054	0.735
4	Specific leaf weight	0.774	-0.107	0.160	0.026	-0.043	-0.084	0.147	-0.184	-0.143	-0.110	0.929
5	Stomatal density	0.026	0.975	0.088	-0.075	-0.007	-0.001	-0.032	0.159	0.014	0.032	0.953
6	Bark thickness	-0.288	-0.166	-0.328	0.333	0.464	-0.050	-0.104	-0.043	0.058	0.449	0.989
7	No. of latex vessel rows	0.067	-0.155	0.122	0.115	0.856	-0.167	0.081	0.177	0.050	-0.143	0.947
8	Density of latex vessels	0.474	0.024	0.310	0.225	0.061	-0.321	0.022	0.405	-0.131	-0.301	0.993
9	Diameter of latex vessels	0.666	0.131	0.170	0.490	0.010	-0.043	0.035	0.133	0.076	-0.222	0.926
10	Laticifer area index	0.105	0.090	-0.084	-0.059	-0.187	0.130	-0.005	0.059	-0.051	0.931	0.933
11	Midrib thickness	-0.088	0.015	0.156	-0.048	0.123	0.040	0.131	-0.074	0.926	-0.036	0.860
12	Lamina thickness	0.008	-0.039	0.068	0.005	-0.152	0.111	0.081	0.052	0.053	-0.076	0.765
13	Palisade layer thickness	-0.218	0.161	0.014	-0.250	0.822	0.045	-0.154	0.052	0.113	-0.084	0.877
14	Initial flow rate	-0.287	-0.278	0.167	0.480	0.368	0.345	-0.207	-0.200	-0.265	-0.053	0.751
15	Final latex volume	0.614	-0.053	0.406	0.560	0.063	-0.057	0.145	0.092	-0.190	0.017	0.806
16	Plugging index	0.798	0.003	-0.007	-0.045	-0.173	0.025	0.518	0.062	-0.091	-0.043	0.954
17	Dry rubber content	0.923	-0.001	0.013	0.014	-0.120	0.018	0.027	0.071	-0.206	0.002	0.829
18	Total solidscontent	-0.131	0.169	-0.036	-0.020	-0.005	-0.062	0.889	-0.031	0.238	-0.008	0.931
19	Thiols in latex	0.141	0.111	0.917	0.077	0.034	0.147	-0.082	-0.110	0.042	0.002	0.953
20	Inorganic phosphorous	0.135	0.081	0.891	0.111	0.073	-0.018	0.088	0.020	0.118	-0.146	0.915
21	Sucrose in latex	0.205	0.191	-0.116	0.527	0.017	0.220	0.269	0.473	-0.035	-0.169	0.871
22	Magnesium in latex	0.205	0.130	-0.212	-0.255	0.010	0.538	-0.495	0.043	0.378	-0.074	0.923
23	Chlorophyll a in leaves	-0.097	-0.030	-0.135	0.082	0.217	-0.897	-0.077	0.134	0.010	-0.135	0.880
24	Chlorophyll b in leaves	-0.211	-0.540	0.065	-0.198	0.364	0.622	-0.209	-0.019	0.048	0.098	0.744
25	Total chlorophyll	0.045	0.954	0.073	-0.131	-0.015	0.093	0.047	-0.204	0.014	0.020	0.853
26	Chlorophyll a:b ratio	0.011	0.755	0.082	-0.010	0.008	-0.135	-0.124	0.578	0.032	0.043	0.752
27	Dry rubber yield	0.970	0.078	0.049	0.020	-0.042	0.026	-0.104	0.029	0.111	0.066	0.749
	Variance accounted for (%)	25.33	10.26	8.51	7.37	7.27	6.94	6.89	6.54	4.71	4.60	
	CV accounted for (%)	25.33	35.59	44.10	51.46	58.73	65.67	72.56	79.10	83.81	88.41	

Table 21. Grouping of characters into factors in mature clones

Factor	Characters included
Factor 1	Girth, girth increment, leaf size, specific leaf weight, density and diameter of latex vessels, final volume of latex, plugging index, dry rubber content, yield
Factor 2	Stomatal density, total chlorophyll content, chlorophyll a:b ratio
Factor 3	Thiol and inorganic phosphorous content of latex
Factor 4	Initial flow rate, sucrose content of latex
Factor 5	Bark thickness, no. of latex vessel rows, palisade layer thickness
Factor 6	Leaf chlorophyll a and b content, magnesium in latex
Factor 7	Total solids in latex
Factor 8	Lamina thickness
Factor 9	Midrib thickness
Factor 10	Laticifer area index

plugging index, dry rubber content and yield. Their factor loadings ranged from 0.474 to 0.970.

The second factor, which accounted for 10.26 per cent of the variability observed, comprised the traits stomatal density, total chlorophyll content and chlorophyll a:b ratio with factor loadings ranging from 0.755 to 0.975. The two factors accounted for 35.59 per cent of the variability observed.

The third factor or factor three was associated with thiol and inorganic phosphorous content of latex which accounted for 8.51 per cent of the variability. The factor loadings were 0.917 and 0.891 respectively. The cumulative variability explained at this stage was 44.10 per cent.

Factor four consisted of initial flow rate and sucrose content of latex with loadings of 0.48 and 0.527 respectively. It explained 7.37 per cent of the variability, with the cumulative variance at this stage being 51.46 per cent. Factor five, comprising bark thickness, number of latex vessel rows and palisade layer thickness, had factor loadings of 0.464 to 0.856 and accounted for 7.27 per cent of the variability. Factor six accounted for 6.94 per cent of the variability in the population and comprised of the characters leaf chlorophyll a and b content and magnesium in latex. The factor loadings were 0.538, -0.897 and 0.622. The total variance accounted for by the six factors was 65.67 per cent. Factor seven, associated with the single character total solids in latex, had a factor loading of 0.889 and was responsible for 6.89 per cent of the variability seen in the population. Factors eight, nine and ten, which consisted of a single trait each (lamina thickness, midrib

thickness and laticifer area index) explained 6.54, 4.71 and 4.60 per cent respectively of the variability in the clones. Their factor loadings were -0.933, 0.926 and 0.931. All the factors together explained 88.41 per cent of the variation in the population at the mature stage.

4.1.7 Discriminant function analysis

A disciminant function was fitted using 19 traits to derive a performance index for the 25 clones at the mature stage. The variables used were girth, girth increment, specific leaf weight, bark thickness, number of latex vessel rows, density of latex vessels, diameter of latex vessels, midrib thickness, lamina thickness, initial flow rate, final volume of latex, plugging index, dry rubber content, total solid content, thiols in latex, inorganic phosphorous, chlorophyll a in leaves, chlorophyll b and average annual yield. The performance index for each clone, along with their corresponding ranks, are given in Table 22. The popular clone RRII 105 was the best clone at the mature stage, followed by RRIM 607 and RRIM 605. The other popular clone RRIM 600 was ranked 16th. The index values ranged from 1363.06 for RRII 105 to 1040.57 for RRIM 615, with a population mean of 1230.97. The expected genetic advance from this population was 178.93 per cent at a selection intensity of five per cent.

4.2 IMMATURE PHASE

Morphological, anatomical and biochemical traits as well as immature yield in the young plants were used to assess the extent of genetic divergence in the given population. Variance and covariance analyses were used to estimate the

Table 22. Performance index and ranks of the clones at the mature stage

Clone	Index value	Rank
RRIM 501	1281.09	8
RRIM 519	1123.76	24
RRIM 526	1245.72	11
RRIM 600	1213.09	16
RRIM 602	1154.97	21
RRIM 603	1294.92	7
RRIM 604	1175.60	20
RRIM 605	1326.64	3
RRIM 607	1344.95	2
RRIM 610	1132.50	22
RRIM 611	1219.37	14
RRIM 612	1275.91	9
RRIM 615	1040.57	25
RRIM 620	1220.27	13
RRIM 622	1222.77	12
RRIM 628	1194.52	19
RRIM 636	1211.75	17
RRIM 701	1312.28	5
RRIM 703	1307.08	6
RRIM 704	1195.43	18
RRIM 705	1318.40	4
RRIM 706	1249.81	10
IAN 873	1132.21	23
RRII 105	1363.06	1
HAR 1	1217.70	15

variability and genetic parameters for the different traits as well as the interrelationships between these characters. The direct and indirect effects of the various traits on yield were computed. The clones were grouped into clusters based on the degree of divergence between them. The dimensions of the factors were reduced through principal component analysis. The clones were ranked based on a performance index using discriminant function analysis.

4.2.1. Mean performance and genetic variability

The mean performance of the 25 clones for the various traits is presented in Tables 23-26. The clones exhibited significant differences for all the traits except number of whorls retained at the end of the first and second years on the main stem, stomatal density per unit leaf area and density of latex vessels. The range, mean and variance at the phenotypic and genotypic levels are presented in Tables 27 and 28. The clones showing the maximum and minimum values for the leaf and bark anatomical traits are shown in Plates 1-8.

4.2.1.1. Time taken to sprout

The average time taken for the clones to sprout was recorded as weeks after planting, and showed high significant clonal differences. The clones took on an average 5.96 weeks to sprout, with individual clones having mean values ranging from 4.15 (RRIM 620) to 10.94 (RRIM 704) weeks. Twenty clones, including the popular cultivars RRII 105 and RRIM 600, were on par for this character. The phenotypic variance for this trait was 3.73 weeks while that at the genotypic level was 1.21 weeks. The environmental variance was relatively high (2.51).

Table 23. Mean performance of clones for immature morphological traits in the first year

Clone	Y1	Y2	Y3	Y4	Y5	Y6	Y7
RRIM 501	4.33	178.47	12.60	6.33	4.40	1.93	62.80
RRIM 519	4.38	160.70	12.39	5.68	4.32	1.37	58.77
RRIM 526	5.42	156.28	12.74	5.43	3.85	1.58	50.65
RRIM 600	6.69	183.69	11.31	6.14	4.44	1.69	66.67
RRIM 602	5.68	166.77	12.82	5.88	4.62	1.27	60.42
RRIM 603	7.78	158.11	13.83	6.44	4.78	1.67	61.78
RRIM 604	5.53	137.33	12.87	5.47	4.13	1.33	53.27
RRIM 605	5.05	173.10	11.56	5.80	4.25	1.55	72.15
RRIM 607	5.92	127.92	16.17	4.47	3.36	1.11	50.67
RRIM 610	5.27	152.76	12.00	5.20	3.82	1.38	49.16
RRIM 611	5.58	168.50	13.79	5.50	4.50	1.00	63.25
RRIM 612	4.83	165.98	11.97	4.68	3.48	1.20	60.28
RRIM 615	6.43	161.02	12.58	5.50	4.42	1.08	63.27
RRIM 620	4.15	182.10	12.20	5.52	4.25	1.27	64.20
RRIM 622	7.67	160.25	13.54	5.50	3.83	1.67	57.42
RRIM 628	5.75	147.75	13.38	5.75	4.67	1.08	63.75
RRIM 636	7.77	126.23	11.79	4.85	3.62	1.23	44.07
RRIM 701	5.32	141.00	13.16	4.77	3.70	1.07	53.02
RRIM 703	5.38	183.70	12.79	6.98	5.52	1.47	72.57
RRIM 704	10.94	130.06	14.40	4.86	4.42	0.44	49.00
RRIM 705	5.50	166.75	13.43	5.94	4.86	1.08	62.97
RRIM 706	5.28	188.25	14.22	6.25	4.42	1.83	72.95
IAN 873	6.78	178.65	14.78	5.75	4.52	1.23	65.15
RRII 105	6.03	176.69	13.18	5.78	4.69	1.08	59.44
HAR 1	5.58	159.25	12.08	5.83	4.58	1.25	62.00
Mean	5.96	161.25	13.02	5.61	4.30	1.32	59.99
$F_{24,48}$	2.44**	1.75*	2.53**	3.01**	2.59**	1.63	2.44**
SE_m	0.92	13.69	0.70	0.34	0.30	0.25	4.88
CD	2.603	38.924	1.981	0.970	0.861	--	13.869

* and ** : Clonal differences significant at P = 0.05 and 0.01 respectively.

Y1 = Time taken to sprout (weeks)   Y5 = Number of whorls retained at the end of first year
Y2 = Height (cm)   Y6 = Number of whorls shed
Y3 = Scion diameter (mm)   Y7 = Total number of leaves produced
Y4 = Number of whorls produced

Table 24. Mean performance of clones for immature morphological traits in the second year

Clone	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17
RRIM 501	22.93	90.24	2.53	9.60	1.67	8.40	8.87	52.24	0.66	402.50
RRIM 519	21.47	77.42	3.20	7.03	2.43	6.18	8.88	68.63	0.78	413.58
RRIM 526	22.38	79.01	3.02	5.85	2.20	5.03	8.45	59.82	0.72	343.50
RRIM 600	24.44	118.41	3.92	7.22	2.72	6.03	10.06	56.44	0.78	403.19
RRIM 602	22.77	79.28	3.07	6.47	2.07	5.47	8.95	70.39	0.86	388.21
RRIM 603	23.61	71.85	4.11	7.33	2.00	5.22	10.56	57.93	0.77	347.22
RRIM 604	18.70	47.97	3.07	3.40	2.13	2.47	8.53	71.47	0.82	381.83
RRIM 605	24.69	116.41	3.72	8.75	2.45	7.48	9.52	75.60	0.79	359.63
RRIM 607	22.68	47.55	3.25	4.14	2.83	3.72	7.72	48.46	0.73	421.53
RRIM 610	20.39	71.42	3.24	6.40	2.62	5.78	8.44	76.41	0.91	435.17
RRIM 611	24.25	78.97	3.50	8.67*	2.75	7.92	9.00	48.06	0.77	424.17
RRIM 612	23.58	97.95	2.97	7.27	2.47	6.77	7.65	46.83	0.75	357.33
RRIM 615	27.23	118.91	3.80	8.48	3.17	7.85	9.30	75.48	0.76	382.67
RRIM 620	22.84	91.66	3.07	11.13	2.17	9.73	8.58	63.23	0.72	350.63
RRIM 622	22.13	64.31	3.67	6.58	2.42	5.33	9.17	59.82	0.77	392.50
RRIM 628	22.00	66.04	3.08	6.58	2.67	6.08	8.83	55.01	0.77	391.88
RRIM 636	18.92	62.86	3.10	5.20	2.08	4.18	7.95	42.10	0.75	374.33
RRIM 701	22.22	70.70	2.78	4.70	2.28	4.20	7.55	50.95	0.67	383.38
RRIM 703	24.77	102.00	4.80	10.03	2.83	8.07	11.78	78.75	0.86	350.33
RRIM 704	19.56	42.05	4.03	4.86	2.81	3.64	8.89	82.23	0.77	416.67
RRIM 705	23.71	79.26	4.61	9.89	2.78	8.06	10.56	56.19	0.73	400.00
RRIM 706	24.11	72.78	4.63	11.05	2.38	8.80	10.88	48.11	0.71	369.75
IAN 873	25.50	73.09	3.82	8.05	2.65	6.88	9.57	59.90	0.80	410.79
RRII 105	23.78	83.01	4.36	8.42	2.69	6.42	10.14	60.27	0.86	373.75
HAR 1	22.29	90.19	3.42	6.42	2.17	5.17	9.25	61.90	0.85	408.54
Mean	22.84	79.73	3.55	7.34	2.46	6.20	9.16	61.05	0.77	387.32
$F_{24,48}$	3.10**	2.70**	2.79**	2.22**	1.65	1.84*	3.23**	4.22**	2.00*	1.43
SE_m	1.14	12.46	0.37	1.39	0.27	1.33	0.58	5.45	0.04	22.06
CD	3.227	35.434	1.047	3.959	-	3.794	1.657	15.493	0.121	—

* and ** : Clonal differences significant at P = 0.05 and 0.01 respectively.

Y8 = Scion diameter (mm)
Y9 = Scion diameter increment (%)
Y10 = No.of new whorls produced (main stem)
Y11 = No.of new whorls produced (whole plant)
Y12 = No.of new whorls retained (main stem)

Y13 = No. of new whorls retained (whole plant)
Y14 = Tot. whorls produced in 2 years(main stem)
Y15 = Leaf size (cm^2)
Y16 = Specific leaf weight (g cm^{-2})
Y17 = Stomatal frequency (no. mm^{-2})

Table 25. Mean performance of clones for immature anatomical traits in the second year

Clone	Y18	Y19	Y20	Y21	Y22	Y23	Y24	Y25
RRIM 501	1.93	2.60	24.41	21.21	0.50	689.98	145.22	45.91
RRIM 519	1.97	4.22	25.97	18.32	0.59	692.68	156.78	65.71
RRIM 526	2.21	4.07	26.98	19.18	0.71	833.13	168.13	68.92
RRIM 600	2.15	3.22	23.73	17.57	0.42	759.10	148.11	52.79
RRIM 602	2.19	4.72	23.92	18.75	0.68	890.87	171.88	68.52
RRIM 603	2.11	3.56	25.51	20.55	0.69	869.42	157.78	48.22
RRIM 604	1.99	3.40	25.04	16.47	0.32	765.83	152.35	53.31
RRIM 605	2.72	4.35	24.25	18.39	0.67	780.88	148.14	49.24
RRIM 607	2.63	5.61	24.08	19.84	0.90	840.78	115.62	47.38
RRIM 610	1.91	3.51	25.15	20.01	0.62	818.16	173.46	68.71
RRIM 611	2.03	3.00	25.67	19.39	0.55	711.48	152.36	49.46
RRIM 612	2.09	3.72	24.74	19.97	0.71	734.45	127.83	38.35
RRIM 615	2.17	4.48	24.50	18.83	0.82	751.32	125.69	51.00
RRIM 620	1.92	2.93	24.71	19.23	0.45	959.38	141.40	47.69
RRIM 622	2.03	3.00	25.53	20.88	0.58	803.34	146.18	59.09
RRIM 628	2.00	3.17	25.56	18.61	0.46	901.43	158.53	48.64
RRIM 636	1.67	2.78	25.30	20.74	0.43	743.98	159.93	43.37
RRIM 701	1.94	4.37	25.02	19.31	0.70	690.76	165.58	59.30
RRIM 703	2.73	4.32	24.26	20.88	0.83	1062.90	184.66	64.19
RRIM 704	2.18	3.61	24.22	18.81	0.46	1088.20	188.89	62.91
RRIM 705	2.07	3.03	24.26	20.82	0.59	911.99	153.66	50.02
RRIM 706	2.02	3.28	25.46	19.73	0.59	747.00	146.06	46.70
IAN 873	2.45	3.62	22.24	20.13	0.67	927.10	176.85	67.20
RRII 105	2.47	5.97	24.29	18.12	0.90	756.45	141.24	49.62
HAR 1	2.97	4.25	24.61	20.30	0.70	921.67	158.38	47.49
Mean	2.18	3.79	24.78	19.44	0.62	826.09	154.59	54.15
$F_{24,48}$	4.11**	5.06**	1.55	3.55**	3.51**	11.84**	11.58**	13.97**
SE_m	0.15	0.38	0.74	0.62	0.08	32.04	5.15	2.41
CD	0.434	1.070	--	1.762	0.231	91.092	14.630	6.859

* and ** : Clonal differences significant at P = 0.05 and 0.01 respectively.

Y18 = Bark thickness (mm)
Y19 = Number of latex vessel rows
Y20 = Density of latex vessels (no. mm^{-1})
Y21 = Diameter of latex vessels (μ)
Y22 = Laticier area index (mm^2)
Y23 = Leaf midrib thickness (μ)
Y24 = Leaf lamina thickness (μ)
Y25 = Leaf palisade layer thickness (μ)

Table 26. Mean performance of clones for juvenile biochemical traits and test tap yield in the second year

Clone	Y26	Y27	Y28	Y29	Y30	Y31	Y32	Y33	Y34
RRIM 501	8.45	67.63	812.92	529.93	4.46	1.47	5.92	3.06	1.37
RRIM 519	7.95	65.99	874.71	671.75	4.08	1.28	5.35	3.24	2.25
RRIM 526	5.97	44.66	529.81	1142.28	3.32	1.00	4.32	3.34	2.22
RRIM 600	8.93	51.25	858.53	1376.72	3.94	1.22	5.16	3.33	1.28
RRIM 602	11.08	42.44	739.72	1001.10	3.74	1.15	4.89	3.32	·1.34
RRIM 603	7.21	49.64	528.16	719.47	5.69	2.03	7.72	2.81	3.81
RRIM 604	6.34	47.53	343.64	718.97	2.66	1.06	3.72	2.63	1.06
RRIM 605	11.07	68.74	488.14	1336.19	4.10	1.28	5.39	3.24	3.32
RRIM 607	17.70	70.95	566.48	864.32	4.93	1.62	6.54	3.14	4.01
RRIM 610	10.08	70.85	501.85	1191.03	3.44	1.03	4.47	3.36	3.03
RRIM 611	10.06	52.78	480.69	800.83	4.40	1.27	5.67	3.47	1.27
RRIM 612	10.81	39.39	1158.36	348.28	5.31	1.66	6.97	3.24	1.29
RRIM 615	9.53	72.13	601.46	885.91	3.80	1.28	5.08	3.12	5.81
RRIM 620	7.90	40.24	367.42	758.52	2.92	0.88	3.80	3.36	1.01
RRIM 622	7.48	64.45	272.00	939.33	4.00	1.31	5.31	3.09	1.57
RRIM 628	10.35	63.75	548.73	792.25	4.22	1.38	5.60	3.11	2.28
RRIM 636	11.17	51.60	529.41	875.48	3.35	1.25	4.60	2.80	1.40
RRIM 701	10.93	44.23	440.23	423.68	4.26	1.41	5.67	3.05	2.24
RRIM 703	9.33	70.81	297.40	779.57	3.68	1.27	4.95	2.97	3.68
RRIM 704	9.47	61.41	671.53	989.73	3.07	0.88	3.95	3.48	1.98
RRIM 705	5.08	85.98	987.84	961.31	4.42	1.33	5.67	3.36	2.47
RRIM 706	9.66	65.37	435.67	461.04	3.87	1.66	5.53	2.46	2.02
IAN 873	9.46	50.03	752.58	534.13	2.95	0.88	3.83	3.44	2.09
RRII 105	9.31	69.62	601.38	1015.67	3.64	1.15	4.79	3.26	2.20
HAR 1	10.63	102.61	283.00	670.78	3.20	0.95	4.14	3.45	2.35
Mean	9.44	60.56	586.87	831.53	3.90	1.27	5.16	3.17	2.29
$F_{24,48}$	15.30**	6.36**	9.65**	6.37**	7.99**	6.70**	7.57**	10.12**	4.11**
SE_m	0.62	5.99	72.59	105.54	0.26	0.11	0.36	0.08	0.56
CD	1.750	17.031	206.397	300.069	0.740	0.304	1.022	0.238	1.586

.172.29

* and ** : Clonal differences significant at P = 0.05 and 0.01 respectively.

Y26 = Latex thiol content (mg 100g⁻¹ latex)
Y27 = Inorganic phosphorous (mg 100g⁻¹ latex)
Y28 = Sucrose in latex (mg 100g⁻¹ latex)
Y29 = Magnesium in latex (μg g⁻¹ latex)
Y30 = Leaf chlorophyll a (mg g⁻¹ fresh leaf)

Y31 = Leaf chlorophyll b (mg g⁻¹ fresh leaf)
Y32 = Total chlorophyll (mg g⁻¹ fresh leaf)
Y33 = Chlorophyll a:b ratio
Y34 = Test tap yield (g plant⁻¹ 10 tappings⁻¹)

Table 27. Variability components for immature morphological traits

Sl. No.	Traits	Phenotypic variance	Genotypic variance	Environmental variance
1	Time taken to sprout (weeks)	3.73	1.21	2.51
2	Height (cm)	702.85	140.57	562.28
3	First year scion diameter (mm)	2.20	0.74	1.46
4	No. of whorls produced in first year (W1)	0.58	0.23	0.35
5	No. of whorls retained (W2)	0.42	0.15	0.28
6	No. of whorls shed (W3)	0.22	0.04	0.18
7	Total no. of leaves	105.54	34.16	71.39
8	Scion diameter in second year (mm)	6.57	2.70	3.87
9	Diameter increment (%)	730.01	264.03	465.98
10	No. of whorls produced on main stem in second year (W4)	0.65	0.24	0.41
11	No. of whorls produced on entire plant (W5)	8.18	2.35	5.82
12	No. of new whorls retained on main stem (W6)	0.26	0.05	0.21
13	No. of whorls retained on the entire plant (W7)	6.84	1.50	5.34
14	Total no. of whorls produced on main stem in two years (W8)	1.78	0.76	1.02
15	Leaf size (cm^{-2})	184.71	95.62	89.08
16	Specific leaf weight (g cm^{-2})	0.007	0.002	0.005
17	Stomatal density (no. mm^{-2})	1668.65	209.34	1459.32

Table 28. Variability components for immature anatomical and biochemical traits and yield

Sl. No.	Traits	Phenotypic variance	Genotypic variance	Environmental variance
1	Bark thickness (mm)	0.14	0.07	0.07
2	Number of latex vessels	1.00	0.57	0.42
3	Density of latex vessels (no. mm^{-1})	1.92	0.30	1.63
4	Diameter of latex vessels (μm)	2.13	0.98	1.15
5	Laticifer area index (mm^2)	0.04	0.02	0.02
6	Leaf midrib thickness (μm)	14204.26	11124.74	3079.53
7	Leaf lamina thickness (μm)	359.52	280.08	79.44
8	Palisade layer thickness (μm)	92.99	75.52	17.46
9	Thiols in latex (mg 100 g^{-1} latex)	6.56	5.42	1.14
10	Inorganic phosphorous (mg 100 g^{-1} latex)	300.11	192.46	107.65
11	Sucrose in latex (mg 100 g^{-1} latex)	61399.67	45589.58	15810.09
12	Magnesium in latex (μg g^{-1} latex)	93256.76	59839.62	33417.16
13	Chlorophyll a in leaves (mg g^{-1} fresh leaf)	0.68	0.47	0.20
14	Chlorophyll b in leaves (mg g^{-1} fresh leaf)	0.10	0.07	0.03
15	Total chlorophyll (mg g^{-1} fresh leaf)	1.24	0.85	0.39
16	Chlorophyll a : b ratio	0.08	0.06	0.02
17	Juvenile yield (g)	1.90	0.97	0.93

4.2.1.2. Height

Clonal differences for this trait were significant only at the 5 per cent level. The average height for the clones ranged from 126.23 cm for RRIM 636 to 188.25 cm for clone RRIM 706, with a general mean of 161.25 cm. Nineteen clones including RRII 105 and RRIM 600 were on par with the tallest clone. The phenotypic and genotypic variances for this trait were 702.85 cm and 140.57 cm respectively, while the environmental component was very high at 562.28 cm.

4.2.1.3. Scion diameter in the first year

The young plants showed highly significant clonal differences for scion diameter at the end of the first year. The variation ranged from 11.31 mm for RRIM 600 to 16.17 mm for RRIM 607, with a general average of 13.02 mm. Clones RRIM 704, RRIM 706 and IAN 873 had a diameter on par with that of RRIM 600. RRII 105 also had a very low scion diameter on par with RRIM 600. The genetic variance for this trait was very low (0.74 mm) while the environmental variance (1.46) contributed the maximum to phenotypic variance (2.19 mm).

4.2.1.4. Flushes produced in the first year

Highly significant clonal differences were exhibited by the 25 clones for the total number of flushes produced in the first year as well as those retained at the end of the first year. However the clones did not differ for the number of whorls shed in the first year, indicating that the clonal differences for total number of flushes could be attributed to the differences in number of whorls retained by each clone.

An average of 5.61 flushes was produced by the 25 clones in the first year. The maximum number of flushes was produced by RRIM 703, with RRIM 501, RRIM 600, RRIM 603 and RRIM 706 being on par. The lowest number of whorls was produced by RRIM 607. The variances at the genotypic and phenotypic levels were however very low, being only 0.23 and 0.58 respectively

The maximum number of flushes retained at the end of the first year was 5.52 (RRIM 703), while the minimum was 3.36 (RRIM 607), while the general mean was 4.3. RRIM 603, RRIM 628, RRIM 705 and RRII 105 were on par with RRIM 703, while RRIM 600 showed only average whorl retention. The genotypic and phenotypic variances were 0.15 and 0.42 respectively, with the environmental variance being relatively high (0.28). There were no significant clonal differences for number of flushes shed in the first year.

4.2.1.5. Number of leaves

The total number of leaves produced in the first year was significantly different among the 25 clones, with clonal means ranging from an average of 44.07 in RRIM 636 to 72.95 in RRIM 706 The variance at the genetic level was very low (34.16) compared to the phenotypic variance for this trait (105.54) The general mean was 59.98. 15 clones including RRIM 600 and RRII 105 were on par with RRIM 706.

4.2.1.6. Scion diameter in the second year

High significant clonal differences were recorded for the scion diameter in the second year of growth, with values ranging from 18.7 mm (RRIM 604) to

27.23 mm (RRIM 615) and a general mean of 22.84 mm. RRIM 600, RRIM 605, RRIM 611, RRIM 703, RRIM 706 and IAN 873 were on par with RRIM 615, while RRII 105 showed only average diameter. A genetic variance of 2.70 was recorded for this trait, as against the environmental variance of 3.87 mm.

4.2.1.7. Scion diameter increment

The 25 clones showed highly variable increase in diameter during the second year of growth, with clonal means ranging from 42.05 per cent (RRIM 704) to 118.91 per cent (RRIM 620). The population mean was 79.73 per cent. Seven clones including RRIM 600 were on par with RRIM 615, while three clones had a diameter increment of less than 50 percent. RRII 105 showed average increment. The variance at the phenotypic level was also very high (730.01%), though the genotypic variance was much lower (264.03%). The environmental variance for this trait was 465.98 per cent.

4.2.1.8. Flushes produced in the second year

The population recorded high significant clonal differences for the number of new flushes produced in the second year on the main stem alone (W4), as well as on the entire plant (including branches) (W5). No significant clonal differences were recorded for the number of flushes retained at the end of the second year on the main stem (W6), while those on the entire plant (W7) were different at the 5 per cent level only. However, the total number of flushes produced on the main stem in two years (W8) showed highly significant clonal differences

The total number of new flushes produced on the main stem in the second year ranged from 2.53 (RRIM 501) to 4.8 (RRIM 703), with a general mean of 3.55. 11 clones including RRIM 600 and RRII 105 were on par with the highest producer. When the whorls on the branches were also included (W5), the average number went up to 7.34, with the highest number being produced by RRIM 620 (11.13) and the lowest by RRIM 604 (3.4). 12 clones including RRIM 600 and RRII 105 were on par with RRIM 620. The total number of flushes produced on the main stem in the two years together (W8) also showed highly significant differences among the clones, with an average of 9.16. RRIM 701 produced the lowest number of flushes (7.55) while RRIM 703 had the maximum (11.78).

The average number of flushes retained on the main stem at the end of the second year (W6) was 2.46, with absolute values ranging from 1.66 (RRIM 501) to 3.16 (RRIM 615) though there were no significant clonal differences. However, when the branches were also included (W7), clonal differences were observed, with the total number of flushes retained ranging from 2.47 (RRIM 604) to 9.73 (RRIM 620). The genotypic and phenotypic variances for these traits ranged from 0.05 and 0.26 respectively for number of new flushes retained on the main stem, to 2.3 and 8.18 respectively for number of new flushes produced on the entire plant in the second year.

4.2.1.9. Leaf size

The clones showed highly significant differences for the character single leaf area The general mean was 61.05 mm^2, while the means of individual clones

showed a range from 42.10 (RRIM 636) to 82.23 mm^2 (RRIM 704). 7 clones had very large leaves on par with the highest, while RRII 105 had average sized leaves. Seven clones including RRIM 600 had very small leaves on par with RRIM 636. The phenotypic, genotypic and environmental variances were 184.71, 95.62 and 89.09cm^2 respectively

4.2.1.10. Specific leaf weight

Clonal differences were significant only at the 5% level for this trait. The clonal mean values ranged from 0.66 g cm^{-2} for RRIM 501 to 0.91 for RRIM 610, with a general mean of 0.77 g cm^{-2}. Seven clones including RRII 105 had specific leaf weights on par with RRIM 610. RRIM 600 had an average specific leaf weight The variances at the phenotypic and genotypic levels were also extremely low at 0.007 and 0.002 g cm^{-2} respectively.

4.2.1.11. Density of stomata

The population showed a general mean of 387.32 stomata mm^{-2}, though no significant clonal differences were observed for this trait. The variance at the phenotypic level was 1668.65, though it was only 209.34 at the genotypic level. The environmental variance was very high for this trait (1459.32).

4.2.1.12. Bark thickness

The clones showed highly significant differences for this trait. Mean bark thickness ranged from 1.67 mm (RRIM 636) to 2.97 (Har 1), with a population

average of 2.18 mm. Only three clones- RRIM 605, RRIM 607 and RRIM 703 were on par with Har 1. RRIM 600 and RRII 105 had average bark thickness. The variance at the phenotypic level was very low (0.14). The genotyic and environmental components contributed equally (0.07 each) to the observed phenotypic variance.

4.2.1.13. Number of latex vessel rows

Highly significant clonal differences were observed for this trait. The average number of latex vessel rows for the individual clones ranged from 2.6 in RRIM 501 to 5.97 in RRII 105, with a population mean of 3.79. The number of latex vessel rows in RRIM 607 was on par with that of RRII 105, while RRIM 600 had an average of 3.22 rows. The variance at the genotypic level was 0.57 while that at the phenotypic level was 1.00.

4.2.1.14. Density of latex vessels

The density of latex vessels per mm of row length showed no significant clonal differences. The population mean was 24.78 vessels mm^{-2}. The genotypic variance was very low (0.30) compared to the phenotypic variance (1.92).

4.2.1.15. Diameter of latex vessels

Highly significant clonal differences were recorded for this character, with clonal means ranging from 16.47 μm (RRIM 604) to 21.21 μm (RRIM 501). The population mean was 19.44 μm. 11 clones had vessel diameters on par with the highest. RRIM 600 and RRII 105 had very small vessel diameters of 17.57 and

18.12 μm respectively. The genotypic variance for this trait was 0.98 μm compared with the phenotypic variance of 2.13 μm.

4.2.1.16. Laticifer area index

Significant clonal differences were observed for laticifer area index, with clonal mean values ranging from 0.32 mm^2 (RRIM 604) to 0.90 mm^2 (RRIM 607). The population mean was 0.62 mm^2. RRIM 526, RRIM 602, RRIM 603, RRIM 605, RRIM 612, RRIM 615, RRIM 701, RRIM 703, RRII 105 and Har 1 were on par with RRIM 607. Eight clones including RRIM 600 had very low laticifer area indices. The phenotypic and genotypic variances were also very low - 0.04 mm^2 and 0.02 mm^2 respectively.

4.2.1.17. Leaf midrib thickness

Significant clonal diferences were recorded for the thickness of the midrib. The population average was 826.09 μm, while the means of individual clones ranged from 689.98 (RRIM 501) to 1088.20 μm (RRIM 704). RRIM 703 was on par with RRIM 704. 12 clones, including the two popular cultivars, had very low leaf midrib thickness on par with RRIM 501. The variance at the genotypic level was also high, with a value of 11124.74 μm.

4.2.1.18. Leaf lamina thickness

The clones showed significant differences for thickness of leaf lamina, with values ranging from 115.62 μm for RRIM 607 to 188.89 μm for RRIM 704.

RRIM 703 was the only clone on par with RRIM 704, while RRIM 605 was on par with RRIM 607. RRIM 600 and RRII 105 had average leaf thickness. The variance at the phenotypic level was 359.52 μm, with a correspondingly high genotypic variance of 280.08 μm.

4.2.1.19. Palisade layer

The palisade layer thickness differed significantly amongst the clones. The mean thickness of the different clones ranged from 38.35 μm (RRIM 612) to 68.92 μm (RRIM 526), with a general mean of 54.15 μm. 6 clones were on par with RRIM 526, while RRIM 600 and RRII 105 had a palisade layer of average thickness. The variances at the phenotypic and genotypic levels were also very high, being 92.99 μm and 75.53 μm respectively, while the environmental variance was only 17.46 μm.

4.2.1.20. Thiols

The latex thiol content of the 25 clones showed high significant differences amongst themselves, with an average of 9.44 mg 100g^{-1} latex. The clonal means ranged from 5.08 mg in RRIM 705 to 17.70 mg 100g^{-1} latex in RRIM 607. RRIM 526 and RRIM 604 also had very low values on par with RRIM 705. RRIM 600 and RRII 105 had an average level of thiol content. The variances at the genotypic level was 5.42 mg 100g^{-1} latex, while the environmental component was only 1.14 mg 100g^{-1} latex.

4.2.1.21. Inorganic phosphorous

Significant clonal differences were seen for inorganic phosphorous content in the latex. A general mean of 60.56 mg 100g^{-1} latex was recorded. RRIM 612

had a value of 39.39 mg, while Har 1 had an average value of 102.61 mg. RRIM 705 recorded 85.98 mg and was on par with Har 1. RRII 105 had an average inorganic phosphorous content, while that of RRIM 600 was very low. The phenotypic and genotypic variances were 300.11 and 192.46 mg 100g^{-1} respectively.

4.2.1.22. Sucrose

The 25 clones showed high significant differences for sucrose content in the latex. The population averaged 586.86 mg sucrose 100 g^{-1} latex, with the average clone values ranging from 272.0 mg (RRIM 622) to 1158.36 mg (RRIM 612). RRIM 705 was found to be on par with RRIM 612. RRII 105 showed a mean equal to the population mean. The variances at the genotypic and phenotypic levels were found to be extremely high at 45589.58 mg and 61399.67 mg respectively.

4.2.1.23. Magnesium content in latex

Significant overall clonal differences were observed for magnesium content in latex, with mean values ranging from 348.28 μg g^{-1} latex (RRIM 612) to 1376.722 μg g^{-1} latex (RRIM 600). RRIM 526, RRIM 605, RRIM 610 and RRII 105 were on par with RRIM 600. The overall mean was 831.53 μg g^{-1} latex. Variance at the genotypic level was also found to be very high at 59839.62 μg, while that at the environmental level was 33417.16 μg.

4.2.1.24. Chlorophyll content in leaves

Highly significant differences were recorded for chlorophyll a, b, total chlorophyll and chlorophyll a:b ratio. The maximum chlorophyll a content was

recorded for RRIM 603 (5.69 mg g^{-1} fresh leaf weight) and the minimum for RRIM 604 (2.66mg). Six clones had low chlorophyll a content on par with RRIM 604, while RRIM 612 was on par with RRIM 603. The variances at the phenotypic and genotypic levels were 0.68 mg and 0.47 mg respectively.

The chlorophyll b content ranged from 0.88 mg g^{-1} fresh leaf weight (RRIM 620) to 2.03 mg (RRIM 603), with a general mean of 1.27 mg. RRIM 600 and RRII 105 had average chlorophyll b content. The variances at the genotypic and environmental levels were only 0.07 and 0.03 mg g^{-1} fresh leaf weight respectively.

Total chlorophyll content ranged from 3.72 mg g^{-1} fresh leaf weight in RRIM 604 to 7.72 mg in RRIM 604. The population mean averaged 5.16 mg. RRIM 600 and RRII 105 recorded average total chlorophyll. RRIM 612 had total chlorophyll content on par with the highest value. The phenotypic and genotypic variances were 1.24 and 0.85 mg respectively.

Chlorophyll a:b ratio ranged from 2.45 RRIM 706 to 3.48 in RRIM 704, with a general average of 3.17. The phenotypic and genotypic variances were only 0.09 and 0.06 respectively for this trait.

4.2.1.25. Yield

Yield on testtapping showed high significant clonal differences. The highest yield was recorded in RRIM 615 (5.81 g per plant per 10 tapping) followed by RRIM 607 (4.01g). RRIM 600 recorded a low yield of 1.28g while the yield of

RRII 105 was 2.20 g. The lowest yield of 1.01 g was recorded in RRIM 620. The 25 clones gave an average yield of 2.29 g at this age. The total phenotypic variance was 1.90 g, with almost equal genotypic and environmental components (0.97 and 0.93 g respectively).

4.2.2. Genetic parameters

The genetic parameters like genotypic and phenotypic coefficients of variation (GCV and PCV), broad sense heritability (H^2) and genetic advance as percentage of mean, based on a selection intensity of 5 per cent (GA) for all the characters are given in Tables 29 and 30. Figures 4 and 5 depict the genetic parameters for the different traits.

The phenotypic coefficients of variation ranged from 5.6 per cent for density of latex vessels to 60.13 per cent for immature yield. Relatively high PCV among the morphological traits was recorded for number of new flushes produced and those retained on the entire plant in the second year (W5 and W7) (38.95 and 42.23%), number of flushes shed by the end of the first year (W3) (35.95%), scion diameter increment in the second year (33.88%), time taken to sprout (32.35%), number of new flushes produced on the main stem in the second year (W4) (22.69%) and leaf size (22.26%). All other morphological traits recorded moderate PCV. Among the bark anatomical traits, laticifer area index and number of latex vessel rows had relatively high PCV (30.67 and 26.32%), bark thickness moderate (17.31%) and density and diameter low (5.6 and 7.51%) PCV. The three leaf anatomical parameters recorded only moderate PCV (12.27 - 17.83%).

Figure 4. Genetic parameters for immature morphological traits*

Y1	Weeks taken to sprout
Y2	Height
Y3	Scion diameter (1)
Y4	Total whorls produced (W1)
Y5	Whorls retained (W2)
Y6	Whorls lost (W3)
Y7	Number of leaves
Y8	Scion diameter (2)
Y9	Diameter increment
Y10	Total whorls produced on the main stem (W4)
Y11	Total whorls produced on the entire plant (W5)
Y12	Whorls retained on the main stem (W6)
Y13	Whorls retained on the entire plant (W7)
Y14	Total whorls produced on the main stem in both years together (W8)
Y15	Leaf size
Y16	Specific leaf weight
Y17	No. of stomata per unit area of leaf

* Y1 – Y7 were recorded in the first year of growth
  Y8 – Y17 were recorded in the second year of growth

Figure 4. Genetic parameters for morphological traits at the immature stage

Figure 5. Genetic parameters for immature anatomical and biochemical traits in the second year of growth

Y18	Bark thickness
Y19	Number of latex vessel rows
Y20	Density of latex vessels
Y21	Diameter of latex vessels
Y22	Laticifer area Index
Y23	Midrib thickness
Y24	Lamina thickness
Y25	Palisade layer thickness
Y26	Thiol concentration in latex
Y27	Inorganic phosphorous in latex
Y28	Sucrose concentration in latex
Y29	Magnesium concentration in latex
Y30	Chlorophyll a in leaves
Y31	Chlorophyll b in leaves
Y32	Total chlorophyll in leaves
Y33	Chlorophyll a:b ratio
Y34	Juvenile yield

Figure 5. Genetic parameters for anatomical and biochemical traits, and yield at the immature stage

Table 29. Estimates of genetic parameters for immature morphological traits

Sl. No.	Traits	PCV (%)	GCV (%)	H² (%)	GA(% over mean)
1	Time taken to sprout (weeks)	32.35	18.42	32.41	21.6
2	Height (cm)	16.44	7.35	20.00	6.77
3	First year scion diameter (mm)	11.39	6.62	33.77	7.92
4	No. of whorls produced in first year (W1)	13.61	8.62	40.09	11.24
5	No. of whorls retained (W2)	15.10	8.90	34.69	10.79
6	No. of whorls shed (W3)	35.95	14.98	17.37	12.86
7	Total no. of leaves	17.13	9.74	32.36	11.42
8	Second year diameter in second year (mm)	11.22	7.20	41.16	9.52
9	Diameter increment (%)	33.88	20.38	36.17	25.25
10	No. of whorls produced on main stem in second year (W4)	22.69	13.86	37.31	17.44
11	No. of whorls produced on entire plant (W5)	38.95	20.93	28.86	23.16
12	No. of new whorls retained on main stem (W6)	20.80	8.78	17.82	7.63
13	No. of whorls retained on the entire plant (W7)	42.23	19.77	21.93	19.08
14	Total no. of whorls produced on main stem in two years (W8)	14.56	9.51	42.67	12.8
15	Leaf size (cm⁻²)	22.26	16.02	51.77	23.74
16	Specific leaf weight (g cm⁻²)	10.95	5.49	25.08	5.66
17	Stomatal density (no. mm⁻²)	10.55	3.74	12.55	2.73

Table 30. Estimates of genetic parameters for immature anatomical and biochemical traits and yield

Sl. No.	Traits	PCV (%)	GCV (%)	H² (%)	GA (% over mean)
1	Bark thickness (mm)	17.31	12.35	50.91	18.16
2	Number of latex vessels	26.32	19.96	57.49	31.17
3	Density of latex vessels (no. mm⁻¹)	5.60	2.20	15.41	1.78
4	Diameter of latex vessels (μm)	7.51	5.09	45.91	7.10
5	Laticifer area index (mm²)	30.67	20.70	45.55	28.78
6	Leaf midrib thickness (μm)	14.43	12.77	78.32	23.28
7	Leaf lamina thickness (μm)	12.27	10.83	77.90	19.68
8	Palisade layer thickness (μm)	17.83	16.05	81.22	29.80
9	Thiols in latex (mg 100 g⁻¹ latex)	27.13	24.66	82.66	46.19
10	Inorganic phosphorous (mg 100 g⁻¹ latex)	28.60	22.90	64.13	37.79
11	Sucrose in latex (mg 100 g⁻¹ latex)	42.22	36.38	74.25	64.58
12	Magnesium in latex (μg g⁻¹ latex)	36.73	29.42	64.17	48.54
13	Chlorophyll a in leaves (mg g⁻¹ fresh leaf)	21.10	17.65	69.97	30.41
14	Chlorophyll b in leaves (mg g⁻¹ fresh leaf)	24.86	20.13	65.53	33.56
15	Total chlorophyll (mg g⁻¹ fresh leaf)	21.53	17.84	68.65	30.45
16	Chlorophyll a : b ratio	9.20	7.98	75.24	14.25
17	Juvenile yield (g)	60.13	42.91	50.92	63.08

All the latex and leaf biochemical parameters displayed high PCV (21.10 - 42.22%), except chlorophyll a:b ratio which had a GCV of only 9.2 per cent.

Estimates of GCV showed a similar trend though they were much lower. The maximum of 42.91 per cent was recorded for immature yield, while the minimum GCV was seen for density of latex vessels (2.2%) followed by stomatal density (3.74%). The morphological traits time taken to sprout, number of flushes shed by the end of the first year (W3), diameter increment, number of new flushes produced and those retained on the main stem in the second year (W4 and W5), number of new flushes retained on the entire plant in the second year (W7), and leaf size exhibited moderate GCV (20.93 - 14.98%) while the GCV of the remaining traits was low. The highest GCV among the bark anatomical traits was displayed by laticifer area index (20.7%). Number of latex vessel rows and bark thickness had moderate GCV while the GCV of density and diameter of latex vessels was low (2.20 and 5.09 respectively). The three leaf anatomical traits had medium levels of GCV. GCV for latex thiols, inorganic phosphorous, sucrose and magnesium was high (22.9 - 36.38%), while that for chlorophyll a, b and total chlorophyll was average (17.65 - 20.13%). Chlorophyll a:b ratio showed a low GCV estimate (7.98%).

The highest heritability (82.66%) was recorded for thiol content of latex followed by palisade layer thickness (81.22%). Stomatal density had the lowest heritability estimate (12.55%) followed by density of latex vessels (15.41%). Heritability estimates for all morphological characters except number of whorls produced in the first year (W1) and both years together (W8), diameter of scion

in the second year and leaf size, were low (<30%). All the eight biochemical parameters and three leaf anatomical traits had very high values of heritability (>60%). Heritability of immature yield, bark thickness, number of latex vessel rows and single leaf area were in the medium range.

Estimates of genetic advance at 5 per cent selection intensity ranged from 1.78 per cent for density of latex vessels to 64.58 per cent for sucrose content and 63.08 per cent for immature yield. All the morphological traits showed low (<16%) to medium (16-28%) estimates of genetic advance. Among the leaf and bark anatomical traits, number of latex vessel rings, laticifer area index and palisade layer thickness of leaf showed relatively high genetic advance, while bark thickness, leaf midrib and lamina thickness exhibited medium values. Of the biochemical traits, only chlorophyll a:b ratio had a low estimate of genetic advance, while the estimates of all the others were high.

4.2.3 Association between characters

The *inter se* phenotypic, genotypic and environmental correlations of immature yield and other morphological, anatomical and biochemical parameters are presented below. The values of correlation coefficients for all the variables at the phenotypic, genotypic and environmental levels are shown separately in Appendices E, F and G respectively.

4.2.3.1. Correlations between immature yield and other parameters

Table 31 gives the phenotypic, genotypic and environmental correlations of immature yield with all the other parameters. Laticifer area index followed by

Table 31. Phenotypic, genotypic and environmental correlations between yield and 33 other variables at the immature stage

	Correlations with immature yield		
	Phenotypic	Genotypic	Environmental
Sprouting week	-0.0226	0.2098	-0.1873
Height	0.0516	-0.3319	0.2514
Scion diameter (1st year)	0.1261	0.2885	0.0113
Whorls produced (1st year) (W1)	0.0794	0.1079	0.0564
Whorls retained (W2)	0.0879	0.2472	-0.0284
Whorls shed (W3)	0.0076	-0.2149	0.1123
Total no. of leaves produced (1st year)	0.1789	0.0663	0.2637
Scion diameter (2nd year)	0.5086**	0.3996	0.6062**
Diameter increment	0.3016**	0.1698	0.4086**
New whorls produced on main stem (2nd year) (W4)	0.2096	0.5091	-0.0223
New whorls produced on entire plant (W5)	0.1339	-0.0410	0.2531
New whorls retained on main stem (W6)	0.2928**	0.8874	0.0401
New whorls retained on entire plant (W7)	0.1472	-0.0608	0.2707
New whorls prod. on main stem in both years together (W8)	0.1720	0.3474	0.0189
Leaf size	0.2109	0.4807	-0.0738
Specific leaf weight	0.1481	0.0931	0.1894
Stomatal density	-0.0586	-0.0689	-0.0628
Bark thickness	0.4128**	0.3923	0.4340**
No.latex vessel rows	0.4622**	0.4878	0.4340**
Density of latex vessels	-0.0619	-0.0924	-0.0559
Diameter of latex vessel	0.0743	0.1922	-0.0362
Laticifer area index	0.6268**	0.6807	0.5784**
Midrib thickness	0.1171	0.1467	0.0749
Lamina thickness	-0.0991	-0.2223	0.1243
Palisade layer thickness	0.0797	0.0368	0.1845
Latex thiols	0.3294**	0.1855	0.7167**
Inorganic phoshorous	0.4076**	0.4534	0.3539**
Latex sucrose	0.0616	-0.2989	0.6888**
Latex magnesium	0.2392*	0.0780	0.4642**
Chlorophyll a	0.2619*	0.2537	0.2875*
Chlorophyll b	0.2720*	0.2732	0.2777*
Total chlorophyll	0.2706*	0.2645	0.2911*
Chlorophyll a : b ratio	-0.0564	-0.0888	-0.0042

* - Significant at 5%   ** - Significant at 1%

scion diameter in the second year showed the highest phenotypic correlations with yield (r= 0.6268** and 0.5086** respectively). Highly significant positive correlations were also obtained with number of latex vessel rows, bark thickness, inorganic phosphorous, thiol content and girth increment, with correlation coefficients ranging from 0.4622** to 0.3016**. The correlations of yield with number of new flushes retained on the main stem in the second year, latex magnesium, chlorophyll a, chlorophyll b and total chlorophyll with testtap yield were significant at the 5 per cent level. A positive phenotypic correlation between yield and leaf size was observed (r=_0.2109), though the relationship was not statistically significant. None of the first year parameters showed any significant phenotypic correlation with yield.

At the genotypic level, number of new flushes retained on the main stem in the second year (W6) showed the maximum correlation with yield (r= 0.8874), followed by laticifer area index (0.6807) and number of new flushes produced on the main stem in the second year (W4) (0.5091). Relatively high positive genotypic correlations were also recorded with number of latex vessel rows, leaf size, inorganic phosphorous, second year scion diameter, bark thickness and number of flushes produced on the main stem in the two years (W8) (r= 0.4878 to 0.3474). Among the first year parameters, height of the plant in the first year showed a negative, though weak (r= -0.3319) genotypic correlation with yield. Number of flushes shed by the end of the first year (W3) was negatively correlated, while number of flushes retained at the end of the first year (W2), time taken to sprout and scion diameter in the first year were positively correlated with yield, though the associations were relatively low (r= 0.2098 to 0.2885). Low positive

correlations of yield were also observed with chlorophyll a and b and total chlorophyll (0.2537 to 0.2732).

The environmental correlations of immature yield with scion diameter and diameter increment in the second year, bark thickness, number of latex vessel rows, laticifer area index and all the biochemical parameters except chlorophyll a:b ratio, were significant and positive (r= 0.7167** to 0.2911*), indicating that the environment influenced the expression of these parameters in the same way.

4.2.3.2. Associations between morphological traits

The *inter se* correlations among the juvenile morphological traits at the genotypic, phenotypic and environmental levels are shown in Table 32. Time taken to sprout was observed to have significant negative phenotypic correlations with height, number of flushes produced in the first year (W1), number of flushes shed by the end of the first year (W3), number of leaves, second year scion diameter, girth increment, (r= -0.4023** to -0.2625*), while its correlation with first year scion diameter was positive (r= 0.3218**). This trait was also significantly negatively correlated with number of new flushes produced and those retained on the entire plant in the second year (W5 and W7), while the correlations with number of new flushes produced on the main stem in the second year (W4) and number of new flushes retained on the main stem in the second year (W6) were positive. Similar correlations were obtained at the genotypic level too. Environment was found to have a low negative effect on the correlations in the first year, while no significant effect was observed on the correlations in the second year. Leaf size, specific leaf weight and stomatal density showed slightly higher genetic correlations than phenotypic with time taken to sprout.

Table 32. Correlations among seventeen immature morphological traits

		Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17
Y1	P	-0.3268**	0.3218**	-0.2345*	-0.0028	-0.3750**	-0.3288**	-0.2625*	-0.4023**	0.2652*	-0.2233	0.1524	-0.2969**	0.0259	0.0712	-0.0073	0.1000
	G	-0.6859	0.3449	-0.1526	0.0549	-0.4808	-0.4236	-0.2231	-0.4209	0.3831	-0.6606	0.4003	-0.8367	0.1317	0.2850	0.2216	0.3195
	E	-0.2069	0.3104*	-0.2821*	-0.0318	-0.3491*	-0.2833*	-0.2872*	-0.3930*	0.2027	-0.0306	0.0754	-0.1016	-0.0371	-0.0797	-0.0990	0.0463
Y2	P		-0.1521	0.6550**	0.5449**	0.3099**	0.8267**	0.6791**	0.5918**	0.3034**	0.7244**	0.0132	0.6984**	0.5582**	-0.0338	0.1886	-0.2243
	G		-0.4273	0.8475	0.5306	1.0501	0.8839	0.7654	0.8812	0.5712	1.1516	-0.0021	1.1337	0.7929	0.1488	-0.2225	-0.3694
	E		-0.0564	0.5995**	0.5605**	0.1404	0.8181**	0.6700**	0.4965**	0.2081	0.5935**	0.0168	0.5833**	0.4823**	-0.1315	0.3079*	-0.1982
Y3	P			-0.1781	0.0495	-0.3556**	-0.0813	0.0463	-0.6557**	0.1251	-0.0826	0.1731	-0.1008	-0.0264	-0.1763	-0.1570	0.1146
	G			-0.1417	-0.0987	-0.1563	-0.1408	0.0973	-0.5976	0.4067	-0.2324	0.4751	-0.3295	0.1510	-0.1952	-0.3050	0.6936
	E			-0.1999	0.1267	-0.4295**	-0.0519	0.0160	-0.6872**	-0.0298	-0.0147	0.0767	-0.0155	-0.1358	-0.1675	-0.0969	-0.0370
Y4	P				0.7878**	0.5338**	0.7586**	0.4278**	0.4300**	0.4447**	0.5037**	-0.0702	0.4032**	0.8411**	0.2196	0.2587	-0.2202
	G				0.9227	0.6637	0.7236	0.4524	0.4456	0.5953	0.8210	-0.2501	0.7128	0.8911	0.2172	0.1064	-0.4050
	E				0.7093**	0.5097**	0.7823**	0.4110**	0.4210**	0.3500*	0.3438**	-0.0047	0.2805*	0.8063**	0.2245	0.3358*	-0.1787
Y5	P					-0.1004	0.7044**	0.3753**	0.2203	0.5763**	0.5040**	0.1743	0.4119**	0.7990**	0.3228**	0.2388*	-0.1482
	G					0.3241	0.5647	0.4375	0.4252	0.6942	0.6076	0.1655	0.4810	0.9041	0.4554	0.4781	-0.0369
	E					-0.2449	0.7751**	0.3387*	0.1079	0.5103**	0.4573**	0.1817	0.3910**	0.7373**	0.2313	0.1398	-0.1859
Y6	P						0.2584	0.1758	0.3922**	-0.0728	0.1216	-0.3525**	0.0858	0.2617	-0.0884	0.0901	-0.1521
	G						0.6800	0.2613	0.2685	0.1140	0.8357	-0.9349	0.8159	0.4327	-0.3506	-0.6664	-0.9221
	E						0.1300	0.1519	0.4474**	-0.1414	-0.0854	-0.2282	-0.0914	0.2090	0.0265	0.2913*	-0.0188
Y7	P							0.7016**	0.5681**	0.4211**	0.6825**	0.1075	0.6445**	0.6887**	0.0360	0.1203	-0.1972
	G							0.8181	0.7635	0.5769	0.9492	0.2266	0.9584	0.7274	0.1411	-0.1520	-0.4786
	E							0.6388**	0.4671**	0.3389*	0.5658**	0.0713	0.5355**	0.6718**	-0.0381	0.2299	-0.1309
Y8	P								0.6961**	0.3318**	0.6096**	0.3332**	0.6307**	0.4453**	0.0071	0.0876	-0.1919
	G								0.7338	0.5503	0.7127	0.5616	0.7638	0.5618	-0.0423	-0.3507	-0.2428
	E								0.6738**	0.1909	0.5625**	0.2604	0.5921**	0.3610**	0.0500	0.3024*	-0.1907
Y9	P									0.1438	0.4892**	0.1259	0.5198**	0.3331**	0.1355	0.1522	-0.2059
	G									0.1794	0.7311	0.1888	0.8406	0.3486	0.1463	-0.0911	-0.6211
	E									0.1231	0.3754**	0.1076	0.4010**	0.3242*	0.1301	0.2597	-0.0985
Y10	P										0.3966**	0.5444**	0.2337	0.8585**	0.1895	0.1548	-0.1192
	G										0.5648	0.5023	0.4311	0.8951	0.2771	0.4078	-0.1723
	E										0.3163*	0.5780**	0.1578	0.8363**	0.1232	0.0439	-0.1106

Table 32 (Contd...)

		Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17
Y11	P											0.0617	0.9688**	0.5279**	-0.0298	-0.0475	-0.1756
	G											0.1289	0.9812	0.7745	0.0010	-0.2628	-0.5738
	E											0.0425	0.9687**	0.4010**	-0.0516	0.0318	-0.0841
Y12	P												0.1029	0.2886**	0.1558	0.0920	0.1184
	G												0.1908	0.1449	0.4556	0.5846	0.8961
	E												0.0814	0.3622**	0.0277	-0.0402	-0.0184
Y13	P													0.3720**	-0.0591	-0.0791	-0.1271
	G													0.6390	-0.0216	-0.3520	-0.4537
	E													0.2638	-0.0845	0.0045	-0.0628
Y14	P														0.2402	0.2416*	-0.1980
	G														0.2770	0.2893	-0.3220
	E														0.2092	0.2243	-0.1744
Y15	P															0.3957***	-0.0745
	G															0.8373	0.2393
	E															0.1564	-0.2086
Y16	P																-0.2090
	G																1.3114
	E																-0.5455**
Y17	P																
	G																
	E																

Y1 Weeks taken to sprout
Y2 Height
Y3 Scion diameter (1)
Y4 Total whorls produced (W1)
Y5 Whorls retained (W2)
Y6 Whorls lost (W3)

Y7 Number of leaves
Y8 Scion diameter (2)
Y9 Girth increment
Y10 Total whorls produced on the main stem (W4)
Y11 Total whorls produced on the entire plant (W5)
Y12 Whorls retained on the main stem (W6)

Y13 Whorls retained on the entire plant (W7)
Y14 Total whorls produced on the main stem in both years together (W8)
Y15 Leaf size
Y16 Specific leaf weight
Y17 Stomatal frequency

Height of the clones was found to have high positive correlations at the phenotypic and genotypic levels with all the whorl and leaf production characteristics in the first year. It was also found to positively influence all whorl production characteristics in the second year (W4 to W8) except number of new flushes retained on the main stem (W6), as well as scion diameter and girth increment in the second year. Height was not significantly correlated at the phenotypic or genotypic levels with leaf size or specific leaf weight, while a low negative genotypic correlation was observed with stomatal density. Significant positive environmental correlations were observed for most of these correlations, except number of flushes shed by the end of the first year (W3), number of new flushes produced, and those retained on the main stem in the second year (W4 and W6).

Scion diameter in the first year was negatively correlated with number of flushes shed by the end of the first year (W3) and with diameter increment in the second year, at all the three levels. No other significant correlation at the phenotypic level was observed. However, at the genotypic level, positive correlations were also obtained with number of new flushes produced and those retained on the main stem in the second year (W4 and W6) (r= 0.4067 and 0.4751 respectively) and with stomatal density (r= 0.6936), while negative correlations were seen with number of new flushes retained on the entire plant in the second year (W7).

Number of flushes produced in the first year (W1) was found to be highly positively correlated at all the three levels with scion diameter and diameter increment in the second year, and all the first and second year whorl production traits except number of new flushes retained on the main stem in the second year

(W6). Similar correlations were obtained with number of flushes retained at the end of the first year (W2) with all other traits except number of new flushes retained on the main stem in the second year (W6). A relatively high negative genotypic correlation (r= -0.4050) of number of flushes produced in the first year (W1) with stomatal density was also seen. Number of leaves produced in the first year was also found to have a significant positive effect on all whorl characteristics in the second year at the genotypic and phenotypic levels, except for number of new flushes retained on the main stem in the second year (W6).

Scion diameter in the second year and diameter increment were positively correlated with each other at all the three levels, as well as with all the second year whorl production characteristics (W4 to W8). However, the correlation of diameter increment with number of new flushes produced and those retained on the main stem in the second year (W4 and W6) was not significant. In general, there were no significant correlations of scion diameter and diameter increment with the leaf morphological characteristics - size, specific leaf weight or stomatal density, except for a relatively high negative correlation between diameter increment and density of stomata (r = -0.6211).

Number of new flushes produced on the main stem in the second year (W4) was highly and positively correlated at the phenotypic, genotypic and environmental levels with number of flushes produced on the main stem in the two years (W8), as well as with the other whorl characteristics in the second year. No significant correlations of this trait were recorded with leaf characteristics, except

for a positive genotypic correlation with specific leaf weight (r= 0.4078). Number of new flushes produced on the entire plant in the second year (W5) was highly correlated with those retained on the entire plant in the second year (W7) and number of flushes produced on the main stem in the two years (W8) at all three levels. Negative correlations of this trait at the genotypic level were recorded with stomatal density (r= -0.5738) and specific leaf weight (r=-0.2628). Number of new flushes retained on the main stem in the second year (W6) showed relatively high positive genotypic correlations with leaf size, specific leaf weight and stomatal density (r= 0.4556, 0.5846 and 0.8961 respectively), though these correlations were not significant at the phenotypic level. Number of new flushes retained on the entire plant in the second year (W7) was positively correlated with number of flushes produced on the main stem in the two years (W8) at the phenotypic and genotypic levels. This trait was negatively correlated at the genotypic level with stomata density and specific leaf weight. The character number of flushes produced on the main stem in the two years (W8) had low, positive phenotypic and genotypic correlations with leaf size and specific leaf weight, and a negative genotypic correlation with stomatal density.

Leaf size was positively correlated at the phenotypic and genotypic levels with specific leaf weight, and at the genotypic level only with stomatal density. Specific leaf weight had a high positive genotypic correlation with stomatal density. This correlation was not significant at the phenotypic level. Environment was found to have a significant negative effect on this correlation.

4.2.3.3. Associations between anatomical traits

The correlations among the eight anatomical bark and leaf characters recorded in the immature plants at the phenotypic, genotypic and environmental levels, are presented in Table 33.

Bark thickness was positively correlated with number of latex vessel rows, laticifer area index and leaf midrib thickness at the phenotypic, genotypic and environmental levels. This trait also showed a low negative correlation with density of latex vessels in each row at the phenotypic level ($r = -0.2567*$) though this relationship was much stronger at the genotypic level ($r = -0.7498$).

Laticifer area index was highly positively correlated with number of latex vessel rows at the genotypic and phenotypic levels ($r = 0.7671**$ and 0.8485 respectively). This relationship was positively influenced by the environment too as indicated by the high positive environmental correlation ($r = 0.6920**$). Density of latex vessels was not correlated phenotypically with laticifer area index, though a negative correlation at the genotypic level was observed ($r = -0.36$). Diameter of latex vessels was found to have significant positive phenotypic and environmental correlations with this trait, though there was no such relationship at the genotypic level. No significant correlations were obtained between laticifer area index and leaf anatomical traits except for a low negative genotypic correlation with lamina thickness ($r = -0.2877$).

Low negative correlations between number of latex vessel rows and diameter of latex vessels at the phenotypic and genotypic levels were detected

Table 33. Phenotypic, genotypic and environmental correlations among eight immature anatomical traits

		Y19	Y20	Y21	Y22	Y23	Y24	Y25
Y18	P	0.5404**	-0.2567*	-0.0316	0.5109**	0.3838**	0.0450	0.0976
	G	0.6911	-0.7498	0.0767	0.7244	0.4232	-0.0093	0.0254
	E	0.3644**	-0.0725	-0.1332	0.3135*	0.3571*	0.1543	0.2677
Y19	P		-0.1762	-0.2445*	0.7671**	0.0611	-0.1015	0.1726
	G		-0.2659	-0.3088	0.8485	-0.0018	-0.2232	0.1825
	E		-0.1618	-0.1791	0.6920**	0.2053	0.1563	0.1693
Y20	P			-0.0009	-0.0657	-0.2538*	-0.0509	-0.0581
	G			-0.0554	-0.3500	-0.4823	-0.0187	0.0363
	E			0.0204	0.0398	-0.2015	-0.1029	-0.1781
Y21	P				0.3018**	0.1079	0.0415	-0.1276
	G				0.1670	0.2509	0.1182	-0.1106
	E				0.4155**	-0.1243	-0.0844	-0.1885
Y22	P					0.0550	-0.1257	0.0838
	G					0.0390	-0.2877	0.0993
	E					0.0924	0.1319	0.0731
Y23	P						0.5377*	0.3505
	G						0.5196	0.2872
	E						0.6023**	0.6021
Y24	P							0.7077
	G							0.6958
	E							0.7569
Y25	P							
	G							
	E							

Y18: Bark thickness
Y19: Number of latex vessel rows
Y20: Density of latex vessels
Y21: Diameter of latex vessels
Y22: Laticifer area index
Y23: Leaf midrib thickness
Y24: Leaf lamina thickness
Y25: Palisade layer thickness

(r= -0.2445* and -0.3088 respectively). Density of latex vessels showed very low negative phenotypic and genotypic correlations with number of latex vessel rows.

Density of latex vessels was not correlated with diameter. Low negative phenotypic and genotypic correlations (r= -0.2538* and -0.4823) were detected with midrib thickness. Diameter of latex vessels also showed a positive but very low genotypic correlation with midrib thickness (r= 0.2509).

High phenotypic and genotypic correlations were observed among the three leaf anatomical traits. Environment also influenced these correlations positively, as indicated by their high environmental correlation values.

4.2.3.4. Associations between biochemical traits

Table 34 gives the phenotypic, genotypic and environmental correlations among the eight latex and leaf biochemical traits.

No significant correlations were observed between thiol content of latex and any of the other biochemical parameters at the genotypic or phenotypic levels, except for a very weak phenotypic correlation with leaf chlorophyll a and total chlorophyll content (r =0.2323* and 0.2315* respectively). Inorganic phosphorous also recorded only a low significant positive phenotypic relation with latex magnesium (r= 0.2536*), and a negative genotypic correlation with sucrose (r= -0.2761). Latex sucrose content recorded a positive phenotypic correlation with chlorophyll a, total chlorophyll and chlorophyll a:b ratio (r= 0.2951**,

Table 34. Phenotypic, genotypic and environmental correlations among immature eight anatomical traits

		Y27	Y28	Y29	Y30	Y31	Y32	Y33
Y26	P	0.1581	0.0455	0.0375	0.2323*	0.1912	0.2315*	0.0449
	G	0.0409	-0.1071	-0.1158	0.2239	0.1850	0.2247	0.0424
	E	0.5145***	0.6122**	0.4889**	0.2719	0.2253	0.2668	0.0554
Y27	P		0.0253	0.2536*	-0.0420	-0.0548	-0.0507	0.1136
	G		-0.2761	0.0431	-0.0059	-0.0514	-0.0251	0.1258
	E		0.7100**	0.6301**	-0.1160	-0.0612	-0.1015	0.0878
Y28	P			0.0615	0.2951**	0.1260	0.2497	0.2871**
	G			-0.1612	0.4556	0.2340	0.3983	0.3233
	E			0.5688**	-0.1198	-0.1250	-0.1219	0.1802
Y29	P				-0.1441	-0.2363*	-0.1743	0.2793*
	G				-0.2537	-0.4112	-0.3056	0.3973
	E				0.0789	0.0863	0.0851	0.0110
Y30	P					0.9011**	0.9915**	-0.1771
	G					0.8878	0.916	-0.0949
	E					0.9324**	0.9917**	-0.3969**
Y31	P						0.9489**	-0.5687**
	G						0.9398	-0.5350
	E						0.9689**	-0.6606**
Y32	P							-0.2959**
	G							-0.2207
	E							-0.4926**
Y33	P							
	G							
	E							

Y26: Latex thiols
Y30: Chlorophyll a

Y27: Inorganic phosphorous in latex
Y31: Chlorophyll b

Y28: Latex sucrose
Y32: Total chlorophyll

Y29: Latex magnesium
Y33: Chlorophyll a:b ratio

0.2497* and 0.2871** respectively). These three correlations were positive at the genotypic level too (r= 0.3233 to 0.4556) while their environmental correlations were negligible. Latex magnesium showed a positive phenotypic correlation with chlorophyll a:b ratio (r= 0.2793*) and negative with chlorophyll b (r= -02363*). At the genotypic level, latex magnesium showed negative correlations with chlorophyll a, b and total chlorophyll (r= -0.2537 to -0.4112) and a positive correlation with chlorophyll a:b ratio (0.3973).

Chlorophyll a, b and total chlorophyll were positively correlated amongst themselves at all three levels. Chlorophyll a:b ratio was not correlated with chlorophyll a, but was negatively correlated with chlorophyll b and total chlorophyll.

The environmental correlations amongst the four latex biochemical traits at the immature stage were high and positive, indicating that they were influenced by the environment in a similar manner. Similar trends were observed amongst chlorophyll a, b and total chlorophyll. Chlorophyll a:b ratio however showed significant negative environmental correlations with the other three chlorophyll traits. The environmental correlations between the latex and leaf biochemical characters were very low indicating that the environment did not influence the correlations between them.

4.2.3.5. Associations between morphological, anatomical and biochemical traits

Apart from the correlations discussed above, correlations between the morphological, anatomical and biochemical traits were also observed (Appendices E, F and G)

Second year scion diameter was positively correlated with bark thickness and laticifer area index, while at the genotypic level, it was also correlated negatively with density of latex vessels and lamina thickness. Number of new flushes produced on the main stem in the second year (W4) and number of flushes produced on the main stem in the two years (W8) were phenotypically positively correlated with bark thickness, while genotypically they were also correlated with midrib thickness. Leaf size and specific leaf weight showed positive phenotypic correlations with bark thickness and leaf anatomical traits. At the genotypic level, their correlations with bark thickness, number of latex vessel rows, leaf midrib, lamina and palisade layer thickness were positive, while negative correlations were recorded with density and diameter of latex vessels. Density of stomata showed relatively high positive associations only at the genotypic level with lamina and palisade layer thickness. Density of latex vessels showed negligible phenotypic and negative genotypic correlations with most of the morphological traits.

Number of whorls produced and retained on the main stem in the first and second years (W2, W4, W6 and W8) also recorded low but positive phenotypic correlations with inorganic phosphorous (r= 0.2645* to 0.2976**). A similar trend was seen at the genotypic level too. Number of new flushes retained on the main stem in the second year (W6), leaf size and specific leaf weight were positively correlated with latex magnesium content at the phenotypic and genotypic levels. Significant positive phenotypic and genotypic correlations were observed between second year diameter and chlorophyll a, b and total chlorophyll. Leaf size and stomatal density were significantly negatively correlated with chlorophyll a, b, and total chlorophyll at the phenotypic level, while genotypically, leaf size

and specific leaf weight were negatively correlated with these three traits. Relatively high positive correlations were recorded between stomatal density and chlorophyll a:b ratio at the phenotypic and genotypic levels (r= 0.4071** and 0.5033 respectively).

Intercorrelations between anatomical and biochemical traits were detected. Significant positive correlations at the phenotypic and genotypic levels were observed of bark thickness with thiols and inorganic phosphorous. Number of latex vessel rows was correlated only with thiol content at both phenotypic and genotypic levels. Density of latex vessels showed positive genotypic correlations with chlorophyll a, b and total chlorophyll (r= 0.2886 to 0.4371), while it was negatively correlated with chlorophyll a:b ratio, thiol content, inorganic phosphorous and sucrose in latex (r= -0.2510 to -0.5370). At the phenotypic level however, these correlations were not significant. Diameter of latex vessels was positively correlated at the genotypic level with inorganic phosphorous, chlorophyll a, b and total chlorophyll, while it was negatively correlated with magnesium. These correlations were not significant at the phenotypic level. Significant positive correlations of laticifer area index were recorded with thiols, inorganic phosphorous chlorophyll a, b and total chlorophyll at the phenotypic and genotypic levels. Significant negative but low, phenotypic correlations were recorded between all the leaf anatomical traits and chlorophyll a, b and total chlorophyll. Similar correlations were seen at the genotypic level also.

4.2.4 Direct and indirect effects on immature yield

Path analysis was carried out to examine the direct and indirect effects of the various morphological, anatomical and biochemical traits on yield at the

immature phase. The parameters included in the analysis were time taken to sprout, height of the plants, scion diameter in the first and second years, number of whorls retained and those shed in the first year (W2 and W3), number of leaves produced, number of new flushes retained on the main stem in the second year (W6), leaf size, inorganic phosphorous content of latex, and chlorophyll a and b content. Table 35 gives the direct and indirect effects of each of these characters on immature yield.

The highest positive direct effect on yield was exerted by number of latex vessel rows (0.6964) followed by number of leaves produced in the first year (0.5397) and number of flushes retained at the end of the first year (W2) (0.4944). Bark thickness showed a very high negative direct effect on yield (-0.7230).

Inspite of the high positive direct effect of number of latex vessel rows, which was further enhanced by its positive indirect effects through number of new flushes retained on the main stem in the second year (W6) and lamina thickness, the net correlation of this trait on yield was reduced due to its negative indirect effect through bark thickness.

In the case of number of leaves produced, its high positive direct effect on yield was supplemented by a positive indirect effect through number of flushes retained at the end of the first year (W2). However, this high positive effect was completely negated by the cumulative negative indirect effects through bark thickness, second year scion diameter, time taken to sprout and height, leading to a net negligible correlation between number of leaves produced and yield.

Table 35. Direct and indirect effects of 15 immature traits on yield

Traits		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Genotypic correlation with yield
Weeks to sprout	1	**0.4240**	0.0788	-0.0232	0.0271	0.1309	-0.2287	0.0623	0.0799	0.0750	-0.0337	-0.1120	-0.2353	-0.0022	0.0043	-0.0375	0.2098
Height	2	-0.2908	**-0.1148**	0.0287	0.2623	-0.2859	0.4771	-0.2137	-0.0004	0.0392	-0.1329	-0.1283	0.0940	-0.0131	0.0033	-0.0564	-0.3319
Scion diameter (1)	3	0.1462	0.0491	**-0.0671**	-0.0488	0.0426	-0.0760	-0.0272	0.0949	-0.0514	-0.1504	0.2303	0.0211	0.0093	-0.0078	0.1238	0.2885
Whorls W2	4	0.0233	-0.0609	0.0066	**0.4944**	-0.0882	0.3048	-0.1222	0.0330	0.1199	-0.3215	0.0446	-0.2224	0.0951	0.0051	-0.0645	0.2472
Whorls W3	5	-0.2038	-0.1206	0.0105	0.1602	**-0.2723**	0.3670	-0.0729	-0.1867	-0.0923	0.0963	-0.2456	0.1321	-0.0107	-0.0080	0.2319	-0.2149
Total no. of leaves	6	-0.1796	-0.1015	0.0094	0.2792	-0.1852	**0.5397**	-0.2284	0.0452	0.0371	-0.3199	-0.0370	0.0957	0.0400	-0.0040	0.0754	0.0663
Scion diameter (2)	7	-0.0946	-0.0879	-0.0065	0.2163	-0.0711	0.4415	**-0.2792**	0.1121	-0.0111	-0.2844	0.1777	0.2117	0.0070	-0.0092	0.0774	0.3996
Whorls W6	8	0.1697	0.0002	-0.0319	0.0818	0.2546	0.1223	-0.1568	**0.1997**	0.1199	-0.3259	0.3508	0.0936	0.0807	-0.0021	-0.0693	0.8874
Leaf size	9	0.1208	-0.0171	0.0131	0.2251	0.0955	0.0762	0.0118	0.0910	**0.2633**	-0.2855	0.2528	-0.2196	0.0693	0.0151	-0.2310	0.4807
Bark thickness	10	0.0198	-0.0211	-0.0140	0.2198	0.0363	0.2388	-0.1098	0.0900	0.1040	**-0.7230**	0.4813	0.0045	0.1366	0.0020	-0.0729	0.3923
NLV	11	-0.0882	0.0212	-0.0222	0.0317	0.0960	-0.0287	-0.0712	0.1006	0.0955	-0.4997	**0.6964**	0.1072	0.0547	-0.0004	-0.0251	0.4878
Lamina thickness	12	0.2078	0.0225	0.0030	0.2290	0.0749	-0.1075	0.1231	-0.0389	0.1204	0.0067	-0.1555	**-0.4802**	-0.0264	0.0151	-0.2161	-0.2223
In. Phosphorous	13	-0.0038	0.0061	-0.0025	0.1917	0.0119	0.0881	-0.0080	0.0657	0.0744	-0.4027	0.1552	0.0517	**0.2452**	0.0002	-0.0199	0.4534
Chlorophyll a	14	-0.0652	0.0135	-0.0189	-0.0909	-0.0783	0.0769	-0.0923	0.0151	-0.1429	0.0531	0.0098	0.2601	-0.0014	**-0.0278**	0.3430	0.2537
Chlorophyll b	15	-0.0411	0.0168	-0.0215	-0.0825	-0.1634	0.1053	-0.0559	-0.0358	-0.1574	0.1364	-0.0453	0.2886	-0.0126	-0.0247	**0.3864**	0.2732

Residue = 0.3333

*Diagonal elements (bold) represent direct effects, while the off-diagonals are the indirect effects

Scion diameter (1) : Scion diameter at the end of the first year
Scion diameter (2) : Scion diameter at the end of the second year
NLV: Number of latex vessel rows

In. Phosphorous: Inorganic phosphorous in latex
W2 and W3: No. of whorls retained and shed in the first year respectively
W6 : No. of whorls retained on the main stem in the second year

The high positive direct effect of number of flushes retained at the end of the first year (W2) on yield was further boosted by its positive indirect effect through number of leaves produced and leaf size. However, this positive effect was counterbalanced by the negative indirect effects through bark thickness and lamina thickness.

The high negative direct effect of bark thickness on yield was further increased by its negative indirect effect through second year scion diameter. This high negative influence was completely offset by the positive indirect effects of bark thickness through number of flushes retained at the end of the first year (W2), number of leaves produced, number of latex vessel rows, inorganic phosphorous and leaf size, resulting in a relatively high positive genotypic correlation of bark thickness with yield.

Chlorophyll b had a relatively high positive direct effect on yield. Its indirect effects through lamina thickness, number of leaves produced, and bark thickness were also positive. The negative indirect effects of this trait through number of flushes shed by the end of the first year (W3) and leaf size reduced its total positive correlation with yield. On the other hand, chlorophyll a was found to have only a negligible direct effect on yield. The net effect of its fairly high positive indirect effects on yield through chlorophyll b and lamina thickness, and its negative indirect effect through leaf size, resulted in a positive genotypic correlation between chlorophyll a and yield.

Lamina thickness had a fairly large direct negative effect on yield, which was supplemented by its negative indirect effect through number of leaves produced,

number of latex vessel rows and chlorophyll b. This negative effect was reduced to a great extent by its positive indirect effects through time taken to sprout, number of flushes retained at the end of the first year (W2), scion diameter in the second year and leaf size.

The positive direct effect of leaf size on yield was further boosted by the indirect effects of this trait through number of flushes retained at the end of the first year (W2), time taken to sprout and number of latex vessel rows. However, this positive effect was reduced to some extent by its negative indirect effects through bark thickness, lamina thickness and chlorophyll b, though the net correlation with yield still remained positive and relatively high.

Inorganic phosphorous was also found to have a positive direct effect on yield, which was further boosted by its positive indirect effects through number of flushes retained at the end of the first year (W2) and number of latex vessel rows. However, its negative indirect effect through bark thickness brought down the net genotypic correlation of this trait with yield slightly.

The direct effect of number of new flushes retained on the main stem in the second year (W6) was positive but low. Inspite of its negative indirect effects through second year scion diameter and bark thickness, the cumulative effect of the positive indirect effects through time taken to sprout, number of flushes shed by the end of the first year (W3), number of leaves produced, number of latex vessel rows and leaf size considerably increased the total genotypic correlation of this trait with yield to 0.8874.

The negative direct effect of scion diameter in the second year was increased through its negative indirect effects through bark thickness. The net genotypic correlation of this trait was however rendered positive due to the counteracting influence of the positive indirect effects through number of flushes retained at the end of the first year (W2), number of leaves produced, number of new flushes retained on the main stem in the second year (W6), number of latex vessel rows and lamina thickness.

The traits included in the path analysis could explain 67 per cent of the variation in the yield as indicated by the residue of 0.3333.

4.2.5 Genetic divergence among clones at the immature stage

The genetic distances between the 25 clones were computed using 16 variables. The D^2 values for the 300 clone combinations are presented in Appendix H. The D^2 values ranged from 6.89 (between RRIM 526 and RRIM 602) to 194.49 (between IAN 873 and RRIM 607).

The 25 clones were grouped into five clusters using the Tocher's method of clustering. The critical D^2 value was fixed as 46.32 for initiating new clusters. The composition of each cluster is given in Table 36. Cluster I was the single largest cluster comprising of 19 clones (RRIM 501, RRIM 519, RRIM 526, RRIM 600, RRIM 602, RRIM 604, RRIM 605, RRIM 610, RRIM 611, RRIM 620, RRIM 622, RRIM 628, RRIM 636, RRIM 701, RRIM 703, RRIM 704, RRIM 705, IAN 873 and Har 1). Cluster II and III comprised of only two clones each (RRIM 615 and RRII 105; and RRIM 603 and RRIM 706 respectively). Clones

Table 36. Clustering pattern of immature clones
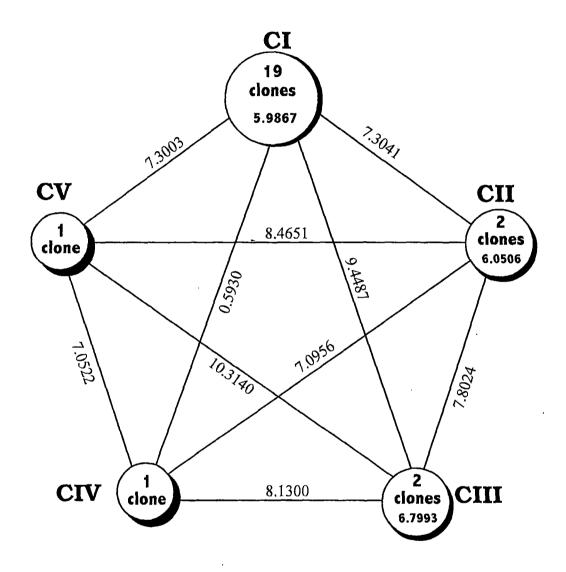
Cluster	No. of clones	Clone
C I	19	RRIM 501, RRIM 519, RRIM 526, RRIM 600, RRIM 602, RRIM 604, RRIM 605, RRIM 610, RRIM 611, RRIM 620, RRIM 622, RRIM 628, RRIM 636, RRIM 701, RRIM 703, RRIM 704, RRIM 705, IAN 873, Har1
C II	2	RRIM 615, RRII 105
C III	2	RRIM 607, RRIM 612
C IV	1	RRIM 603
C V	1	RRIM 706

RRIM 603 and RRIM 706 formed independent clusters (C IV and C V). Figure 6 gives the cluster diagram of the 25 clones at the immature stage.

The mean inter and intra cluster distances are given in Table 37. The intra cluster distance ranged from 5.99 for C I to 6.80 for C III. The least inter cluster distance was recorded between clusters C I and C IV (6.59) while the maximum distance was recorded between C III and C V (10.31).

Clustering was found to be independent of the country of origin, as shown by the clustering pattern of the three non Malaysian clones: IAN 873 and Har 1 (of Brazilian and Liberian origin respectively) were grouped with the Malaysian clones, while RRII 105 (the only clone of Indian origin) was grouped with another Malaysian clone.

Table 38 gives the cluster means for the 16 traits. Cluster I, with the maximum number of clones, showed superiority for only one trait, viz. lamina thickness. Cluster II, comprising of clones RRIM 615 and RRII 105, showed superiority for five traits second year scion diameter, number of new flushes retained on the main stem in the second year (W6), leaf size, number of latex vessel rows, inorganic phosphorous, and juvenile yield. Cluster III, which consisted of two clones (RRIM 607 and RRIM 612), was superior for bark thickness only. Cluster IV, consisting of one clone only (RRIM 603), showed superiority for number of flushes retained at the end of the first year (W2), chlorophyll a and b content. RRIM 706, forming Cluster V, was superior for the traits plant height, first year scion diameter, number of leaves produced, and early sprouting.

Bold   - Intra cluster distances
Normal - Inter cluster distances

Figure 6. Cluster diagram of 25 clones at the immature stage

Table 37. Average inter- and intra- cluster distances (D) among immature clones

	C I	C II	CIII	CIV	C V
C I	**5.9867**	7.3041	9.4487	6.5930	7.3003
C II		**6.0506**	7.8024	7.0956	8.4651
CIII			**6.7993**	8.1300	10.3140
CIV				**0.0000**	7.0522
C V					**0.0000**

Diagonals (bold) represent the intra cluster distance, while the off diagonals represent the inter cluster distance

Table 38. Contribution of immature traits to genetic divergence

Cluster	No. of clones	Cluster averages							
		Sprouting week	Height	Scion diameter (1st year)	Whorls retained (1st year)	Whorls shed (1st year)	Total no. of leaves	Scion diameter (2nd year)	Whorls retained (W6)
I	19	5.94	160.70	12.82	4.33	1.31	59.54	22.42	2.42
II	2	6.23	168.86	12.88	4.56	1.08	61.36	25.51	2.93
III	2	5.38	146.95	14.07	3.42	1.16	55.48	23.13	2.65
IV	1	7.78	158.11	13.83	4.78	1.67	61.78	23.61	2.00
V	1	5.28	188.25	14.22	4.42	1.83	72.95	24.11	2.38
Mean		6.12	164.57	13.56	4.30	1.41	62.22	23.75	2.48
SD		1.01	15.38	0.67	0.52	0.33	6.50	1.16	0.34
CV % (Cluster level)		1.64	0.93	0.49	1.21	2.32	1.04	0.49	1.39
CV % (Genotypic level)		26.60	14.71	9.27	12.21	32.68	14.08	8.61	18.86

Contd...

Table 38 (Contd....)

					Cluster averages				
Cluster	No. of clones	Leaf size	Bark thickness	No. of latex vessels	Lamina thickness	Inorganic phosphorous	Chlorophyll a	Chlorophyll b	Juvenile yield
I	19	62.59	2.16	3.59	160.55	60.37	3.70	1.17	2.01
II	2	67.87	2.32	5.23	133.46	70.88	3.72	1.21	4.00
III	2	47.64	2.36	4.66	121.72	55.17	5.12	1.64	2.65
IV	1	57.93	2.11	3.56	157.78	49.64	5.69	2.03	3.81
V	1	48.11	2.02	3.28	146.06	65.37	3.87	1.66	2.02
Mean		56.83	2.19	4.06	143.92	60.29	4.42	1.54	2.90
SD		8.90	0.14	0.84	16.40	8.33	0.92	0.36	0.96
CV % (Cluster level)		1.57	0.64	2.06	1.14	1.38	2.09	2.30	3.31
CV % (Genotypic level)		15.46	12.13	17.16	5.77	17.13	11.56	14.60	42.12

The relative contribution of the different characters to genetic divergence, both at the cluster level as well as the genotypic level are also given in Table 38. The relative contribution at the cluster and genotypic levels was assessed using the respective coefficients of variation. Maximum variability was found with juvenile yield at the cluster level and genotype level. This was followed by number of whorls shed in the first year (W3) at the cluster level and inorganic phosphorous at the genotype level. Juvenile yield is the character which contributes maximum to genetic divergence in rubber at this stage of growth.

4.2.6 Factor analysis

Factor analysis was carried out using all the 34 morphological, anatomical and biochemical variables. The environment correlation matrix used is given in Appendix C. The principal component method was applied and nine factors were extracted. The results are summarized in Table 39. The characters constituting the factor groups are listed in Table 40.

The first factor accounted for 21.46 per cent of the variability in the population, and was correlated with the variables plant height, number of leaves, total number of whorls produced and those retained in the first year, scion diameter and increment in the second year, number of new whorls produced and those retained on the entire plant in the second year, number of new whorls produced on the main stem in the second year and in the two years together. Their factor loadings ranged from 0.595 to 0.925.

Table 39. Factor loadings and communalities of 34 variables on nine principal factors derived at the immature stage

Sl. No.	Variable	Factor loadings									Communality
		F1	F2	F3	F4	F5	F6	F7	F8	F9	
1	Weeks to sprout	-0.303	-0.093	0.026	0.136	**0.796**	0.008	0.093	-0.056	-0.086	0.773
2	Height	**0.916**	0.009	-0.044	0.017	-0.264	0.137	-0.100	0.048	0.014	0.943
3	Scion diameter (1)	-0.140	0.281	0.090	-0.008	0.234	-0.082	0.205	**-0.758**	0.152	0.858
4	Whorls produced (W1)	**0.848**	-0.113	0.158	0.359	-0.006	-0.243	0.024	0.052	-0.084	0.954
5	Whorls retained.(W2)	**0.760**	-0.019	-0.017	0.343	0.345	-0.044	0.100	-0.002	-0.098	0.836
6	Whorls shed (W3)	0.418	-0.182	0.319	0.145	**-0.540**	-0.386	-0.108	0.100	-0.007	0.793
7	Leaves produced	**0.925**	0.111	0.084	-0.116	-0.061	0.000	-0.025	-0.028	-0.101	0.904
8	Scion diameter (2)	**0.710**	0.475	0.137	-0.221	-0.045	0.223	0.026	0.551	0.116	0.867
9	Diameter increment	0.633	0.215	0.041	-0.189	-0.245	0.242	-0.095	0.558	-0.032	0.924
10	Whorls produced on main stem (W4)	**0.595**	0.191	0.059	0.078	0.559	-0.174	0.329	-0.025	-0.080	0.859
11	Whorls produced on entire plant (W5)	**0.892**	-0.046	-0.053	-0.185	-0.095	0.040	0.065	0.047	0.308	0.947
12	Whorls reained on main stem (W6)	0.107	0.456	-0.197	-0.177	0.394	0.265	**0.554**	0.077	-0.063	0.831
13	Whorls retained on entire plant (W7)	**0.822**	-0.023	-0.096	-0.255	-0.208	0.152	0.080	0.078	0.360	0.959
14	Whorls produced on main stem in two years (W8)	**0.826**	0.048	0.123	0.248	0.324	-0.238	0.206	0.015	-0.094	0.974
15	Leaf size	0.114	0.253	-0.427	**0.507**	0.220	-0.044	0.158	0.349	-0.163	0.740
16	Specific leaf weight	0.063	0.246	-0.202	**0.552**	0.077	0.045	0.196	0.180	-0.407	0.654
17	Stomatal density	-0.298	-0.159	-0.089	0.151	-0.190	0.453	**0.678**	-0.344	-0.114	0.953
18	Bark thickness.	0.322	**0.789**	-0.028	0.154	0.178	0.055	0.019	-0.091	-0.185	0.829
19	No. of latex vessel rows	-0.133	**0.882**	0.011	0.085	-0.040	0.014	0.005	-0.020	-0.250	0.868
20	Den.sity of latex vessels	-0.319	-0.253	0.173	-0.011	-0.191	**-0.492**	-0.016	0.380	0.289	0.703

Table 39 (Contd...)

Sl. No.	Variable	F1	F2	F3	F4	F5	F6	F7	F8	F9	Communality
21	Diameter of latex vessels	0.140	-0.062	0.343	0.087	0.048	0.004	0.082	-0.229	**-0.771**	0.805
22	Laticifer area index	0.112	**0.900**	0.223	0.054	-0.050	0.022	0.045	-0.025	0.213	0.925
23	Midrib thickness	0.171	0.133	-0.302	0.364	**0.686**	0.054	-0.080	0.124	0.188	0.802
24	Lamina thickness	0.009	-0.215	-0.267	**0.777**	0.316	0.009	-0.124	-0.048	0.107	0.851
25	Palisade thickness	-0.106	0.153	-0.380	**0.827**	-0.033	0.076	0.046	0.018	0.083	0.879
26	Thiol content of latex	-0.341	**0.543**	0.109	-0.258	-0.112	0.158	0.101	-0.365	-0.108	0.682
27	Inorganic phosphorous content	0.239	0.178	0.092	0.025	0.086	-0.093	**0.857**	0.030	0.102	0.860
28	Sucrose in latex	0.054	-0.124	0.365	-0.071	-0.038	**0.770**	-0.018	0.047	-0.081	0.760
29	Magnesium in latex	-0.044	0.123	-0.199	0.241	0.140	0.089	0.318	**0.588**	-0.282	0.668
30	Chlorophyll a in leaves	0.037	0.167	**0.913**	-0.194	-0.060	0.142	0.026	-0.006	0.151	0.947
31	Chlorophyll b in leaves	0.082	0.901	**0.907**	-0.250	-0.052	-0.243	-0.006	-0.118	-0.062	0.979
32	Total chlorophyll in leaves	0.047	0.153	**0.931**	-0.240	-0.063	0.035	0.012	-0.038	0.127	0.962
33	Chlorophyll a:b ratio	-0.040	0.147	-0.289	0.175	0.064	**0.819**	0.074	0.196	0.170	0.885
34	Juvenile yield	0.072	**0.680**	0.191	-0.009	0.187	-0.198	0.386	0.222	0.184	0.810
	Variance accounted for (%)	21.462	12.010	11.194	8.639	7.980	7.103	6.231	5.895	4.730	
	Cumulative variance accounted for (%)	21.462	33.473	44.667	53.306	61.286	68.389	74.619	80.514	85.244	

Table 40. Factors groups in immature clones

Factor	Characters included
Factor 1	Height, number of leaves, total number of whorls produced and those retained in the first year, scion diameter and increment in the second year,number of new whorls produced and those retained on the entire plant in the second year, number of new whorls produced on the main stem in the second year, and in the two years together
Factor 2	Juvenile yield, bark thickness, no. of latex vessel rows, laticifer area index and latex thiol content
Factor 3	Total chlorophyll, chlorophyll a and b
Factor 4	Leaf size, specific leaf weight, leaf lamina and palisade layer thickness
Factor 5	Time taken to sprout, no.of whorls shed in the first year, leaf midrib thickness
Factor 6	Density of latex vessels, latex sucrose content, chlorophyll a:b content
Factor 7	No. of new whorls retained on themain axis in the second year, stomatal frequency, latex inorganic phosphorous content
Factor 8	Scion diameter in the first year, latex magnesium
Factor 9	Diameter of latex vessels

The second factor, which accounted for 10.26 per cent of the variability observed, comprised the traits juvenile yield, bark thickness, number of latex vessel rows, laticifer area index and latex thiol content, with factor loadings ranging from 0.543 to 0.900. The two factors together accounted for 33.47 per cent of the variability observed.

Factor three was correlated with total chlorophyll, chlorophyll a and b which accounted for 11.19 per cent of the variability. The cumulative variability explained at this stage was 44.67 per cent.

Factor four consisted of leaf size, specific leaf weight, leaf lamina and palisade layer thickness and explained 8.64 per cent of the variability. Factor five, comprising time taken to sprout, number of whorls shed in the first year, leaf midrib thickness, accounted for 7.98 per cent of the variability. Factor six accounted for 7.10 per cent of the variability in the population and comprised of the characters density of latex vessels, latex sucrose content, chlorophyll a:b content. Factor seven, correlated with characters number of new whorls retained on the main stem in the second year, stomatal density and latex inorganic phosphorous content, was responsible for 6.23 per cent of the variability seen in the population. Factors eight (consisting of scion diameter in the first year and latex magnesium) and nine (which had the lone trait diameter of latex vessels), explained 5.90 and 4.73 per cent of the variability in the clones, respectively. All the factors together explained 85.24 per cent of the variation in the population at the immature stage.

4.1.7 Discriminant function analysis

A disciminant function was fitted with 16 variables to derive a performance index for the 25 clones at the immature stage. The variables used were time taken to sprout, plant height, scion diameter in the first year, number of flushes retained at the end of the first year (W2), number of flushes shed by the end of the first year (W3), number of leaves produced, second year scion diameter, number of new flushes retained on the main stem in the second year (W6), bark thickness, number of latex vessel rows, inorganic phosphorous, leaf size, lamina thickness, chlorophyll a and chlorophyll b. The performance index for each clone, along with their corresponding ranks are given in Table 41. The index values ranged from 164.83 for RRIM 612, to 268.07 for RRIM 703. The popular clones RRII 105 and RRIM 600 were ranked 7th and 12th respectively at this stage. Their corresponding indices were 228.69 and 221.84, compared to the population average of 218.31. The genetic advance that could be expected at a selection intensity of 5 per cent was 54.57 per cent.

4.3. MATURE- IMMATURE RELATIONSHIPS

4.3.1 Correlations between immature traits with corresponding mature traits and yield

Simple correlations were computed between the common individual traits at both the stages. Simple correlations were also worked out for all the immature traits with mature yield. The results are presented in Table 42.

Table 41. Performance index and ranks of the clones at the immature stage

Clone	Index value	Rank
RRIM 501	214.10	16
RRIM 519	221.85	11
RRIM 526	218.57	13
RRIM 600	221.84	12
RRIM 602	232.99	6
RRIM 603	206.42	19
RRIM 604	215.71	15
RRIM 605	240.33	4
RRIM 607	184.7110	24
RRIM 610	224.39	9
RRIM 611	204.81	20
RRIM 612	164.83	25
RRIM 615	223.92	10
RRIM 620	207.51	18
RRIM 622	213.20	17
RRIM 628	216.85	14
RRIM 636	185.14	23
RRIM 701	191.24	22
RRIM 703	268.07	1
RRIM 704	241.96	3
RRIM 705	227.27	8
RRIM 706	204.41	21
IAN 873	238.41	5
RRII 105	228.69	7
HAR 1	260.43	2

Table 42. Correlations of immature traits with corresponding mature traits and mature yield

Immature trait	Correlation with corresponding mature trait	Correlation with mature yield
Weeks to sprout	-	-0.1622
Height	-	0.1414
Scion diameter (1)	-	0.2141
Whorls produced (W1)	-	0.0733
Whorls retained.(W2)	-	-0.0862
Whorls shed (W3)	-	. 0.2701
Leaves produced	-	0.1770
Scion diameter (2)	0.0691	0.0951 .
Diameter increment	0.1763	-0.0180
Whorls produced on main stem (W4)	-	0.3012
Whorls produced on entire plant (W5)	-	0.0282
Whorls reained on main stem (W6)	-	-0.0122
Whorls retained on entire plant (W7)	-	-0.0673
Whorls produced on main stem in two years (W8)	-	0.2182
Leaf size	0.0322	-0.1431
Specific leaf weight	-0.1604	-0.1023
Stomatal density	0.5181**	-0.3211
Bark thickness.	0.4053*	0.4051*
No. of latex vessel rows	0.7462**	0.4562*
Density of latex vessels	0.4394*	-0.0040
Diameter of latex vessels	0.3994*	-0.0653
Laticifer area index	0.5221**	0.3722
Midrib thickness	0.2313	-0.1182
Lamina thickness	. 0.0263	-0.2360
Palisade thickness	-0.4582*	-0.0830
Thiol content of latex	0.8341**	0.2174
Inorganic phosphorous content	0.8113**	0.0331
Sucrose in latex	0.8821**	-0.1571
Magnesium in latex	0.9092**	0.0032
Chlorophyll a in leaves	-0.2051	0.1311
Chlorophyll b in leaves	-0.2772	0.2521
Total chlorophyll in leaves	-0.2432	0.1682
Chlorophyll a:b ratio	-0.0783	-0.3374
Juvenile yield	-0.0244	-0.0184

Among the morphological traits, significant correlations were detected between stomatal density at the two stages (r = 0.5181**). Of the bark and leaf anatomical characters, number of latex vessel rows followed by laticifer area index showed significant positive correlations (r = 0.7462** and 0.5221** respectively). Positive correlations were also seen for density of latex vessels, bark thickness and diameter of latex vessels (r = 0.4053* to 0.4394*). Palisade layer thickness showed a negative correlation between the two stages (r = -0.4582*). Among the biochemical parameters, thiol content, inorganic phosphorous, sucrose and magnesium showed very high positive correlations between the two stages (r= 0.8113** to 0.9092**), while none of the chlorophylls recorded significant relationships.

For the relationship between immature attributes and mature yield, significant positive correlations were obtained with number of latex vessel rows and bark thickness (r = 0.4562* and 0.4051* respectively).

4.3.2 Comparison between the two stages for the performance of the clones

The simple correlation coefficient between the performance indices of the 25 clones obtained at the immature and mature stages was computed. The correlation obtained was statistically non significant (r= -0.1628), indicating that the performance of the clones at the immature stage of two years and on the basis of the variables used for the formulation of the indices, cannot be used to predict the clone performance in the mature stage.

4.3.3 Regression of mature yield on immature attributes

A step wise regression analysis of mature yield on the immature attributes, using a bound rate of 20 per cent, revealed that only one variable, number of latex vessel rows at the immature stage, could account for 20 per cent of the variation in mature yield. The regression equation was fitted as follows

$$Y = 20.717 + 11.3 \ X1,$$

where X1 was number of latex vessel rows . This equation accounted for 20.83 per cent of the variability in yield in the mature phase. The standard error of the regression coefficient was 4.807.

MINIMUM

RRIM 612

MAXIMUM

RRIM 604

MATURE STAGE

RRIM 526

IMMATURE STAGE

RRIM 640
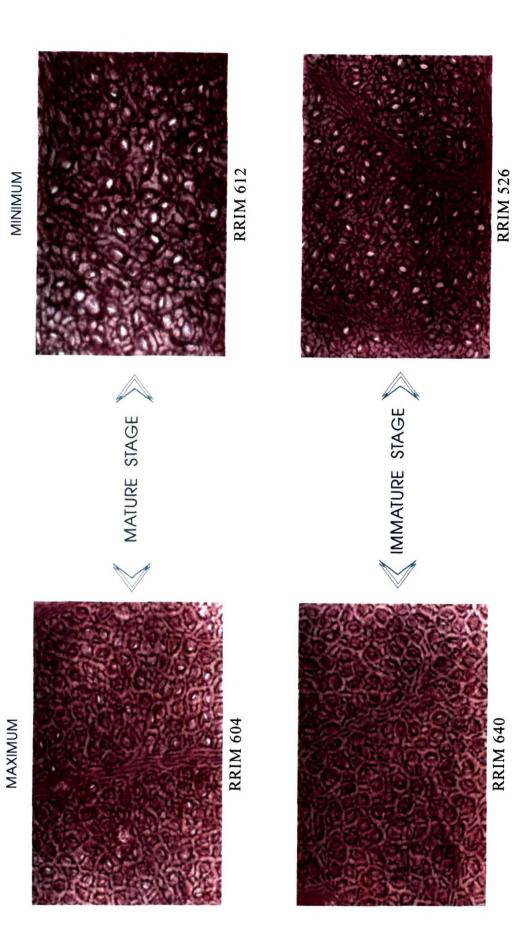
Plate 1. Variability for number of stomata per unit area

MINIMUM

RRIM 519

MATURE STAGE

IMMATURE STAGE

RRIM 501

MAXIMUM

RRIM 705

RRIM 704
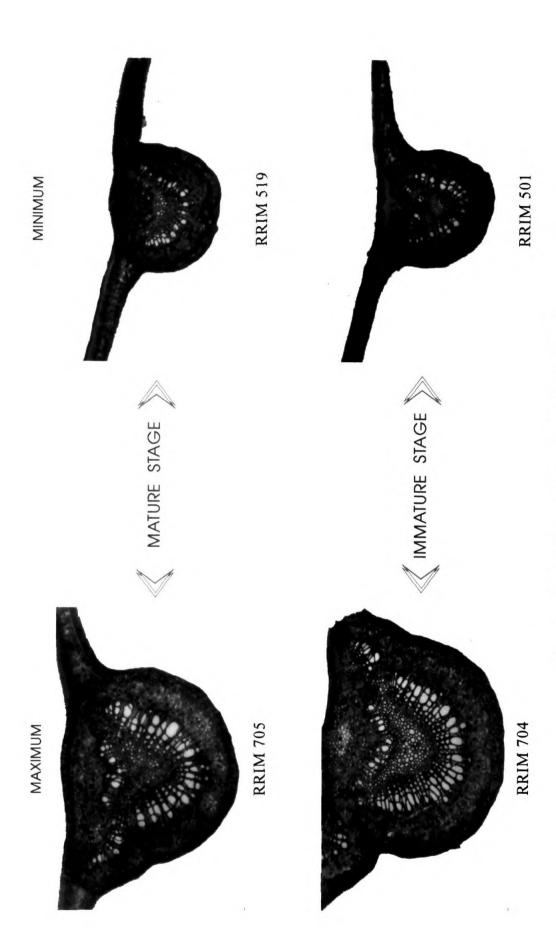
Plate 2. Variability for leaf midrib thickness

MINIMUM

RRIM 622

MATURE STAGE

MAXIMUM

RRIM 615

RRIM 607

IMMATURE STAGE

RRIM 704

Plate 3. Variability for leaf lamina thickness

MINIMUM

RRIM 519

MAXIMUM

RRIM 604

MATURE STAGE

RRIM 612

RRIM 526

IMMATURE STAGE
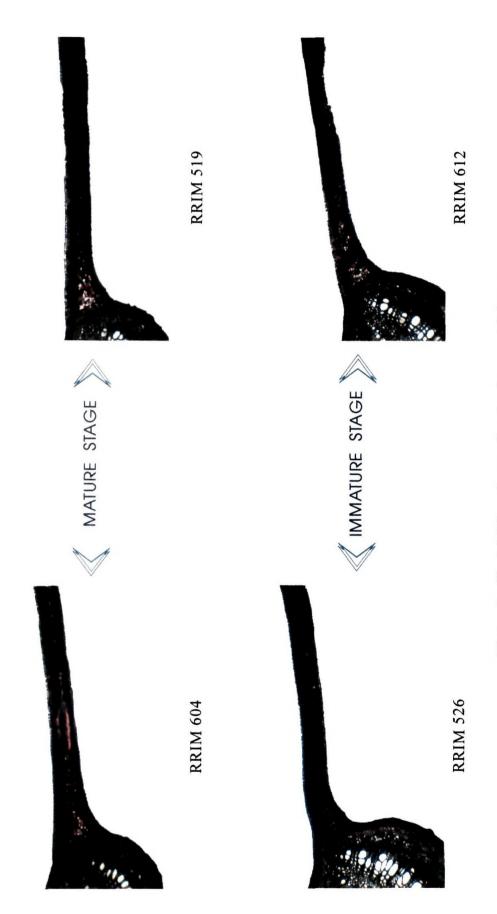
Plate 4. Variability for palisade layer thickness

MINIMUM

RRIM 610

MATURE STAGE

MAXIMUM

RRIM 602

RRIM 636

IMMATURE STAGE

Har 1
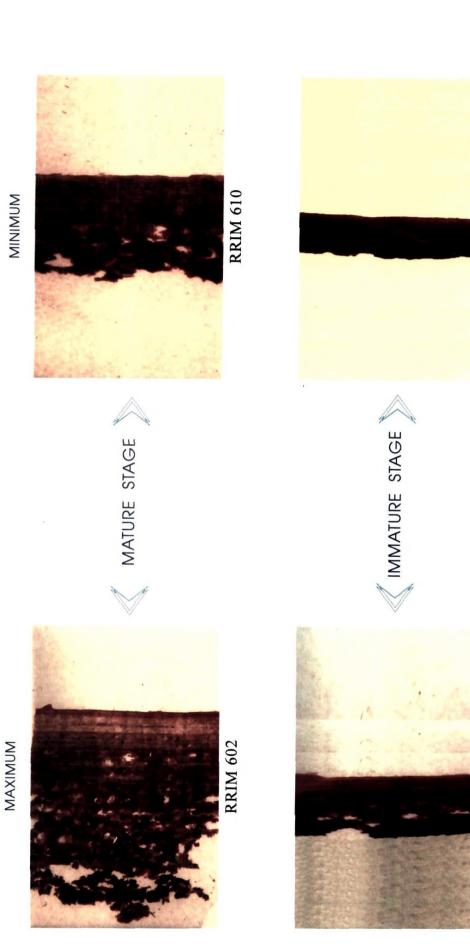
Plate 5. Variability for bark thickness

MINIMUM

RRIM 615

MATURE STAGE

MAXIMUM

RRIM 607

IMMATURE STAGE

RRIM 501

RRIM 105

Plate 6. Variability for number of latex vessel rows

MAXIMUM

MINIMUM

RRIM 622

RRIM 615

IMMATURE STAGE

MAXIMUM
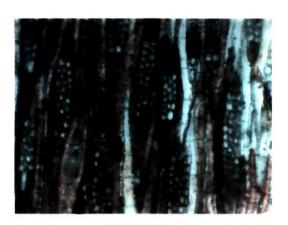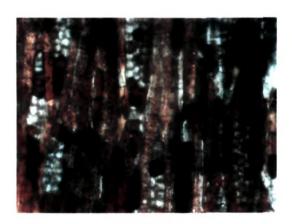
MINIMUM

RRIM 526

IAN 873

Plate 7. Variability for density of latex vessels

MATURE STAGE

MAXIMUM   MINIMUM

RRIM 615   RRIM 604

IMMATURE STAGE

MAXIMUM   MINIMUM

RRIM 501   RRIM 604
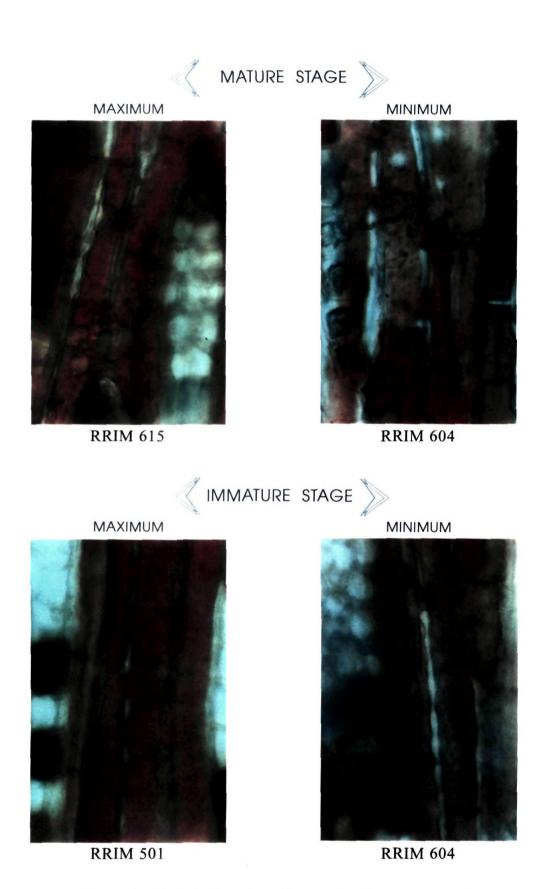
Plate 8. Variability for diameter of latex vessels

DISCUSSION

5. DISCUSSION

Natural rubber obtained from the tree *Hevea brasiliensis,* is one of the most important cash crops of India. It is grown over an area of 5.59 lakh ha (Rubber Board, 2001), and its cultivation is expanding into nontraditional areas too. Considerable genetic improvement has been made in the crop during the last 100 years of its domestication. However, a wide gap still exists between its theoretical yield potential of 9.5 t ha^{-1} (Templeton, 1969), and the present productivity of 1.6 t ha^{-1} at the national level. Further improvement will depend on the extent of genetic variability available in the crop, and utilization of the heritable variation in the crop. Yield in *Hevea* is a complex trait governed by a number of morphological, structural, physiological and biochemical factors. The accountability of different sets of major factors in controlling rubber yield of *Hevea* clones have been found to vary at different growth phases (Ho, 1976) and in different environments (Jayasekara *et al.,* 1977; Meenattoor *et al.,* 1992).

Tapping of the tree commences when it has attained a girth of 50 cm at a height of 125 cm from the bud union, which usually takes five to six years. The tree is then tapped economically for the next twenty years at least, during which the four panels of bark on the trunk (BO-1&2 and BI-1&2) are exhausted. The long immaturity period and perennial nature of the crop require a long evaluation period, which is one of the major stumbling blocks in the breeding and genetic

improvement of the crop. Moreover, most of the genetic studies to date have been confined to the first few years of production, involving the BO-1 and 2 panels only. The third and fourth panels have not been subjected to detailed studies and little is known about the behaviour of the tree at this stage. Experiments involving comparison of traits in the immature and mature stages, aimed at identification of early selection parameters, are usually restricted to the BO-1 panel yield. However, as the tree is exploited economically in the third and fourth panels too, a detailed examination of the morphological, anatomical, physiological and biochemical parameters of the source and sink attributes of the tree at this stage, as well as its comparison with immature stage performance, will contribute to our overall understanding of the plant's yielding behaviour.

The present study was taken up to evaluate the performance of a set of 25 clones in the mature and immature stages, as well as to carry out detailed genetic analysis of the characters in both stages. The experiment consisted of three parts:

1.Mature phase: Estimation of genetic divergence, identification of the principal factors influencing mature yield (in the BI-2 panel), and formulation of a selection index, based on a number of morphological, anatomical, biochemical and physiological parameters in the mature stage.

2.Immaure phase: Estimation of genetic divergence, identification of the principal factors influencing immature yield, and formulation of a selection index, based on a number of morphological, anatomical and biochemical parameters in the immature stage (first two years of growth).

3.Immature-mature relationships: Identification of characters that show the same trend in the immature and mature phases, and those immature traits correlated with mature yield; regression of mature yield on immature traits.

Though a number of studies have been carried out on the clonal variability and associations among various traits, studies involving path analysis, genetic divergence and clustering, factor analysis, and performance index in rubber are scanty.

5.1. MATURE PHASE

The extent of variability for 27 morphological, anatomical physiological and biochemical traits as well as dry rubber yield in 25 mature clones was estimated. The genetic parameters for the different traits as well as the interrelationships between these characters were computed. The direct and indirect effects of the various traits on yield were analysed. Clones were grouped into clusters based on the degree of divergence between them and the factors of divergence identified through principal component analysis. The performance of the clones was assessed on the basis of an index formulated using discriminant function.

5.1.1. Genetic variability

Genetic variability in the crop forms the backbone of any genetic improvement programme. One of the most important plant breeding procedures, selection, acts on existing genetic differences in a population (Dabholker, 1992). Hence, variability is a key factor which determines the amount of progress to be expected from selection. Therefore, in any crop improvement programme a

knowledge of the extent of genetic variation present is essential (Falconer, 1960; Mather and Jinks, 1977). This has to be obtained by measuring the phenotypic values which are the external expression of the genetic worth as modified by the environment. The phenotypic variation is then partitioned into its genotypic and environmental components (Johnson, 1909).

Whitby (1919) was the first to assess variability in *Hevea brasiliensis* in seedling populations. Later, with the popularization of clones, other workers worked on the variability in clonal populations derived from hybridization and clonal selection programmes (Simmonds, 1968; Mydin, 1992; Licy, 1997).

In the present study, of the 27 morphological, anatomical, physiological and biochemical characters on which observations were recorded, significant clonal differences were observed for all the traits except density and diameter of latex vessels, and chlorophyll a:b ratio. Clonal differences were significant at 1 per cent level of probability for girth, leaf size, specific leaf weight, stomatal density, bark thickness, number of latex vessel rows, laticifer area index, leaf midrib, lamina and palisade layer thickness, initial flow rate, final volume of latex, plugging index, dry rubber content, thiols, inorganic phosphorous, sucrose, magnesium and leaf chlorophyll a, b and total chlorophyll content, and average annual dry rubber yield, while variation for girth increment and total solids content was significant at the 5 per cent level.

A number of early workers have reported high clonal differences for dry rubber yield (Gilbert *et al.*,1973; Nga and Subramaniam, 1974; Tan *et al.*, 1975; Saraswathyamma and Sethuraj, 1975). The significant differences obtained for yield in the present study are also in conformity with the findings of Markose (1984),

Premakumari (1992), Mydin (1992) and Licy (1997). Clonal differences obtained in this experiment for girth and girth increment are in keeping with the findings of Paardekooper and Samosorn (1969), Sethuraj and George (1980), Markose (1984), Mydin (1992) and Licy (1997). Significant clonal differences for girth increment on tapping were reported by Vollema (1941) and Premakumari *et al.* (1988a) though no significant variability was observed for this trait in another study by Premkumari (1992). The significant clonal differences for yield, girth and girth increment were also reflected in the range and phenotypic variability obtained.

The yield of rubber depends on the ability of the plant to accumulate dry weight and convert a proportion of this into latex and rubber (Swaminathan, 1977). Although studies on dry matter accumulation suggest that variability in photosynthetic rate might exist in rubber, there is hardly any information at the plant and leaf level. In most crops including soyabean, wheat, rice, maize, etc., and trees like *Lolium* species and *Pinus contorta,* there is evidence that photosynthetic rate per unit leaf area varies. There is evidence in some plants that a smaller leaf size and greater thickness are correlated with higher photosynthetic rates. Specific leaf weight has also been found to be correlated with photosynthetic rate in a number of plants (Pearce *et al.,* 1969; Dornhoff and Shibles, 1970). Wilson and Cooper (1969) made a diallel analysis of photosynthetic rates and related leaf characters and found that photosynthetic rates, chlorophyll content and mesophyll cell size had higher narrow sense heritability. They further made selections on the basis of average mesophyll cell size, which led to improvement in net assimilation rates and the productivity of *Lolium* species. The basis for such studies lies in the fact that the smaller cell size reduces intercellular spaces and enhances mesophyll

resistance. This is known to lead to better water use efficiency. Swaminathan (1977) opined that in the improvement of a plantation crop like rubber, the light interception has to be brought as close as possible to 100 per cent, but without making the lower leaves parasitic. A plant having large leaves at the top could intercept almost all the light, but would result in so much shading that the efficiency of the lower leaves would be reduced. Therefore selection for smaller leaves may provide a better canopy for higher photosynthetic efficiency. However, Ishii (1998) reported that though in many cases the leaf photosynthetic rate was correlated with yield, in others it showed no correlation with yield or growth because of the masking effect of stronger limiting factors of yield such as sink capacity.

Source characters like leaf size, number, specific leaf weight, stomatal density, chlorophyll content, *etc.* are therefore important determinants of the assimilatory capacity of the tree. However, relatively few genetic studies have been carried out on the morphological, structural and biochemical parameters of leaves in *Hevea*. Madhavan *et al.* (1993) reported variation for leaf size and specific leaf weight in mature trees of wild *Hevea* germplasm, which is in conformity with the present findings. Stomata in *Hevea,* are present exclusively on the abaxial surface (hypostomatic) and are distributed evenly except on the midrib and veins where their density is low. The functional significance of stomata is related to photosynthesis, transpiration, adaptation to environmental constraints and disease occurrence (Premkumari, 1992). Significant clonal differences for stomatal density obtained in the present study are in agreement with the observations of Senanayake and Samaranayake (1970) in 25 clones. Premakumari *et al.* (1988b) also found that both size and density of stomata were clonal traits. However Gomez and Hamzah (1980) could detect no significant differences among clones for this trait.

Among the anatomical traits of the leaf, the leaf midrib is important for the translocation of photosynthates from their sites of production in the leaf lamina. Photosynthesis is concentrated mainly in the palisade layer of the leaf lamina. The present study revealed high clonal differences for thickness of leaf midrib, lamina and palisade layer, which agrees with the findings of Gomez and Hamzah (1980) for thickness of leaf and palisade layer. Premkumari (1992) however obtained no significant clonal differences for these traits. The present findings on the existence of clonal variabilty for chlorophyll a, b and total chlorophyll, and lack of variability for chlorophyll a:b ratio corroborate the work of Mydin (1992).

Among the bark anatomical traits, significant clonal differences were obtained in the present study for bark thickness, number of latex vessel rows and laticifer area index. No differences were observed for density and diameter of latex vessels. Significant differences for bark thickness were also reported by Tan *et al.* (1975), Markose (1984), Mydin (1992) and Licy (1997), though Premkumari (1992) did not obtain significant differences for this trait. The number of latex vessel rings was reported to be a clonal character (Vischer, 1921;1922; Bobilioff, 1923; Sanderson and Sutcliffe, 1929; Gomez, 1982 and Premakumari *et al.*, 1988a), which is in accordance with the present findings. Latex vessel diameter and density have also earlier been reported to be clonal characters (Gomez *et al.*, 1972; Premakumari *et al.*, 1985), which does not agree with the findings of this study. Premakumari *et al.* (1988a) also observed highly significant clonal differences for laticifer area index and suggested it as a major yield component. The range of variation and phenotypic variability obtained here were the highest for laticifer area index, while they were very low for density and diameter of latex vessels.

Plugging index has been established as a clonal character (Sethuraj, 1968; Milford *et al.* 1969). Saraswathyamma and Sethuraj (1975), Markose (1984), Premakumari (1992), Mydin (1992) and Licy (1997) observed clonal variations in latex flow characteristics initial flow rate, final volume of latex, plugging index and dry rubber content. This was confirmed by the results of this study too, where significant clonal differences were recorded for all these traits.

Rubber tree yield depends on two limiting factors- latex flow and its *in situ* regeneration. Lutoids play an important role in stopping latex flow after tapping. The regeneration of latex between two tappings is controlled by pH, ion composition and biochemical energy in laticifers. The biochemical characters like pH, bursting index, sucrose, total solids, inorganic phosphorous thiols and magnesium ion content are important for determining potential production (Siswanto, 1994). Jacob *et al.* (1989) have also stressed that the values of these parameters, although influenced by many factors like age of the tree, ecoclimatic and seasonal factors, still show significant clonal differences, and their biochemical profile can be used for clone identification. It was possible to include only latex total solids content, thiols, inorganic phosphorous magnesium and sucrose in this study. Clonal differences obtained for the latex biochemical traits total solids content, thiols, inorganic phosphorous, sucrose and magnesium are in keeping with the observations of Jacob *et al.* (1989) and Licy (1997). A high range of variability was also seen for initial flow rate and final volume of latex .

The high range of variation and phenotypic variability observed for the traits girth, girth increment, laticifer area index, initial flow rate, final volume of

latex, thiol content of latex, inorganic phosphorous, sucrose, magnesium, and yield were supported by fairly high values of their corresponding genotypic variabilities, indicating that there was sufficient variability for the breeder to work upon for the improvement of these traits. The wide range of variability exhibited by many traits in rubber despite its narrow genetic base has been reported in early reports too (Fyfe and Gilbert 1963; Gilbert *et al.* 1973), and is probably due to the highly heterozygous nature of the crop.

5.1.2. Genetic parameters

The primary objective of measuring phenotypic variation is to partition it into components attributable to different causes. (Dabholker, 1992). The partitioning of the total variability into its heritable and non heritable components is essential in order to obtain an estimate of the actual usable genetic variability, separated from the influence of environment. The expression of the phenotypic and genotypic variability for the different traits as percentage of the respective means will provide unitless estimates of the respective coefficients of variation (PCV and GCV), which are essential for making comparisons across different traits. The heritability (broad sense) estimate gives the proportion of the total variation that is due to the genetic makeup of the plant. The genetic advance is an estimate of the genetic gain that can be expected in the next generation at a given selection intensity. Johnson *et al.* (1955) suggested that heritability estimates along with genetic advance furnished a better picture than heritability alone. This was later emphasized by Ramanujan and Thirumalacher (1967). The estimates of genetic parameters PCV, GCV, heritability in the broad sense and genetic advance were examined for all the traits.

Estimates of GCV were lower than the corresponding PCV for all the characters, indicating the influence of environment in the expression of these traits. This difference was greater in the expression of chlorophyll a:b ratio implying the predominant role of environment in this trait. Low PCV and GCV were observed for number of stomata per unit area, density of latex vessels, diameter of latex vessels, total solids content and chlorophyll a:b ratio, indicating that selection for these traits will be ineffective. Variability from other sources *viz.* wild germplasm, fresh introductions, induction of variability through mutations, etc., will have to be brought in for the improvement of these traits. The comparatively moderate to high levels of genetic variability observed for most traits, especially girth increment, laticifer area index, initial flow rate, final volume of latex, latex biochemical parameters (except for total solids content) and yield, indicated that these traits would respond to selection in crop breeding programmes. The high genetic variability observed for yield, girth increment, initial flow rate, final volume of latex, plugging index and low values for dry rubber content are in keeping with the findings of Markose (1984), Mydin (1992) and Licy (1997). However, in contrast to the results of the same studies, girth and bark thickness of the clones included in this study recorded only moderate levels of PCV and GCV. High genetic variability for girth and yield was also obtained by Nga and Subramaniam (1974). Premakumari (1992) obtained high PCV and GCV for laticifer area index and number of latex vessel rows and low estimates for density and diameter of latex vessels, which is in complete agreement with the present findings. Licy *et al.* (1992) also reported moderate to high GCV for number of latex vessel rows. The observations of high genetic variability for latex biochemical parameters thiols,

inorganic phosphorous, sucrose and magnesium and low GCV for total solids content corroborate the findings of Licy (1997).

Heritability is the fraction of the measured or phenotypic variance which is caused by the genetic constitution of the plant. It is estimated as the ratio of the genotypic variance to the phenotypic variance. The portion of total genetic variability that is usable differs depending on whether the crop is self, cross or asexually propagated. In asexually propagated crops, broad sense heritability is relevant as the entire genotypic variability is usable (Dabholker, 1992). Heritability for the various characters studied ranged from 12.53 per cent for density of latex vessels to 67.39 per cent for sucrose content of latex. The heritability estimates were moderate to high for most of the traits except for girth increment, density and diameter of latex vessels, and chlorophyll a:b ratio which exhibited very low values. This is in general agreement with the findings of Mydin (1992), Premkumari (1992) and Licy (1997). However, other authors obtained high heritability estimates for density and diameter of latex vessels (Premkumari, 1992), girth increment (Mydin, 1992 and Licy, 1997), which were not observed in the present study. Simmonds (1989) observed that heritability of economic characters in rubber is generally high. High heritability for yield and girth was also reported by Nga and Subramaniam (1974); Tan *et al.* (1975); Liang *et al.* (1980) and Alika and Onokpise (1982).

Estimates of genetic advance at 5 per cent selection intensity ranged from 1.98 per cent for density of latex vessels to 59.80 per cent for latex volume yield. Moderate to high levels of genetic advance recorded for girth, girth increment,

initial flow rate, final volume of latex, plugging index, and dry rubber yield obtained in the presence study, agree with the findings of Mydin (1992). Licy (1997) also obtained high estimates of GA for latex thiols, inorganic phosphorous, sucrose and magnesium and low genetic advance for total solids content, in agreement with the present results. Mydin however obtained very low genetic advance for chlorophyll a, chlorophyll b and total chlorophyll, while the present study reveals the existence of moderate levels for these traits.

Moderate to high estimates of heritability coupled with high genetic advance observed in the present experiment for yield, girth, laticifer area index, initial flow rate, final volume of latex, plugging index, latex thiols, inorganic phosphorous, sucrose, magnesium, chlorophyll b and total chlorophyll imply the preponderance of additive gene action in the inheritance of these traits, making them amenable to selection. Similar conclusions were drawn by Mydin (1992) and Licy (1997) for yield, initial flow rate, plugging index and final volume of latex, while Licy (1997) also obtained the same for latex thiols, inorganic phosphorous, sucrose and magnesium. High heritability coupled with low genetic advance observed for stomatal density, bark thickness, leaf midrib lamina and palisade layer thickness indicate that selection will not be effective for these traits as they are governed by non additive gene action. Exploitation of heterosis for these traits will be possible if dominance is involved in the non additive gene effects (Singh and Narayanan, 1983).

5.1.3. Associations among mature attributes

When selection is applied on a population for improving a particular trait in any plant breeding programme, changes are brought about not only in the given

trait, but also in a number of other traits related with it, which may be desirable or otherwise. This is due to the existence of associations among the various traits, which may be due to linkage or pleiotropy (Falconer, 1960). This phenomenon can be taken advantage of to facilitate simultaneous improvement in two or more traits. Correlations provide information on the direction and magnitude of such associations, though it does not give any idea about cause and effect between the variables. Thus a knowledge of the interrelationships among the various parameters of interest is an essential prerequisite to any successful crop improvement procedure. The total observable correlation between two traits is the phenotypic correlation and provides an overall picture of the relationship between the traits. The genotypic correlation gives us an idea of the genetic component of this correlation, and therefore a more reliable prediction of the resultant effect of selection. The effect of environment on the strength of correlation between two variables is provided by the environmental correlation. The correlations at the phenotypic, genotypic and environmental levels of 27 variables at the mature phase are discussed below.

5.1.3.1. Correlations between yield and other parameters

Very high phenotypic correlations for yield were observed with final volume of latex and initial flow rate, followed by girth, girth increment, number of latex vessel rows, laticifer area index, bark thickness and inorganic phosphorous content. The corresponding genotypic correlations were much higher in all cases except for girth, where it was slightly lower. This effect has been attributed by Johnson *et al.* (1955) and Oraon *et al.* (1977) to be due to the masking effect of the

environment in the genetic associations between characters. Significant positive environmental correlations were observed between these traits. The higher genotypic correlation of yield with girth increment than girth itself conforms to the findings of Premakumari *et al.* (1989), who observed that girth increment under tapping rather than actual girth was more important for sustained high yields. Diameter of latex vessels exerted a relatively high, while specific leaf weight, midrib and lamina thickness had moderate, negative correlations with yield though their phenotypic correlations were not significant. Moderate positive genotypic correlation of yield with density of latex vessels, total solids content, dry rubber content, thiols and chlorophyll a were observed though the respective phenotypic correlations were not significant. The high positive correlations of yield, especially with final volume of latex and initial flow rate obtained in the present study, as well as the trend of higher genotypic correlations than phenotypic, were in perfect accord with the findings of Mydin (1992) and Licy (1997). Yield has been found to be positively correlated with girth and·number of latex vessel rows (Narayanan *et al.*, 1973; Tan *et al.*, 1975; Tan and Subramaniam,1976), and negatively with plugging index (Paardekooper and Samosorn, 1969; Milford *et al.*, 1969; Sethuraj *et al.*, 1974). Yield is also reported to be positively correlated with latex biochemical characters thiols, inorganic phosphorous and sucrose and negatively with total solids content and magnesium (Licy, 1997). However, Wycherley (1975), Markose (1984), Olapade (1988) and Premkumari (1992) reported negative correlations between yield and girth. The relatively higher genotypic correlation of yield with girth increment than girth obtained here is in accordance with the observations of Nazeer *et al.* (1986) and Premkumari *et al.* (1987), who emphasized the importance of girth increment on tapping rather than girth *per se* for maintaining yield in renewed bark.

Lynen (1969) stated that a high value of inorganic phosphorous indicates an active laticiferous system and hence a high positive association between inorganic phosphorous and latex production. A moderate level of correlation between inorganic phosphorous and yield was obtained in the present study, which is corroborated by the results obtained by Esbach *et al.* (1984). Jacob *et al.* (1989) have discussed the role of the various biochemical parameters on yield. Thiols play a role in rubber yield by scavenging the potentially harmful free radicals produced during cell metabolism and by activating key enzymes. A low positive correlation was obtained here for thiols with yield. Several authors have demonstrated a direct correlation between thiol concentration and production (Esbach *et al.*, 1984; Prevot *et al.*, 1984; Jacob *et al.*, 1986). Sucrose is the precursor of rubber molecules; however, the interpretation of sucrose content is difficult as a high sucrose content can imply either a good loading of the laticiferous system, or a poor utilization of the substrate. The present study did not reveal any correlation between the two traits yield and sucrose. Magnesium plays two opposing role in the latex: it is an activator of numerous enzymes in the latex while it is also an inhibitor of some such as invertase and acid phosphatase. A low negative correlation was obtained between magnesium, and yield in the present case, indicating the negative role of magnesium in the present case outweighed its positive effect. This is in contrast to the findings of Esbach *et al.* (1984).

There was a complete absence of correlation of yield with stomata density at all the three levels in the present study, in accordance with the findings of Balasimha *et al.* (1985) in cocoa, though Gomez and Hamzah (1980) reported weak negative correlations in rubber.

5.1.3.2 Correlations among morphological parameters

Among the five morphological parameters girth, girth increment, leaf size, specific leaf weight and stomata density, significant positive correlations were observed only between girth and girth increment. Specific leaf weight was negatively correlated with leaf size and girth. The genotypic correlations for all the traits were much stronger than the phenotypic correlations. Stomatal density was not correlated with any of the other morphological traits, which agrees with the findings of Abraham (2000). Very high genotypic correlations were obtained between girth and girth increment in the early years of tapping by Mydin (1992) and Licy *et al.* (1993) in keeping with the present findings.

5.1.3.3 Correlations among anatomical parameters

Significant positive correlations of bark thickness with number of latex vessel rows, laticifer area index and negative with diameter of latex vessels were detected. Number of latex vessel rows was correlated with laticifer area index only, while density was not correlated with any of the other laticifer traits. Diameter was positively correlated with laticifer area index. The results obtained in the present study are in conformity with earlier reports (Ho *et al.*, 1973; Narayanan *et al.*, 1974; Hamzah and Gomez, 1982; Premakumari *et al.*, 1987; Licy and Premakumari, 1988; Premkumari, 1992). The three leaf anatomical parameters midrib thickness, lamina thickness and palisade layer thickness, showed no phenotypic correlations with any of the laticifer traits. Leaf midrib and palisade layer thickness were not correlated, while lamina thickness showed a positive correlation with midrib and palisade layer thickness.

Inspite of the absence of phenotypic correlations between leaf and bark anatomical traits, low positive correlations at the genotypic level were obtained between bark and palisade layer thickness, and of palisade layer thickness with number of latex vessel rows and laticifer area index. Relatively high genotypic correlations of midrib thickness with density and diameter of latex vessels, and density with lamina thickness were detected. Low negative genotypic correlations between number of latex vessel rows and midrib thickness, density and lamina thickness, and laticifer area index with midrib thickness were obtained. Relatively high negative correlations were seen between number of latex vessel rows and lamina thickness, density of latex vessels and palisade layer thickness, laticifer area index and lamina thickness, and between bark and midrib thickness.

5.1.3.4 Correlations among physiological parameters

Among the four physiological parameters- initial flow rate, final volume of latex, plugging index and dry rubber content, positive high levels of correlation at all three levels were obtained between initial flow rate and final volume of latex. The genotypic correlations of plugging index with initial flow rate were low but positive, while those with final volume of latex were low and negative. Dry rubber content was not associated with any of these traits. Mydin (1992) and Licy (1997) observed a negligible genotypic correlation between initial flow rate and plugging index, while that between plugging index and final volume of latex was relatively high.

5.1.3.5 Correlations among biochemical parameters

At the phenotypic level, the only significant correlation that could be

detected among the latex biochemical traits was between latex thiols and magnesium which was negative. This is in contrast to the positive correlation obtained by Licy (1997), who also obtained significant intercorrelations for most other traits except sucrose. However, in the present study, at the genotypic level, total solids content had relatively high positive correlations with sucrose, while the correlations between thiols and magnesium, and between sucrose and magnesium were moderately high and negative. Negative correlations between thiols and magnesium at the genotypic level were also obtained by Licy in the same study. High positive phenotypic and genotypic correlations were observed among leaf chlorophyll a, b and total chlorophyll. Chlorophyll a:b ratio showed a positive phenotypic correlation with chlorophyll a, while its correlations with chlorophyll b and total chlorophyll were negative. At the genotypic level, the correlation of chlorophyll a:b ratio with chlorophyll a and total chlorophyll became very low, while that with chlorophyll b was high. Mydin (1992) also reported absence of correlation between total chlorophyll and chlorophyll a:b ratio.

Correlations between leaf and latex biochemical parameters were also detected. At the phenotypic level, a significant positive correlation was observed between latex thiols and chlorophyll b in the leaf. At the genotypic level, this correlation was 0.2723. Thiol content was also found to have a high negative genotypic correlation with chlorophyll a:b ratio, while a low positive correlation was detected between total solid content and chlorophyll a:b ratio. Sucrose showed a relatively low negative genotypic correlation with chlorophyll b, and a high positive correlation with chlorophyll a:b ratio. Latex magnesium was found to be genotypically correlated with chlorophyll a and total chlorophyll, with the

corresponding environmental correlations being negligible. This may be an indication of the overall magnesium status of the tree, as magnesium is also an important component of chlorophyll.

The present study reveals high genotypic correlations of morphological traits girth increment and girth, physiological traits final volume of latex and initial flow rate and anatomical traits number of latex vessel rows and laticifer area index with mature yield. The biochemical traits had relatively low to moderate correlations with yield.

5.1.4. Direct and indirect effects of 19 variables on yield

Path analysis was used to partition the total genotypic correlation of 19 variables with yield, in order to examine the relative importance of these traits in yield determination and to identify potential traits contributing to yield. The results revealed that initial flow rate followed by bark thickness and chlorophyll a exerted high positive direct effects on yield. Midrib thickness, specific leaf weight and inorganic phosphorous also had relatively high positive direct effects on yield.

The high positive direct effects of initial flow rate and bark thickness on yield were accompanied by relatively smaller indirect effects (both positive and negative) through other traits, which resulted in a slight lowering of the total correlation observed with yield. However, as most of the genotypic correlation with yield was accounted for by these traits, they can be used effectively as selection parameters for yield. The high direct effect of initial flow rate in the present study was corroborated by the report of Mydin (1992), while Markose

(1984) and Premkumari (1992) obtained negligible direct effect of this trait on yield. Mydin in the same study observed negligible direct effect of bark thickness on yield.

The extremely high positive direct effect of chlorophyll a was however completely nullified by its high negative indirect effects mainly through specific leaf weight, chlorophyll b and midrib thickness, leaving a net negligible correlation with yield. Midrib thickness was also found to have a moderately high positive influence on yield which was however, counteracted by its negative indirect effects especially through initial flow rate, chlorophyll a and bark thickness. In the case of specific leaf weight too, the high positive direct effect was completely outweighed by the relatively higher negative indirect effects mainly through chlorophyll a, bark thickness and number of latex vessel rows, resulting in a total negative correlation with yield. Hence, unless restricted selection is applied for these traits, chlorophyll a, midrib thickness, and specific leaf weight cannot be used as selection parameters. These traits have a direct bearing on the photosynthetic capacity of the tree. Inspite of their high positive direct effect, their total correlation with yield was negligible. Ishii (1998) opined that though in many cases the leaf photosynthetic rate was correlated with yield, in others it showed no correlation with yield or growth because of the masking effect of stronger limiting factors of yield such as sink capacity.

Even though moderate to high correlations of final volume of latex, girth, girth increment, number of latex vessel rows, density and diameter of latex vessels were recorded with yield, their direct effects were very extremely low or even

negative. Hence selection for these traits will be ineffective in improving yield, unless all the accompanying indirect effects are also selected for. The negligible direct effect of final volume of latex on yield obtained in this study is supported by the findings of Mydin (1992), but is in direct contrast to the positve and high direct effect observed by Markose (1984), Liang *et al.* (1988) and Premkumari (1992). The negative or negligible direct effects of number, density and diameter of latex vessels on yield obtained in the present study are in accordance with the results obtained by Markose (1984) and Premkumari (1992). Girth and girth increment were also found to have negligible direct effects by Mydin (1992), while Premkumari (1992) reported that girth had a negative direct effect. However Liang *et al.* (1988) reported a positive direct effect for girth.

The moderately high positive direct effect of inorganic phosphorous on yield was enhanced by its positive effect through specific leaf weight and chlorophyll a. However, the cumulative effect of the small individual negative influences through a number of other traits brought down the total correlation with yield. Hence, selection for this trait will not be effective in increasing yield.

Dry rubber content and total solids content of latex exhibited negligible direct effects though a weak positive correlation with yield was ultimately expressed. This was due to the relatively high positive indirect effects through chlorophyll a and bark thickness for dry rubber content and chlorophyll a, bark thickness and initial flow rate for total solid content. Mydin (1992) obtained a negative direct effect for dry rubber content.

The negligible residue (0.0672) obtained in the present study implies that almost all the variation in yield in the present study could be accounted for by these variables. The results reveal the possibility of using initial flow rate and bark thickness as selection parameters for improving yield. This is further supported by the fact that a large proportion of the indirect effects of other traits also appeared to be manifested through these traits. Hence simultaneous selection for these traits will be highly rewarding. Mydin (1992) identified dry rubber yield under stress, annual mean volume of latex and latex flow rate as the important parameters that could be used for selection. Inspite of the moderate to high correlations of girth, girth increment, number of latex vessel rows, final volume of latex density and diameter of latex vessels, obtained in the presence study selection for these traits *per se* will not effectively improve yield, as their direct effects are low.

5.1.5 Genetic divergence

Genetic divergence in a population is an essential prerequisite for any plant breeding programme. It has been proved that there is a close relationship between the extent of heterosis obtained in the F_1 and the genetic diversity between the parents. The D^2 statistic has been widely used in a number of crop plants to measure the genetic distance between different genotypes. Vairavan *et al.* (1973) in rice, Bavappa and Mathew (1982) in arecanut, Valsalakumari *et al.* (1985) in banana, Balakrishnan and Nampoothiri (1987) and Santhi (1989) in sugarcane have successfully employed this technique in estimating the genetic distance between the varieties.

In rubber, the genetic base is known to be very narrow (Schultes, 1977; Simmonds,1989). Efforts have been made to widen this base by collecting wild

germplasm from the original habitat of this crop in the Brazilian forests. However, this has not yet been incorporated into the cultivars, and hence the genetic base of cultivated rubber, comprising of the 'Wickham' germplasm is still small. Genetic divergence was previously estimated in a population of 20 Wickham clones by Markose (1984), who obtained eight clusters. In another study, Mydin (1992) also grouped 40 Wickham clones into eight clusters. Abraham *et al.* (1997) clustered 35 Wickham clones into 13 genetically divergent clusters.

The 25 clones in the present experiment were grouped into seven clusters, using 19 parameters. Clustering was found to be irrespective of their country of origin, indicating absence of any relationship between geographical and genetic diversity. This is in accordance with the observations of Vairavan *et al.* (1973) and Bavappa and Mathew (1982) in other crops, and with Markose (1984) Mydin (1992) and Abraham *et al.* (1997) in rubber. Paiva (1994) also drew the same conclusions while clustering 100 primary clones of rubber in Brazil. However, Chevallier (1988), using isozymes in wild germplasm collected from three geographically different locations in Brazil- Acre, Rondonia and Mato Grosso, found that the material from Rondonia, which falls between Acre and Mato Grosso, formed a genetically distinct cluster with intermediate distances from the other two distinct clusters. This difference in the association between geographic and genetic distances between the Wickham and wild germplasm, could be due to the fact that the original Wickham material had been collected from a very small area in Brazil, while the latter represents a much greater spectrum of diversity. As the present day clones have undergone only two or three cylces of selection from the original unselected material (Simmonds, 1989), there has not been sufficient time

for the clones in the secondary centers to evolve into genetically divergent groups. This situation is compounded by the free exchange of clones between countries, which again tends to obliterate differences between clones of different countries of origin.

Most of the clones in the present experiment fell into one single large cluster comprising 18 clones, while two clones formed another cluster. The remaining six clones were highly divergent and formed independent clusters. This indicates that a large amount of diversity is still present which can be exploited. The maximum inter cluster distance was observed between C IV and C VII (12.13). C VII (RRII 105) was found to show the maximum distance with other clusters, indicating its general divergence from the other clones. C IV (RRIM 607) and C VII (RRIM 615) were also found to be widely divergent, with a genetic distance of 10.34. Arunachalam *et al.* (1984) is of the opinion that though selection of parents based on genetic distance is desirable, extreme parental divergence may not always result in high magnitudes of heterosis, and hence selection of parents separated by intermediate genetic distances is more desirable. Thakur and Zarger (1989) and Mydin (1992) have supported this view.

The superiority of each cluster for various yield contributing traits is summarized in Table 43. The largest cluster- C I did not have the maximum values for any trait. C IV comprising the clone RRIM 607 was found to be superior for the maximum number of traits. C II was superior for five traits. As the genetic distance between these clusters (C IV and C II) was also found to be in the intermediate range, hybridization between these clusters is most likely to produce

heterotic offspring. It is evident from the general superiority of C IV that using it in any crossing programme with any of the other groups is likely to be fruitful. Mydin (1992) is also of the opinion that selection of parents based on individual attributes may not be as effective as that based on a number of important traits collectively, particularly when the aim is to achieve improvement in a complex quantitative trait like yield in rubber.

Among the traits included in the evaluation of divergence in the present study, initial flow rate, final volume of latex, yield, girth increment, thiol content and inorganic phosphorous content were found to contribute the maximum to genetic divergence at both the cluster and the genotype levels, while the traits dry rubber content, total solids content, density and diameter of latex vessels were found to contribute the least. Though the results obtained by Mydin (1992) are in general agreement with those obtained here, plugging index and dry rubber content were also found to be important contributors to divergence which is contrary to the findings of this study. Markose (1984) reported that girth, branching height, and girth increment, contribute more towards genetic divergence than dry rubber content and volume of latex.

5.1.6 Factor analysis

The general genetic diversity observed in a perennial crop like *Hevea* is a result of the interactions between a large number of traits. Recording of observations, processing and analyzing of data on all these complex variables is cumbersome and wasteful. Factor analysis is an extremely useful statistical tool to

Table 43. Superiority of clusters for different traits at the mature stage

Cluster No.	Traits showing superiority
C I	--
C II	Girth, girth increment, bark thickness, dry rubber content and total solid content
C III	Diameter of latex vessels and plugging index
C IV	Latex vessel rows, diameter of latex vessels, initial flow rate, final volume of latex, thiol content, inorganic phosphorous, and yield
C V	Specific leaf weight, diameter of latex vessels and lamina thickness
C VI	Density of latex vessels and midrib thickness
C VII	Chlorophyll a and chlorophyll b

reduce the large number of complex variables into a few hypothetical factors on which the breeder can concentrate. The variables in each factor group show similar inheritance patterns, and hence handling just one representative variable from each group will be sufficient to bring about changes in all other variables in that group.

Factor analysis was carried out using 27 morphological, anatomical, physiological and biochemical traits from the 25 mature clones and 10 principal factors, which accounted for 88.41 per cent of the variability observed in the population, were identified. The first factor, accounting for 25 per cent of the variability, consisted of variables girth, girth increment, leaf size, specific leaf weight, density and diameter of latex vessels, final volume of latex, plugging index, dry rubber content and yield. Mydin (1992), also found that yield, final volume of latex and plugging index were associated with the factor contributing the most to divergence. Girth and girth increment were also linked to the first factor in one of the clusters analysed, while they were separate in the second cluster of the same study. However Mydin, in the same report, obtained results contrary to the present one with respect to bark thickness and dry rubber content: bark thickness was linked to the first factor while dry rubber content was associated with the second factor, while the opposite was true in this study. The variables constituting the first factor in the present study are yield and the important yield contributing morphological and physiological traits. Hence, factor1 can be called the yield factor, and yield can be taken to represent this group. In cases where yield recording is difficult, girth or girth increment which have equally high factor loadings can be used instead.

The second factor, which accounted for 10.26 per cent of the variability observed, comprised the traits stomatal density, total chlorophyll content and chlorophyll a:b ratio. These three variables are connected with the photosynthetic efficiency of the plant. Stomatal density can be used as the marker of variability for this group.

Factor three was associated with thiol and inorganic phosphorous content of latex which accounted for 8.51 per cent of the variability. These variables are associated with the latex regeneration and the general health of the laticiferous system. Thiols can be used as the marker here.

Factor four consisted of initial flow rate and sucrose content of latex and explained 7.37 per cent of the variability. These parameters are involved in the yield of rubber.

Factor five, comprising bark thickness, number of latex vessel rows and palisade layer thickness, accounted for 7.27 per cent of the variability. These were the primary anatomical constituents of rubber yield, and hence this factor can be called the anatomical factor. Number of latex vessel rows will effectively serve as the representative of this group.

Factor six accounted for 6.94 per cent of the variability in the population and comprised of the characters leaf chlorophyll a and b content and magnesium in latex. These were the important biochemical parameters contributing to yield. Chlorophyll a can be used as the representative.

Factors seven, eight, nine and ten, which consisted of a single trait each (total solids content, lamina thickness, midrib thickness and laticifer area index) explained 6.89, 6.54, 4.71 and 4.60 per cent respectively of the variability in the clones, and contributed independently to divergence.

It was thus seen that 27 variables were effectively reduced to 10 factors which explained 88.41 per cent of the variability in yield.

Jacob *et al.* (1989) used principal component analysis on a set of seven latex biochemical traits and observed that sugars, thiols, redox potential, bursting index, magnesium and inorganic phosphorous formed factor 1 while pH of latex alone was the second factor. In the present study too, thiols and inorganic phosphorous together formed a separate factor. However, sucrose and magnesium fell in separate factor groups in the present study.

5.1.7. Performance index

The overall performance of the clones was evaluated using the variables girth, girth increment, specific leaf weight, bark thickness, number of latex vessel rows, density of latex vessels, diameter of latex vessels, midrib thickness, lamina thickness, initial flow rate, final volume of latex, plugging index, dry rubber content, total solids content, thiols in latex, inorganic phosphorous, chlorophyll a in leaves, chlorophyll b and average annual yield. The popular clone RRII 105 was the best clone at the mature stage, followed by RRIM 607 and RRIM 605. The other popular clone RRIM 600 was ranked only 16th. The index values ranged from 1363.06 for RRII 105 to 1040.57 for RRIM 615, with a population mean of 1230.97. Eleven clones (RRII 105, RRIM 607, RRIM 605, RRIM 705, RRIM

701, RRIM 703, RRIM 603, RRIM 501, RRIM 612, RRIM 706, RRIM 526) performed better than the population average for this trait. The expected genetic advance from this population was 178.93 per cent at a selection intensity of five per cent.

5.2. IMMATURE PHASE

5.2.1.Genetic variability

The 25 clones were evaluated for their variability for the various traits was examined at the immature stage also, using a total of 34 morphological, anatomical and biochemical traits and yield. Significant clonal differences were observed for all the traits at this stage too, except for number of flushes shed by the end of the first year (W3), number of new flushes retained on the main stem in the second year (W6), stomatal density and density of latex vessels. Weeks to sprouting, first year scion diameter, number of flushes produced and those retained in the first year (W1 and 2), total number of leaves produced in the first year, scion diameter in the second year, diameter increment, number of new flushes produced on the main stem and on the entire plant including branches, in the second year (W4 and W5), and number of flushes produced on the main stem in the two years (W8), leaf size, specific leaf weight, bark thickness, number of latex vessel rows, diameter of latex vessels, laticifer area index, leaf midrib, lamina and palisade layer thickness, latex thiols, inorganic phosphorous, sucrose and magnesium, chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a:b ratio showed significant clonal differences at the 1 per cent level, while height, number of new

flushes retained on the entire plant in the second year (W7) and specific leaf weight showed significant clonal differences only at the 5 per cent level. Saraswathyamma and Panikkar (1989) also recorded significant variability among progenies for juvenile traits.

Leaf size and specific leaf weight, which showed significant clonal variability at the immature phase, continued to do so at the mature phase too. Clonal variability for stomatal density was not significant at the immature phase. However, at the mature phase, high clonal differences for this trait became pronounced. Among the bark and leaf anatomical parameters, significant variability was found at both the stages for all traits except density of latex vessels. The significant clonal differences for diameter of latex vessels were obliterated at the mature stages. The significant variability obtained here or girth and height in the first year of growth are in contrast to the earlier findings of Markose (1984) in 10 month old seedlings and Mydin (1992) in seedling progenies, who concluded that the age of one year is too early for the expressionof genotyic differences for these traits. However Abraham (2000) obtained highly significant clonal differences for these traits in one year old clonally propagated wild germplasm. Highly significant clonal differences were also reported for number of leaves produced, number of leaf flushes produced and those retained at the age of one year. Good immature vigour is one of the most important attributes associated with yield potential in rubber (Tan, 1987), and is one of the early selection criteria in *Hevea* breeding.

Mydin (1992) reported that seedlings at the age of two years showed significant variability for girth, number of leaf flushes, number of latex vessel rows and rubber yield on testtaping, which is in conformity with the results of the present

study. However, contrary to the same report, clonal variability was observed for bark thickness too in the present study. Significant clonal variability was also reported for girth, height, number of leaf flushes per plant in 14 month old plants (Goncalves *et al.*, 1994). A number of earlier studies also confirm the presence of variability for juvenile yield, girth and leaf area in Wickham clones (Moreti *et al.*, 1994; Boock *et al.*, 1995) in keeping with the present findings. Significant clonal variability for leaf size and anatomical traits were also reported by Abraham (2000) in wild germplasm at the immature stage. Contrary to the same study, clonal differences for stomata density were not significant at this age in the Wickham clones examined in the present experiment.

5.2.2. Genetic parameters

The partitioning of the total phenotypic variance into its heritable and non heritable components was carried out at the immature phase also.

The values of GCV were found to be considerably lower than their corresponding PCVs, indicating the substantial role of environment in the expression of most traits. The highest estimates of GCV and PCV were observed for immature yield, which is in conformity with the findings of Mydin (1992) in Wickham clones and Abraham (2000) in wild germplasm. Relatively high PCV and GCV were recorded in the present study for the traits time taken to sprout, number of flushes shed by the end of the first year (W3), diameter increment, number of new flushes produced and those retained on the entire plant in the second year (W5 and 7), number of latex vessel rows, laticifer area index, latex thiols, inorganic phosphorous, sucrose and magnesium and juvenile yield. Leaf size, specific leaf weight, density and diameter of latex vessels and chlorophyll a:b ratio showed extremely low

estimates of genotypic coefficient of variation. The high GCV and PCV observed

for number of flushes and number of latex vessel rows support the findings of

Mydin (1992) and Abraham (2000).

Higher heritability estimates were recorded for all the anatomical and

biochemical traits (except density of latex vessels), than for the morphological

traits, indicating the greater influence of environment on the latter. Among the

morphological traits, moderate to high heritability was observed for leaf size, time

taken to sprout, whorl characteristics of the first year except number of flushes

shed by the end of the first year (W3), and those of the second, except for number

of new flushes retained on the entire plant in the second year. Mydin (1992) also

obtained high heritability for number of latex vessel rows, yield, number of flushes

and girth. The highest genetic advance was recorded for sucrose content followed

by juvenile yield. Very high genetic advance estimates were recorded for all the

anatomical and biochemical traits except bark thickness, density and diameter of

latex vessels, leaf lamina thickness, and chlorophyll a:b ratio, while those for

morphological traits was generally moderate to low. Licy (1997) also recorded

high values of heritability and genetic advance, for biochemical characters

High heritability combined with high genetic advance recorded for most

of the anatomical and biochemical traits and yield (except density and diameter of

latex vessels and chlorophyll a:b ratio which had very low genetic advance

estimates) indicate the preponderance of additive gene action in these traits. Tan

and Subramanium (1976) found that additive gene effects are predominantly involved

in the inheritance of yield, bark thickness and number of latex vessel rows in the nursery.

However, only low to moderate levels of genetic advance were obtained in the present

study for bark thickness. Moderate to high heritability followed by low genetic advance seen for the traits height, first year scion diameter, bark thickness and diameter of latex vessels, implies the inheritance of these traits is governed mainly by non additive gene action and hence will not respond to selection. Other techniques like heterosis breeding can be exploited for their improvement.

5.2.3. Associations among immature traits

Information on *inter se* associations of traits at the juvenile stage was used to identify traits that contribute to juvenile yield, for the formulation of a selection index. The various inter character associations at the phenotypic and genotypic levels are dicussed below.

5.2.3.1. Correlations between immature yield and other parameters

Laticifer area index, scion diameter in the second year, number of latex vessel rows, bark thickness, inorganic phosphorous, thiol content, girth increment, number of new flushes produced and those retained on the main stem in the second year, latex magnesium, chlorophyll a, chlorophyll b and total chlorophyll were positively associated with testap yield at both the phenotypic and genotypic levels. Relatively high positive genotypic correlations were also recorded with leaf size, and number of flushes produced on the main stem in the two years (W8). Among the first year parameters, height of the plant in the first year showed a negative, though weak genotypic correlation with yield. Low positive genotypic correlations of yield were also observed with chlorophyll a and b and total chlorophyll. Positive correlations with girth, bark thickness and number of latex vessel rows were

reported earlier (Tan and Subramaniam, 1976; Licy and Premakumari, 1988, Varghese *et al.*, 1989; Mydin, 1992). The present finding of a negative correlation between plant height and scion diameter in the first year are contrary to the results of Alika (1982). Abraham (2000) did not obtain significant correlation between yield and bark thickness, density, or diameter of latex vessels. The present study reveals that the morphological traits girth, girth increment and foliar attributes, anatomical traits bark thickness, laticifer area index and number of latex vessel rows, biochemical parameters latex magnesium, inorganic phosphorous and thiols, and to a lesser extent, chlorophyll content, contribute to juvenile yield.

5.1.3.2. Associations between morphological traits

As is to be expected, clones that sprouted earlier were observed to have greater height, more number of flushes produced in the first year (W1), number of flushes shed by the end of the first year (W3), number of leaves, second year scion diameter and girth increment, but had lower scion diameter in the first year. Clones that sprouted early also tended to branch early, as evidenced by the negative correlations of time taken to sprout with number of new flushes produced and those retained on the entire plant in the second year (W5 and W7), and positive correlations with number of new flushes produced on the main stem in the second year (W4) and number of new flushes retained on the main stem in the second year (W6). Clones that sprouted earlier also tended to have smaller leaves by the second year, which is an indication of physiological maturity.

Height of the clones at the end of the first year was found to have high positive correlations at the phenotypic and genotypic levels with all the whorl and

leaf production characteristics in the first year. First year height was also found to positively influence all whorl production characteristics in the second year (W4 to W8) except number of new flushes retained on the main stem (W6), as well as scion diameter and girth increment in the second year. Height was not significantly correlated at the phenotypic or genotypic levels with leaf size or specific leaf weight, while a low negative genotypic correlation was observed with stomatal density. Significant positive environmental correlations were observed for most of these traits, except number of flushes shed by the end of the first year (W3), number of new flushes produced, and those retained on the main stem in the second year (W4 and W6). Mydin (1992) obtained significant associations of first year height with flushes produced and those retained, and number of leaves, which is in complete agreement with the present findings.

Scion diameter in the first year had low negative correlations with other morphological traits in the first year, probably due to the greater opposite influence of its association with height. It was negatively correlated with number of flushes shed by the end of the first year (W3) and with diameter increment in the second year, at all the three levels. Mydin (1992) in contrast obtained highly significant correlations with all the other first year characters. This was due to the positive correlation between height and scion girth obtained. No other significant correlation at the phenotypic level was observed. However, at the genotypic level, positive correlations were also obtained with number of new flushes produced and those retained on the main stem in the second year (W4 and W6) and with stomatal density, while negative correlations were seen with number of new flushes retained on the entire plant in the second year (W7).

Number of flushes produced and those retained in the first year (W1 and W2) were found to be highly positively correlated at all the three levels with scion diameter and diameter increment in the second year, and all the first and second year whorl production traits except number of new flushes retained on the main stem in the second year (W6). A relatively high negative genotypic correlation of number of flushes produced in the first year (W1) with stomatal density was also seen. This probably is an adaptation of the plant to reduce transpiration losses as its total leaf surface area increases with increase in number of flushes. Number of leaves produced in the first year was also found to have a significant positive effect on all whorl characteristics in the second year at the genotypic and phenotypic levels, except for number of new flushes retained on the main stem in the second year (W6). Varghese *et al.* (1989) reported that morphological characters like girth, number of flushes, and total number of leaves contribute to juvenile vigour, which in turn is reflected in yield.

Scion diameter in the second year and diameter increment were positively correlated with each other at all the three levels, as well as with all the second year whorl production characteristics (W4 to W8). However, the correlation of diameter increment with number of new flushes produced and those retained on the main stem in the second year (W4 and W6) was not significant. In general, there was no significant correlation between scion diameter and diameter increment with the leaf morphological characteristics - size, specific leaf weight or stomatal density, except for a relatively high negative correlation between diameter increment and density of stomata.

Number of new flushes produced on the main stem in the second year (W4) was highly and positively correlated at the phenotypic, genotypic and environmental levels with number of flushes produced on the main stem in the two years (W8), as well as with the other whorl characteristics in the second year. No significant correlations of this trait were recorded with leaf characteristics, except for a positive genotypic correlation with specific leaf weight. Number of new flushes produced on the entire plant in the second year (W5) was highly correlated with those retained on the entire plant in the second year (W7) and number of flushes produced on the main stem in the two years (W8) at all three levels. Negative correlations of this trait at the genotypic level were recorded with stomatal density and specific leaf weight. Number of new flushes retained on the main stem in the second year (W6) showed relatively high positive genotypic correlations with leaf size, specific leaf weight and stomatal density, though these correlations were not significant at the phenotypic level. Number of new flushes retained on the entire plant in the second year (W7) was positively correlated with number of flushes produced on the main stem in the two years (W8) at the phenotypic and genotypic levels. This trait was negatively correlated at the genotypic level with stomata density and specific leaf weight. The character number of flushes produced on the main stem in the two years (W8) had low, positive phenotypic and genotypic correlations with leaf size and specific leaf weight, and a negative genotypic correlation with stomatal density.

Leaf size was positively correlated at the phenotypic and genotypic levels with specific leaf weight, and at the genotypic level only with stomatal density. Specific leaf weight had a high positive genotypic correlation with stomatal density.

This correlation was not significant at the phenotypic level. Environment was found to have a significant negative effect on this correlation.

5.2.3.3. Associations between anatomical traits

Positive correlations of bark thickness with number of latex vessel rows, laticifer area index and leaf midrib thickness and negative correlation with density of latex vessels at the juvenile stage were obtained. Positive correlations between bark thickness and number of latex vessel rows at this stage were reported earlier (Mydin 1992; Abraham, 2000). Laticifer area index recorded high positive correlation with number of latex vessel rows. Density of latex vessels was not correlated phenotypically with laticifer area index, though a negative correlation at the genotypic level was observed. Diameter of latex vessels was found to have significant positive phenotypic correlation with laticifer area index , which did not exist at the genotypic level. No significant correlations were obtained between laticifer area index and leaf anatomical traits except for a low negative genotypic correlation with lamina thickness.

Density of latex vessels was not correlated with diameter. Low negative phenotypic and genotypic correlations were detected with midrib thickness. Diameter of latex vessels also showed a positive but very low genotypic correlation with midrib thickness.

High phenotypic and genotypic correlations were observed among the three leaf anatomical traits. Environment also influenced these correlations positively, as indicated by their high positive environmental correlation values.

5.2.3.4. Associations between biochemical traits

No significant correlations were observed between thiol content of latex and any of the other latex or leaf biochemical parameters at the genotypic or phenotypic levels, except for a very weak phenotypic correlation with leaf chlorophyll a and total chlorophyll content. Inorganic phosphorous also recorded only a low significant positive phenotypic relation with latex magnesium, and a negative genotypic correlation with sucrose, in agreement with the results obtained by Licy (1997). Latex sucrose content recorded a positive phenotypic correlation with chlorophyll a, total chlorophyll and chlorophyll a:b ratio. This finding probably implies that clones with greater chlorophyll content do indeed produce more photosynthates, though the correlation is not very high. These three correlations were positive at the genotypic level too while their environmental correlations were negligible. This finding will also have to be confirmed from further studies. If the correlation holds good in other studies too, then chlorophyll content, which is easier to measure than sucrose, will help in locating clones for superiority for this trait. Latex magnesium showed a positive phenotypic correlation with chlorophyll a:b ratio and negative with chlorophyll b. At the genotypic level, latex magnesium showed negative correlations with chlorophyll a, b and total chlorophyll and a positive correlation with chlorophyll a:b ratio.

Chlorophyll a, b and total chlorophyll were highly and positively correlated amongst themselves at all three levels. Chlorophyll a:b ratio was not correlated with chlorophyll a, but was negatively correlated with chlorophyll b and total chlorophyll.

The environmental correlations amongst the four latex biochemical parameters at the immature stage were high and positive, indicating that they were influenced by the environment in a similar manner. Similar trends were observed amongst chlorophyll a, b and total chlorophyll. Chlorophyll a:b ratio however showed significant negative environmental correlations with the other three chlorophyll estimates. The environmental correlations between the latex and leaf biochemical characters were very low indicating that the environment did not influence the correlations between these characters.

The results show that at the immature stage, the morphological character number of new flushes retained on the main stem in the second year (W6) had the highest genotypic association with immature yield, followed by the anatomical trait laticifer area index. Most of the biochemical traits were relatively less important at this stage, with the exception of inorganic phosphorous, which had a moderate level of correlation with yield. The pscion diameter, number of new flushes produced on the main stem in the second year (W4), number of flushes produced on the main stem in the two years (W8) leaf size, bark thickness and number of latex vessel rows were also relatively more important to yield at this stage.

5.2.4. Direct and indirect effects on immature yield

Path analysis was carried out using 15 variables collected at the immature phase to examine the relative importance of the various traits in the expression of yield at the immature stage.

Number of latex vessel rows was found to exert the highest positive direct effect on yield, while bark thickness had a very high negative direct effect on yield. Relatively high positive direct effects were also exhibited by total number of leaves produced in the first year, number of flushes retained at the end of the first year (W2), time taken to sprout, and chlorophyll b content, while lamina thickness, number of flushes shed by the end of the first year (W3) and scion diameter in the second year showed relatively higher negative direct effects.

The high positive direct effect of number of latex vessel rows was accompanied by a small positive indirect effect through lamina thickness, and a fairly large undesirable negative indirect effect through bark thickness, which reduced its total effect on yield. Bark thickness on the other hand had a very high negative direct effect, which was counterbalanced by its positive indirect effects through number of latex vessel rows, total number of leaves, number of flushes retained at the end of the first year (W2), number of new flushes retained on the main stem in the second year (W6) and lamina thickness, resulting in a positive correlation with yield. The high positive direct effect of number of latex vessel rows and high negative direct effect of bark thickness observed were contrary to the results in the mature clones of this study, where bark thickness had a high positive influence on yield while that of number of latex vessel rows was low and negative.

The relatively high positive direct effect of total number of leaves was enhanced slightly by its positive indirect effect through number of flushes retained at the end of the first year (W2). This high positive effect was completely nullified

by its high negative indirect effects through bark thickness, scion diameter, number of flushes shed by the end of the first year (W3) and time taken to sprout. Number of flushes retained at the end of the first year (W2) also had a high positive direct effect on yield, accompanied by an almost equally large positive direct effect through total number of leaves. However, the relatively large negative effects through bark thickness, lamina thickness and scion diameter in the second year, drastically reduced this effect, though the net correlation with yield was still positive.

The fairly large positive direct effect of chlorophyll b was accompanied by its positive indirect effects through lamina thickness, total number of leaves and bark thickness and negative effects through leaf size and number of flushes shed by the end of the first year (W3). The net effect was still positive. In contrast to the positive direct effect obtained here, chlorophyll b exerted a low but negative direct effect at the mature stage.

The moderate positive direct effects of inorganic phosphorous on juvenile yield was further boosted by its association with number of flushes retained at the end of the first year (W2), and number of latex vessel rows, while a fairly large negative effect through bark thickness was seen. However, a net positive effect of this trait on yield was obtained. Relatively high positive direct effect for this trait was obtained at the level of mature clones, indicating the relative importance of this trait on yield at both stages. Similarly, the moderate positive direct effect of leaf size was accompanied by equally large positive indirect effects through number of latex vessel rows and number of flushes retained at the end of the first year, while negative effects through bark thickness, chlorophyll b and lamina thickness were observed. Here too, the total effect on yield was positive and relatively high.

Number of new flushes retained on the main stem in the second year (W6) had a relatively low direct effect on yield. However, its comparatively large positive indirect effects, exerted mainly through number of latex vessel rows, number of flushes shed by the end of the first year and leaf size served to boost its effect to give a very high genotypic correlation with yield.

The direct effects of first year scion diameter and chlorophyll a were negligible, contrary to the mature clones, where chlorophyll a exerted a very high positive direct effect. The first year scion diameter exerted positive influence through number of latex vessel rows and time taken to sprout, while relatively low negative influence through bark thickness was also displayed. The high indirect effect of chlorophyll a through chlorophyll b resulted in its positive correlation with yield.

The second year scion diameter exerted a moderate negative direct effect on yield, though its correlation was positive and fairly high. The negative direct effect was accompanied by large positive indirect effect through number of leaves, and number of flushes retained at the end of the first year (W2), which was responsible for the net positive correlation of this trait with yield.

Leaf lamina thickness had a relatively high negative direct effect on yield. Relatively large indirect negative effects were recorded through chlorophyll b number of latex vessel rows and total number of leaves, while positive effects were also observed through time taken to sprout and number of flushes retained at the end of the first year.

A residue of 0.33 was obtained from this analysis, compared to the negligible residue obtained in the same clones at the mature stage. This implies that there were other factors contributing to the variability in yield, which have not been included in this study. Physiological parameters initial flow rate, final volume of latex, plugging index, dry rubber content and total solids content, which were included in the path analysis for mature clones, could not be recorded for the immature clones due to the insufficient latex produced at this stage. As these parameters have been shown to influence yield in mature clones, it would be desirable to extend such studies to the fourth and fifth years also when sufficient latex will be available to make such recordings possible. Among the parameters recorded, it was seen that the anatomical trait number of latex vessel rows had the maximum positive direct effect on yield at the immature stage, followed by morphological traits number of leaves produced and number of flushes retained at the end of the first year (W2). Bark thickness had a very high negative direct influence. At this stage, biochemical parameters inorganic phosphorous, chlorophyll a and chlorophyll b were found to be relatively less important than number of latex vessel rows, number of leaves produced and number of flushes retained at the end of the first year as they had only a moderate positive direct effect on yield.

5.2.5 Genetic distance and clustering

The genetic distances among the 25 clones at the immature stage were computed using 16 variables and the clones grouped in such a way that the average inter cluster distance was always greater than the average intra cluster distance.

Five clusters were obtained, with the three non Malaysian clones also being grouped along with the Malaysian clones, implying that genetic diversity was in no way linked with geographical diversity. This corroborates earlier findings in wild germplasm at the same stage of growth, that genetic and geographical diversity are not correlated (Abraham *et al.*, 1995; Abraham, 2000), as well as other studies in mature rubber clones, as discussed earlier.

Most of the clones (19 in number) including the two non Malaysian clones IAN 873 and Har 1 fell into a single large group. The second and third clusters comprised two clones each, with the Indian clone RRII 105 being included in C II along with RRIM 615. The clones RRIM 603 and RRIM 706 were included in C IV and C V respectively. This indicates that while most of the clones at this age are genetically similar, some clones are extremely divergent. The genetic distance between the clusters was maximum between the combination C III (RRIM 607 and RRIM 612) and C V (RRIM 706) (10.31), followed by C I and C III (9.45), while the minimum was obtained between C I and CIV. Clustering of clones at the immature stage in rubber has been previously attempted only in the wild germplasm (Abraham *et al.*, 1995; Abraham, 2000) where 100 and 81 wild accessions were respectively grouped into seven and nine clusters.

The superiority of the clusters for the various traits is shown in Table 44. The largest cluster CI showed the maximum value for only one trait laminar thickness. Cluster CII showed superiority for most of the important yield contributing traits and yield itself. Clusters IV (RRIM 603) and V (RRIM 706) were superior for three and four variables respectively. It is interesting to note that the popular clone RRII 105, in C II which was classified as superior for yield, itself showed only average yield in the immature stage.

An examination of the contribution of the variables to genetic diversity at the immature stage revealed that yield was the single most important trait contributing to genetic divergence at both cluster and genotype levels, while scion diameter in the first and second years and first year plant height had the least effect. In addition, number of flushes shed by the end of the first year, chlorophyll b, chlorophyll a, number of latex vessel rows, time taken to sprout and leaf size were important characters contributing to divergence at the cluster level, while only a slight change was seen in this order at the genotype level.

5.2.6. Factor analysis

Factor analysis was carried out in the immature clones too using 34 morphological, anatomical, physiological and anatomical traits, to reduce the large number of variables to a few meaningful factors. Nine principal factors were identified which could explain 85.24 per cent of the variation in the population at the immature stage.

The first factor accounted for 21.46 per cent of the variability in the population, and was associated with the variables plant height, number of leaves, total number of whorls produced and those retained in the first year, scion diameter and increment in the second year, number of new whorls produced and those retained on the entire plant in the second year, number of new whorls produced on the main stem in the second year and in the two years together. These variables were connected with the growth and vigour of the plants and hence this factor can be called the 'vigour factor', and can be represented by height.

Table 44. Superiority of clusters for different traits at the immature stage

Cluster No.	Traits showing superiority
C I	Lamina thickness
C II	Second year scion diameter, number of new flushes retained on the main stem in the second year (W6), leaf size, number of latex vessel rows, inorganic phosphorous, and juvenile yield
C III	Bark thickness
C IV	Number of flushes retained at the end of the first year (W2), chlorophyll a and b content.
C V	Plant height, first year scion diameter, number of leaves produced, and early sprouting.

The second factor, which accounted for 10.26 per cent of the variability observed, comprised the traits juvenile yield, bark thickness, number of latex vessel rows, laticifer area index and latex thiol content. This factor is associated with yield and important yield contributing factors, and hence can be called the 'yield factor'. Laticifer area index is the best representative trait for this factor.

Factor three was associated with total chlorophyll, chlorophyll a and b which accounted for 11.19 per cent of the variability. This factor can be called the 'chlorophyll factor', and can be represented by total chlorophyll .

Factor four consisted of leaf size, specific leaf weight, leaf lamina and palisade layer thickness and explained 8.64 per cent of the variability. This factor can be referred to as the 'leaf factor' and can be represented by palisade layer thickness.

Factor five, comprising time taken to sprout, number of whorls shed in the first year and leaf midrib thickness, accounted for 7.98 per cent of the variability in the population. Time taken to sprout contributed the maximum to divergence in this group and can be regarded as representative of this factor.

Factor six accounted for 7.10 per cent of the variability in the population and comprised of the characters density of latex vessels, latex sucrose content, chlorophyll a:b content. Chlorophyll a:b ratio is representative of this factor.

Factor seven, associated with characters number of new whorls retained on the main stem in the second year, stomatal density and latex inorganic phosphorous content, was responsible for 6.23 per cent of the variability seen in

the population. The variables of this factor (except for stomata) are associated with juvenile yield and can be represented by inorganic phosphorous content.

Factors eight (consisting of scion diameter in the first year and latex magnesium) and nine (which had the lone trait diameter of latex vessels), explained 5.90 and 4.73 per cent of the variability in the clones, respectively. These factors contributed independently to the genetic divergence in the population.

It can be inferred from the above analysis that for any genetic studies in the juvenile stage, only the traits height, laticifer area index, total chlorophyll, palisade layer thickness, time taken to sprout, chlorophyll a:b ratio, latex magnesium and diameter of latex vessels need be evaluated.

Abraham (2000) succeeded in reducing a set of 33 morphological and anatomical variables to 12 factors in juvenile wild germplasm, which could explain 82.3 per cent of the total variance observed.

5.2.7 Performance index

The 25 clones were ranked on the basis of an index formulated using the variables time taken to sprout, plant height, scion diameter in the first year, number of flushes retained at the end of the first year (W2), number of flushes shed by the end of the first year (W3), number of leaves produced, second year scion diameter, number of new flushes retained on the main stem in the second year (W6), bark thickness, number of latex vessel rows, inorganic phosphorous, leaf size, lamina thickness, chlorophyll a and chlorophyll b. The index values ranged from 164.83

for RRIM 612, to 268.07 for RRIM 703. 13 clones (RRIM 703, Har 1, RRIM 704, RRIM 605, IAN 873, RRIM 602, RRII 105, RRIM 705, RRIM 610, RRIM 615, RRIM 519, and RRIM 600) performed better than the population average. The popular clones RRII 105 and RRIM 600 were ranked 7th and 12th respectively at this stage. The theoretical genetic advance that could be expected at a selection intensity of 5 per cent was 54.57 per cent. Mydin (1992) assessed the perfomance of progenies of 20 clones of *Hevea* at the age of two years, by computing an index based on testtap yield, girth, number of latex vessel rows, and number of leaf flushes. Varghese *et al.* (1993) also worked out growth indices at the immature stage for young clones of *Hevea.*

5.3 MATURE - IMMATURE RELATIONSHIPS

5.3.1. Relative importance of traits to yield at each stage

An examination of the correlations of the various traits with immature and mature yield reveals the relative importance of these traits at the two stages. In the immature stage, the morphological trait number of new flushes retained on the main stem in the second year(W6) played a predominant role in the expression of yield followed by the anatomical trait laticifer area index. Girth increment had only a very low positive correlation with yield. At the mature stage however, girth increment had the highest contribution to yield, while number of latex vessel rows and final volume of latex were equally important. Biochemical parameters at both stages contributed relatively less than the other characters to variation in yield, except for inorganic phosphorous in the immature stage which showed a moderate association with yield

5.3.2. Associations for traits between the mature and immature stages

Simple correlations were computed between the common individual traits in both the stages. Simple correlations were also worked out for all the immature traits with mature yield.

5.3.2.1 Correlations between immature traits with corresponding mature traits

Significant correlations were obtained between the immature and mature phases for magnesium content of latex, followed by sucrose, thiols, inorganic phosphorous, number of latex vessel rows, laticifer area index, stomatal density, density and diameter of latex vessels. A low but significant negative correlation was observed for palisade layer thickness. All other parameters including yield did not show any significant relationship. Premkumari (1992) also obtained significant correlations between juvenile and mature number of latex vessel rows and laticifer area index, though no correlations were obtained for density and diameter of latex vessels. Licy (1997) obtained relatively high correlations for magnesium, inorganic phosphorous content and to a lesser extent thiols and total solids content between early phase and first three years of mature tapping. No correlation was observed for sucrose.

Morphological characters appear to be more affected than the bark anatomical and latex physiological traits as evidenced by the relatively higher correlations of the latter. The lack of correlations between the mature and immature stages for morphological parameters like girth and girth increment may be due to

the difference in age of the two sets of plants. Moreover, once tapping commences, the girthing pattern of clones is bound to change as different clones react differently to tapping in respect of further growth. This assumption is supported by reports of clonal differences for girth increment under tapping (Premakumari, 1992). Templeton (1968; 1969) also studied the growth of *Hevea* clones before and during exploitation, as well as the photosynthetic rates and leaf area index under different growth periods. He observed varying trends due to age for the different traits and reported that girthing continues for the major part of the economic life period, but the rate is reduced during the exploitation period.

For the leaf morphological attributes, a general decrease in leaf size was observed in the mature clones. However, though there was no change in the average specific leaf weight of the clones, individual changes in the clones were observed, reducing the correlations of these two traits in the two phases to negligible levels. Changes in leaf size and specific leaf weight over age appear to have reduced the correlations of the leaf anatomical and biochemical correlations as well, with the palisade layer thickness being the most affected and ultimately expressing a negative relationship. Lack of substantial correlations of stomatal density with leaf size and specific leaf weight at both stages might account for the correlation between stomatal density at the immature and mature stages remaining relatively intact.

5.3.2.2 Correlations between immature traits and mature yield

For the relationship between immature attributes and mature yield, significant positive correlations were obtained only with number of latex vessel

rows and bark thickness. The number of whorls produced on the main stem in the first two years was found to have a very low positive correlation with mature yield but the relationship was not statistically significant. This was not very surprising, given the changes in the plant's morphological parameters, especially girth which was a major factor contributing to yield in each stage, which in turn affected the other correlations. Ho (1972; 1976) and Tan (1987) reported that rubber yield on testtapping nursery plants was highly correlated with early mature yield. Ho (1972) also found that number of latex vessel rows at the juvenile phase is an important parameter determining mature yield, which is in agreement with the present findings. The traits girth, number of flushes, testap yield and number of latex vessel rows, are being currently used as early selection criteria, and have been fairly effective in identifying clones for high yield in the early years. However, such correlation studies have not been extended to the later stages of production, partly because more emphasis is given to achieving high yield in the early years. It is also generally believed that no correlation can be observed at this stage. This study however reveals the importance of number of latex vessel rows as predictor of yield in the later panels, and which should be given more importance than other parameters including testtap yield, for identifying clones with sustained high yield in both the early as well as late stages of production.

5.3.3. Genetic divergence and performance of clones in the two stages of growth

An examination of the genetic divergence patterns and the grouping of clones in the two stages reveals a great deal of similarity between the two sets,

which is surprising considering the wide difference in the age of the plants as well as in the variables used for clustering. The range of genetic distances obtained at the two stages (6.89 - 194.49 and 8.06 - 147.04) was very similar when compared with those obtained by Mydin (1992) (1347.69 - 225744.50) in another set of mature clones of rubber. Moreover, the clustering pattern also showed great similarities. In both cases, a single large cluster was formed with 18 and 19 clones each in the mature and immature stages. Of these, 16 clones were common. The two non Malaysian clones IAN 873 and Har 1 were included in the first cluster in both cases. At the mature stage, one cluster with two clones, and five clusters with single clones were formed, while at the immature stage, two clusters with two clones each, and two independent clusters were formed. In both cases, RRIM 603 was independent. Clones RRIM 615 and RRII 105, which formed independent groups in the mature phase were clubbed together in the immature stage. Similarly RRIM 607, which was independent in the mature set, was clubbed with just one other clone in the immature phase. All this implies that clustering of clones at the immature stage itself will give a sufficient indication of the clusters at the mature stage. However, this will have to be confirmed from further studies in other sets of clones, in order to ascertain whether this is a general trend or not.

The overall performance of the 25 clones in the two stages was compared on the basis of their performance indices obtained using discriminant function. Simple correlations were worked out between the two indices. As expected from the observed performance of the clones for the individual traits, no significant correlation was obtained, indicating that the general performance of the clones in the mature stage cannot be predicted from their general performance in the immature stage with the given variables. The variables that went into the formulation of the

selection index at each stage were selected on the strength of their phenotypic and genotypic correlations with yield. The change in the general performance of the clones from the juvenile phase to the mature one probably commenced with tapping, when clonal differences for girth increment under tapping began to be expressed. As girth increment was found to have the highest correlation with yield, the overall interrelationships would have begun to change. Over the years, these accumulated differences would have led to the drastic differences observed at the late maturity stage.

A comparison of the performance of clones for yield in the two stages reveals that the highest yielder RRIM 607 in the mature phase, also gave a very high immature yield and was ranked second at this stage. RRIM 703 and RRIM 605 also gave superior yields in both stages on par with the highest in each case. The performance of RRIM 600 at both stages was average. RRII 105, the popular Indian clone which gave a mature yield on par with the highest, gave only an average yield at the immature stage. RRIM 615 which gave the highest immature yield, gave a very low mature yield on par with the lowest. RRIM 603 and RRIM 610 were other clones that gave promising immature yield but were found to give only low to average yield in the mature stage.

5.3.4 Regression analysis

A step wise regression analysis of mature yield on the immature attributes, using a bound rate of 20 per cent, revealed that only one variable, number of latex vessel rows at the immature stage, could account for 20.83 per cent of the variation in mature yield.

SUMMARY

6. SUMMARY

This study was undertaken at the Rubber Research Institute of India from 1996 to 1998 using mature and young clones of 25 genotypes of *Hevea*, with the objectives of estimating the variability, correlations, direct and indirect effects of various traits influencing yield, genetic divergence and the factors contributing to divergence, identifying those variables that remain stable in both stages of the crop, and to examine the extent to which mature yield could be predicted using immature attributes. A number of morphological, structural, physiological and biochemical parameters were observed at the two stages of growth.

Significant clonal differences at the immature stage was observed for all the traits except number of whorls retained at the end of the first and second years on the main stem, stomatal density per unit leaf area and density of latex vessels. At the mature stage, clonal differences for diameter of latex vessels and chlorophyll a:b ratio were not significant, while that for stomatal density became more pronounced.

There was high genetic variability at the mature stage for most traits, especially girth increment, laticifer area index, initial flow rate, final volume of latex, latex biochemical parameters (except for total solids content) and yield,

indicating that there was sufficient variability for the breeder to work on for the improvement of these traits. However number of stomata per unit area, density of latex vessels, diameter of latex vessels, total solids content and chlorophyll a:b ratio had very low variability. The heritability estimates were moderate to high for most of the traits except for girth increment, density and diameter of latex vessels, and chlorophyll a:b ratio which exhibited very low values. Moderate to high levels of genetic advance were recorded for girth, girth increment, initial flow rate, final volume of latex, plugging index, and dry rubber yield. Moderate to high estimates of heritability coupled with high genetic advance observed in the present experiment for yield, girth, laticifer area index., initial flow rate, final volume of latex, plugging index, latex thiols, inorganic phosphorous, sucrose, magnesium, chlorophyll b and total chlorophyll imply the preponderance of additive gene action in the inheritance of these traits, making them amenable to selection. High heritability coupled with low genetic advance observed for stomatal density, bark thickness, leaf midrib lamina and palisade layer thickness indicate that selection will not be effective for these traits as they are governed by non additive gene action. Among the immature plants, high genetic variability was observed for immature yield, time taken to sprout, number of flushes shed by the end of the first year (W3), diameter increment, number of new flushes produced and those retained on the entire plant in the second year (W5 and 7), number of latex vessel rows, laticifer area index, latex thiols, inorganic phosphorous, sucrose and magnesium and juvenile yield. Leaf size, specific leaf weight, density and diameter of latex vessels and chlorophyll a:b ratio showed extremely low estimates of genotypic coefficient of variation. Higher heritability estimates were recorded for all the anatomical and biochemical traits except density of latex vessels, than for the morphological traits, indicating

the greater influence of environment on the latter. High heritability combined with high genetic advance was recorded for most of the anatomical and biochemical parameters and yield (except density and diameter of latex vessels and chlorophyll a:b ratio which had very low genetic advance estimates) indicating the preponderance of additive gene action in these traits. Moderate to high heritability followed by low genetic advance were seen for the traits height, first year scion diameter bark thickness, diameter of latex vessels, which implies the inheritance of these traits is governed mainly by non additive gene action, and hence will not respond to selection.

At the mature phase, strong genotypic correlations of average annual yield were observed with final volume of latex and initial flow rate, girth, girth increment, number of latex vessel rows, laticifer area index, bark thickness and inorganic phosphorous content, while at the immature stage, laticifer area index, scion diameter in the second year, number of latex vessel rows, bark thickness, inorganic phosphorous, thiol content, girth increment , number of new flushes produced and those retained on the main stem in the second year, latex magnesium, chlorophyll a, chlorophyll b, total chlorophyll, leaf size, and number of flushes produced on the main stem in the two years (W8), were positively associated with testap yield at both the phenotypic and genotypic levels. In the immature stage, the morphological trait number of new flushes retained on the main stem in the second year (W6) played a predominant role in the expression of yield followed by the anatomical trait laticifer area index. Girth increment had only a very low positive correlation with yield. At the mature stage however, girth increment had the highest contribution to yield, while number of latex vessel rows and final volume of latex

were equally important. Biochemical parameters at both stages contributed relatively less than the other characters to variation in yield, except for inorganic phosphorous in the immature stage which showed moderate association with yield.

The direct effects of the various traits at both phases were estimated through path analysis. At the mature phase, initial flow rate and bark thickness could be used effectively as selection parameters for yield, as their direct effects were the highest. This is further supported by the fact that a large proportion of the indirect effects of other traits also appeared to be manifested through these traits. Hence simultaneous selection for these traits will be highly rewarding. Inspite of the moderate to high correlations of girth, girth increment, number of latex vessel rows, final volume of latex, density and diameter of latex vessels, selection for these traits *per se* will not effectively improve yield, as their direct effects are low. A negligible residue was obtained in the present study, implying that almost all the variation in mature yield in the present study could be accounted for by these variables. At the immature stage, number of latex vessel rows was found to exert the highest positive direct effect on yield, while bark thickness had a very high negative direct effect on yield. A residue of 0.33 indicates that other variables contributing to variability in yield at this stage have not been included. These could be the physiological parameters initial flow rate and final volume of latex, which were shown to be important contributors to mature yield variability.

Genetic divergence was assessed using the D^2 statistic and Tocher's method of clustering was employed to group the clones in the two stages. Seven and five clusters respectively were formed for the mature and immature groups of

clones. A great deal of similarity was found in the clustering pattern of the clones at the two stages, inspite of the difference in age and the variables used to compute the genetic distance. Most of the clones fell into one major group (Cluster I) with 18 and 19 clones respectively, of which 16 clones were in common. The clustering patterns of the remaining clones were also similar, with many of them being independent or forming two clone clusters. This indicates that though most of the clones were genetically close as they fell into one cluster, the remaining clones included in different clusters having divergence can be exploited in hybridization programmes.

The large number of variables in the two stages of growth were resolved into a few meaningful factors through principal component analysis. At the mature stage, 10 factors were identified which were principally associated with yield, stomatal density, latex biochemical components, initial flow rate, bark structural traits and chlorophyll content. These factors explained 88.41 per cent of the divergence observed in the clones. The nine factors identified at the immature stage were mainly associated with vigour, yield, chlorophyll content and leaf structural traits. These factors explained 85.24 per cent of the divergence.

The perfomance of the 25 clones at the two stages of growth was evaluated on the basis of indices formulated using discriminant function analysis. 19 and 15 variables respectively that contributed to the performance of the plants at the mature and immature stages were included. There was no correlation between the ranks of the clones at the two stages.

Correlations between immature attributes and corresponding mature attributes were carried out to identiy those traits that were relatively more stable as the plants aged. The results revealed that latex biochemical traits thiols, inorganic phosphorous, sucrose and magnesium, bark structural traits number of latex vessel rows, laticifer area index, stomatal density, density and diameter of latex vessels were relatively stable over the years, while morphological traits and yield appear to be the most affected with increase in age. Correlations between mature yield in the BI 2 panel and immature attributes of two year old plants revealed that the association with immature bark thickness and number of latex vessel rows were still retained at this age. Step wise regression of mature yield on immature attributes showed that number of latex vessel rows could explain only 21 per cent of the variability in mature yield. As no good fit was obtained, yield at this stage cannot be predicted using attributes of the first two years of growth.

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* Originals not seen

APPENDICES

Appendix A. Phenotypic correlations among traits of 25 clones at the mature stage

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.0000**	0.4720**	0.1383	-0.2783*	-0.0948	0.5875**	0.4980**	-0.0213	-0.2062
X2	0.4720**	1.0000**	-0.0821	-0.0070	-0.0989	0.2783*	0.2047	-0.0617	-0.0483
X3	0.1383	-0.0821	1.0000**	-0.4100**	-0.0394	0.2309*	0.0254	-0.1446	0.0514
X4	-0.2783*	-0.0070	-0.4100**	1.0000**	0.0514	-0.2462*	-0.2196	0.0510	0.2457*
X5	-0.0948	-0.0989	-0.0394	0.0514	1.0000**	-0.2153	0.0080	0.0659	-0.1579
X6	0.5875**	0.2783*	0.2309*	-0.2462*	-0.2153	1.0000**	0.5631**	-0.2931**	-0.0519
X7	0.4980**	0.2047	0.0254	-0.2196	0.0080	0.5631**	1.0000**	-0.1372	-0.0088
X8	-0.0213	-0.0617	-0.1446	0.0510	0.0659	-0.2931**	-0.1372	1.0000**	-0.1855
X9	-0.2062	-0.0483	0.0514	0.2457*	-0.1579	-0.0519	-0.0088	-0.1855	1.0000**
X10	0.6789**	0.3216**	0.0888	-0.1822	-0.1541	0.5632**	0.7930**	0.0211	0.3288**
X11	-0.2307*	-0.2177	0.2003	0.2017	0.0177	-0.1325	-0.0369	0.0993	0.1445
X12	-0.1394	-0.1333	0.1109	0.2266	0.1180	0.0295	-0.1248	-0.1497	0.0502
X13	0.1792	0.0251	0.3224**	0.1883	0.0656	0.1682	0.1222	-0.1924	0.1765
X14	0.6678**	0.4878**	-0.0529	-0.2027	-0.1517	0.3620**	0.3520**	-0.0264	-0.2193
X15	0.6322**	0.4845**	-0.0720	-0.1494	-0.2586*	0.3959**	0.4348**	-0.0083	-0.1578
X16	0.1745	0.1002	0.0529	-0.1104	0.1677	0.0539	-0.0378	-0.0201	-0.1202
X17	0.4129**	0.2377*	-0.1171	0.0038	0.1365	0.2869*	0.3218**	-0.0559	0.0672
X18	0.3840**	0.2166	0.0552	-0.1133	0.1910	0.3371**	0.3065**	-0.2559*	0.0637
X19	0.1299	0.1437	-0.0574	-0.1304	-0.0474	0.1656	0.1748	0.0084	0.0710
X20	-0.1708	-0.0268	-0.2427*	0.0914	0.1522	-0.0084	0.1689	-0.0390	0.1598
X21	0.1791	0.2700	-0.2625*	-0.0386	-0.1079	0.0509	0.1273	-0.1495	0.1342
X22	-0.2515*	-0.0923	-0.0874	0.1224	0.0353	-0.1704	-0.2720*	-0.0612	-0.1169
X23	-0.0503	-0.0909	-0.1146	-0.3785**	0.0285	-0.1270	-0.0464	0.2268	-0.1951
X24	0.0699	-0.0709	0.3052**	-0.4250**	0.0098	0.1978	0.1744	0.0511	-0.0155
X25	0.0005	-0.0984	0.0781	-0.4702**	0.0133	0.0216	0.0539	0.1831	-0.1336
X26	-0.0608	0.0059	-0.2913**	0.0420	0.0166	-0.2061	-0.1224	0.0815	-0.1427
X27	0.5966**	0.5317**	-0.1091	-0.1369	-0.0344	0.3529**	0.4862**	0.0996	-0.2113

(contd...)

X1 – Girth	X10 – Laticifer area index	X19- Latex thiols
X2 – Girth increment	X11 - Leaf midrib thickness	X20 – Inorganic phoshorous.
X3 – Leaf size	X12 - Leaf lamina thickness	X21 – Latex sucrose
X4 – Specific leaf weight	X13 - Leaf palisade layer thickness	X22 – Latexmagnesium
X5 – Stomatal density	X14 – Initial flow rate	X23 – Leaf chlorophyll a
X6 – Bark thickness	X15 - Final volume of latex	X24 – Chlorophyll b
X7 – No. latex vessel rows	X16 – Plugging index	X25 – Tot.chlorophyll
X8 – Dens. latex vessels	X17 – Dry rubber content	X26 – Chl.a:b ratio
X9 – Diameter. latex vessels	X18 – Total solids content	X27 – Average annual yield

Appendix A (contd...)

	X10	X11	X12	X13	X14	X15	X16	X17	X18
X1	0.6789**	-0.2307*	-0.1394	0.1792	0.6678**	0.6322**	0.1745	0.4129**	0.3840**
X2	0.3216**	-0.2177	-0.1333	0.0251	0.4878**	0.4845**	0.1002	0.2377*	0.2166
X3	0.0888	0.2003	0.1109	0.3224**	-0.0529	-0.0720	0.0529	-0.1171	0.0552
X4	-0.1822	0.2017	0.2266	0.1883	-0.2027	-0.1494	-0.1104	0.0038	-0.1133
X5	-0.1541	0.0177	0.1180	0.0656	-0.1517	-0.2586*	0.1677	0.1365	0.1910
X6	0.5632**	-0.1325	0.0295	0.1682	0.3620**	0.3959**	0.0539	0.2869*	0.3371**
X7	0.7930**	-0.0369	-0.1248	0.1222	0.3520**	0.4348**	-0.0378	0.3218**	0.3065**
X8	0.0211	0.0993	-0.1497	-0.1924	-0.0264	-0.0083	-0.0201	-0.0559	-0.2559*
X9	0.3288**	0.1445	0.0502	0.1765	-0.2193	-0.1578	-0.1202	0.0672	0.0637
X10	1.0000**	-0.0565	-0.1637	0.1872 *	0.4264**	0.4986**	-0.0018	0.3875**	0.3127**
X11	-0.0565	1.0000**	0.2300*	0.1974	-0.3144**	-0.2572*	-0.0574	-0.1851	-0.2289
X12	-0.1637	0.2300*	1.0000**	0.4936**	-0.1104	-0.0962	-0.0149	0.0224	-0.0200
X13	0.1872	0.1974	0.4936**	1.0000**	0.0233	0.0209	0.0540	0.0624	0.2286
X14	0.4264**	-0.3144**	-0.1104	0.0233	1.0000**	0.8238**	0.3490**	0.0580	0.1211
X15	0.4986**	-0.2572*	-0.0962	0.0209	0.8238**	1.0000**	-0.1987	0.0896	0.0814
X16	-0.0018	-0.0574	-0.0149	0.0540	0.3490**	-0.1987	1.0000**	-0.0278	0.1109
X17	0.3875**	-0.1851	0.0224	0.0624	0.0580	0.0896	-0.0278	1.0000**	0.7573**
X18	0.3127**	-0.2289	-0.0200	0.2286	0.1211	0.0814	0.1109	0.7573**	1.0000**
X19	0.2162	-0.0808	-0.1127	0.1182	0.1683	0.1561	0.0573	-0.0469	0.0388
X20	0.0618	0.0719	-0.0028	-0.0487	-0.1098	0.0827	-0.3293**	0.0098	-0.1257
X21	0.2460*	-0.0987	-0.4035**	-0.1404	0.2622*	0.1530	0.1545	0.1408	0.2241
X22	-0.3776**	0.0252	0.1305	-0.1221	-0.0042	-0.1077	0.0807	-0.1375	-0.1015
X23	-0.0834	-0.2228	0.0928	-0.1333	0.0029	-0.0651	0.1232	0.0454	0.0688
X24	0.1438	-0.1003	0.0400	0.0204	-0.0215	-0.0057	-0.0102	0.0480	0.1588
X25	0.0207	-0.2054	0.0716	-0.0800	-0.0116	-0.0501	0.0783	0.0621	0.1289
X26	-0.1517	-0.0582	0.0015	-0.1743	0.0139	-0.0553	0.1119	0.0293	-0.0772
X27	0.4908**	-0.1971	-0.0781	0.0554	0.6344**	0.8179**	-0.2142	0.1783	0.0673

(contd...)

X1 – Girth	X10 – Laticifer area index
X2 – Girth increment	X11 - Leaf midrib thickness
X3 – Leaf size	X12 - Leaf lamina thickness
X4 – Specific leaf weight	X13 - Leaf palisade layer thickness
X5 – Stomatal density	X14 – Initial flow rate
X6 – Bark thickness	X15 - Final volume of latex
X7 – No. latex vessel rows	X16 – Plugging index
X8 – Dens. latex vessels	X17 – Dry rubber content
X9 – Diameter. latex vessels	X18 – Total solids content

X19- Latex thiols
X20 – Inorganic phoshorous.
X21 – Latex sucrose
X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix A (contd...)

	X19	X20	X21	X22	X23	X24	X25	X26	X27
X1	0.1299	-0.1708	0.1791	-0.2515*	-0.0503	0.0699	0.0005	-0.0608	0.5966**
X2	0.1437	-0.0268	0.2700*	-0.0923	-0.0909	-0.0709	-0.0984	0.0059	0.5317**
X3	-0.0574	-0.2427*	-0.2625*	-0.0874	-0.1146	0.3052**	0.0781	-0.2913*	-0.1091
X4	-0.1304	0.0914	-0.0386	0.1224	-0.3785**	-0.4250**	-0.4702**	0.0420	-0.1369
X5	-0.0474	0.1522	-0.1079	0.0353	0.0285	0.0098	0.0133	0.0166	-0.0344
X6	0.1656	-0.0084	0.0509	-0.1704	-0.1270	0.1978	0.0216	-0.2061	0.3529**
X7	0.1748	0.1689	0.1273	-0.2720*	-0.0464	0.1744	0.0539	-0.1224	0.4862**
X8	0.0084	-0.0390	-0.1495	-0.0612	0.2268	0.0511	0.1831	0.0815	0.0996
X9	0.0710	0.1598	0.1342	-0.1169	-0.1951	-0.0155	-0.1336	-0.1427	-0.2113
X10	0.2162	0.0618	0.2460*	-0.3776**	-0.0834	0.1438	0.0207	-0.1517	0.4908**
X11	-0.0808	0.0719	-0.0987	0.0252	-0.2228	-0.1003	-0.2054	-0.0582	-0.1971
X12	-0.1127	-0.0028	-0.4035**	0.1305	0.0928	0.0400	0.0716	0.0015	-0.0781
X13	0.1182	-0.0487	-0.1404	-0.1221	-0.1333	0.0204	-0.0800	-0.1743	0.0554
X14	0.1683	-0.1098	0.2622*	-0.0042	0.0029	-0.0215	-0.0116	0.0139	0.6344**
X15	0.1561	0.0827	0.1530	-0.1077	-0.0651	-0.0057	-0.0501	-0.0553	0.8179**
X16	0.0573	-0.3293**	0.1545	0.0807	0.1232	-0.0102	0.0783	0.1119	-0.2142
X17	-0.0469	0.0098	0.1408	-0.1375	0.0454	0.0480	0.0621	0.0293	0.1783
X18	0.0388	-0.1257	0.2241*	-0.1015	0.0688	0.1588	0.1289	-0.0772	0.0673
X19	1.0000**	0.1955	0.0910	-0.2310*	0.1548	0.2323*	0.2213	-0.1547	0.2124
X20	0.1955	1.0000**	-0.0496	-0.0110	0.0704	0.1096	0.1004	-0.0360	0.2895*
X21	0.0910	-0.0496	1.0000**	-0.1031	-0.0572	-0.1993	-0.1216	0.1502	-0.0345
X22	-0.2310*	-0.0110	-0.1031	1.0000**	0.1553	0.1175	0.1537	-0.0287	-0.1498
X23	0.1548	0.0704	-0.0572	0.1553	1.0000**	0.4059**	0.8831**	0.3539**	0.0523
X24	0.2323*	0.1096	-0.1993	0.1175	0.4059**	1.0000**	0.7832**	-0.5936**	0.0388
X25	0.2213	0.1004	-0.1216	0.1537	0.8831**	0.7832**	1.0000**	-0.0640	0.0475
X26	-0.1547	-0.0360	0.1502	-0.0287	0.3539**	-0.5936**	-0.0640	1.0000**	-0.0170
X27	0.2124	0.2895*	-0.0345	-0.1498	0.0523	0.0388	0.0475	-0.0170	1.0000**

X1 – Girth
X2 – Girth increment
X3 – Leaf size
X4 – Specific leaf weight
X5 – Stomatal density
X6 – Bark thickness
X7 – No. latex vessel rows
X8 – Dens. latex vessels
X9 – Diameter. latex vessels

X10 – Laticifer area index
X11 - Leaf midrib thickness
X12 - Leaf lamina thickness
X13 - Leaf palisade layer thickness
X14 – Initial flow rate
X15 - Final volume of latex
X16 – Plugging index
X17 – Dry rubber content
X18 – Total solids content

X19- Latex thiols
X20 – Inorganic phoshorous.
X21 – Latex sucrose
X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix B. Genotypic correlations among traits of 25 clones at the mature stage

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.0000	0.8036	0.1138	-0.4735	-0.0131	0.5812	0.5319	0.1939	-0.42
X2	0.8036	1.0000	-0.1860	-0.5980	-0.0936	0.7080	1.1210	-0.0571	-0.17
X3	0.1138	-0.1860	1.0000	-0.5023	0.0011	0.3278	-0.0388	-0.6973	-0.62
X4	-0.4735	-0.5980	-0.5023	1.0000	0.0954	-0.4480	-0.5174	-0.0577	0.99
X5	-0.0131	-0.0936	0.0011	0.0954	1.0000	-0.1426	0.0255	-0.5140	-0.07
X6	0.5812	0.7080	0.3278	-0.4480	-0.1426	1.0000	0.7235	-0.2120	-0.26
X7	0.5319	1.1210	-0.0388	-0.5174	0.0255	0.7235	1.0000	-0.2806	-0.00
X8	0.1939	-0.0571	-0.6973	-0.0577	-0.5140	-0.2120	-0.2806	1.0000	-0.10
X9	-0.4296	-0.1781	-0.6225	0.9994	-0.0776	-0.2645	-0.0012	-0.1081	1.00
X10	0.7796	1.0139	-0.1494	-0.2811	-0.1677	0.6846	0.8620	-0.0071	0.10
X11	-0.4851	-0.4168	0.2441	0.4029	0.0654	-0.3231	-0.2861	0.4532	0.61
X12	-0.5107	-0.3348	0.1373	0.5146	0.3141	-0.1507	-0.4373	-0.2774	0.45
X13	0.1444	-0.1015	0.4504	0.1994	0.1960	0.3215	0.1950	-0.5630	0.35
X14	0.7195	0.8733	-0.2409	-0.4128	-0.0202	0.3522	0.7286	0.3262	-0.63
X15	0.6187	0.9380	-0.0712	-0.3053	-0.2458	0.4331	0.7398	0.4082	-0.42
X16	0.2042	-0.0962	-0.1339	-0.3114	0.4385	-0.0390	0.0019	-0.0331	-0.30
X17	0.4612	0.1284	-0.4699	0.2022	0.1144	0.2767	0.2272	-0.1107	0.33
X18	0.5761	0.2257	-0.1587	0.0135	0.3775	0.4138	0.3807	-0.2013	0.18
X19	0.3351	-0.1077	-0.1383	-0.2476	-0.1829	0.4159	0.7188	-0.3925	-0.17
X20	-0.3390	-0.1580	-0.5207	0.3974	0.2992	-0.0768	0.2681	0.2349	0.17
X21	0.4138	0.3422	-0.3055	-0.2360	-0.1776	0.1348	0.2915	0.0583	0.20
X22	-0.4158	-0.3686	-0.2391	0.2749	0.0667	-0.4164	-0.4500	0.0685	-0.62
X23	-0.0674	0.0500	-0.2474	-0.5212	0.0802	-0.0352	0.1941	-0.1633	-0.48
X24	0.0123	-0.2377	0.0080	-0.5005	0.0481	0.3961	0.2599	0.2380	-0.74
X25	-0.0319	-0.1132	-0.1173	-0.5520	0.0622	0.1778	0.2228	0.0165	-0.64
X26	-0.0335	0.3837	-0.2417	0.0773	0.2197	-0.6270	-0.0143	-0.6741	0.82
X27	0.5623	0.9222	-0.1529	-0.3008	0.0025	0.5357	0.8610	0.3002	-0.49

(contd...)

X1 – Girth	X10 – Laticifer area index	X19- Latex thiols
X2 – Girth increment	X11 - Leaf midrib thickness	X20 – Inorganic phoshorous.
X3 – Leaf size	X12 - Leaf lamina thickness	X21 – Latex sucrose
X4 – Specific leaf weight	X13 - Leaf palisade layer thickness	X22 – Latexmagnesium
X5 – Stomatal density	X14 – Initial flow rate	X23 – Leaf chlorophyll a
X6 – Bark thickness	X15 - Final volume of latex	X24 – Chlorophyll b
X7 – No. latex vessel rows	X16 – Plugging index	X25 – Tot.chlorophyll
X8 – Dens. latex vessels	X17 – Dry rubber content	X26 – Chl.a:b ratio
X9 – Diameter. latex vessels	X18 – Total solids content	X27 – Average annual yield

Appendix B. (contd...)

	X10	X11	X12	X13	X14	X15	X16	X17	X18
X1	0.7796	-0.4851	-0.5107	0.1444	0.7195	0.6187	0.2042	0.4612	0.5761
X2	1.0139	-0.4168	-0.3348	-0.1015	0.8733	0.9380	-0.0962	0.1284	0.2257
X3	-0.1494	0.2441	0.1373	0.4504	-0.2409	-0.0712	-0.1339	-0.4699	-0.1587
X4	-0.2811	0.4029	0.5146	0.1994	-0.4128	-0.3053	-0.3114	0.2022	0.0135
X5	-0.1677	0.0654	0.3141	0.1960	-0.0202	-0.2458	0.4385	0.1144	0.3775
X6	0.6846	-0.3231	-0.1507	0.3215	0.3522	0.4331	-0.0390	0.2767	0.4138
X7	0.8620	-0.2861	-0.4373	0.1950	0.7286	0.7398	0.0019	0.2272	0.3807
X8	-0.0071	0.4532	-0.2774	-0.5630	0.3262	0.4082	-0.0331	-0.1107	-0.2013
X9	0.1074	0.6130	0.4584	0.3582	-0.6374	-0.4290	-0.3008	0.3307	0.1867
X10	1.0000	-0.2177	-0.4163	0.2749	0.6980	0.7272	0.0227	0.4989	0.6751
X11	-0.2177	1.0000	0.1658	0.3502	-0.5257	-0.4351	-0.1025	-0.3776	-0.3239
X12	-0.4163	0.1658	1.0000	0.7410	-0.6762	-0.5584	-0.1011	0.0088	-0.0151
X13	0.2749	0.3502	0.7410	1.0000	-0.0894	-0.0105	-0.0393	0.1185	0.2641
X14	0.6980	-0.5257	-0.6762	-0.0894	1.0000	0.8707	0.2619	0.0075	0.1707
X15	0.7272	-0.4351	-0.5584	-0.0105	0.8707	1.0000	-0.2273	0.1059	0.2380
X16	0.0227	-0.1025	-0.1011	-0.0393	0.2619	-0.2273	1.0000	-0.1912	-0.1429
X17	0.4989	-0.3776	0.0088	0.1185	0.0075	0.1059	-0.1912	1.0000	0.9297
X18	0.6751	-0.3239	-0.0151	0.2641	0.1707	0.2380	-0.1429	0.9297	1.0000
X19	0.5070	0.0872	-0.1319	0.1839	0.4472	0.3506	0.1741	0.1157	0.1192
X20	-0.0426	0.0773	0.1163	-0.0098	-0.0967	0.1343	-0.4694	-0.0581	-0.1352
X21	0.5408	-0.1781	-0.4786	-0.1063	0.5464	0.3021	0.3601	0.2462	0.5276
X22	-0.7449	-0.0514	0.2441	-0.0351	-0.1061	-0.2417	0.0772	-0.2049	-0.2057
X23	-0.1209	-0.2704	0.2422	-0.3041	0.1270	0.1403	-0.0333	0.4410	0.2214
X24	-0.0137	-0.1645	0.2858	-0.0557	-0.0066	0.0884	-0.1882	0.0484	0.0904
X25	-0.0783	-0.2262	0.2875	-0.1925	0.0620	0.1210	-0.1175	0.2613	0.1680
X26	0.0734	-0.1836	-0.4934	-0.4271	0.0252	-0.0336	0.0924	0.5626	0.2561
X27	0.6479	-0.3084	-0.3623	-0.0441	0.7766	0.9112	-0.1553	0.2757	0.3581

(contd...)

X1 – Girth
X2 – Girth increment
X3 – Leaf size
X4 – Specific leaf weight
X5 – Stomatal density
X6 – Bark thickness
X7 – No. latex vessel rows
X8 – Dens. latex vessels
X9 – Diameter. latex vessels

X10 – Laticifer area index
X11 - Leaf midrib thickness
X12 - Leaf lamina thickness
X13 - Leaf palisade layer thickness
X14 – Initial flow rate
X15 - Final volume of latex
X16 – Plugging index
X17 – Dry rubber content
X18 – Total solids content

X19- Latex thiols
X20 – Inorganic phoshorous.
X21 – Latex sucrose
X22 – Latex magnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix B. (contd...)

	X19	X20	X21	X22	X23	X24	X25	X26	X27
X1	0.3351	-0.3390	0.4138	-0.4158	-0.0674	0.0123	-0.0319	-0.0335	0.5623
X2	-0.1077	-0.1580	0.3422	-0.3686	0.0500	-0.2377	-0.1132	0.3837	0.9222
X3	-0.1383	-0.5207	-0.3055	-0.2391	-0.2474	0.0080	-0.1173	-0.2417	-0.1529
X4	-0.2476	0.3974	-0.2360	0.2749	-0.5212	-0.5005	-0.5520	0.0773	-0.3008
X5	-0.1829	0.2992	-0.1776	0.0667	0.0802	0.0481	0.0622	0.2197	0.0025
X6	0.4159	-0.0768	0.1348	-0.4164	-0.0352	0.3961	0.1778	-0.6270	0.5357
X7	0.7188	0.2681	0.2915	-0.4500	0.1941	0.2599	0.2228	-0.0143	0.8610
X8	-0.3925	0.2349	0.0583	0.0685	-0.1633	0.2380	0.0165	-0.6741	0.3002
X9	-0.1703	0.1792	0.2062	-0.6264	-0.4874	-0.7469	-0.6470	0.8275	-0.4980
X10	0.5070	-0.0426	0.5408	-0.7449	-0.1209	-0.0137	-0.0783	0.0734	0.6479
X11	0.0872	0.0773	-0.1781	-0.0514	-0.2704	-0.1645	-0.2262	-0.1836	-0.3084
X12	-0.1319	0.1163	-0.4786	0.2441	0.2422	0.2858	0.2875	-0.4934	-0.3623
X13	0.1839	-0.0098	-0.1063	-0.0351	-0.3041	-0.0557	-0.1925	-0.4271	-0.0441
X14	0.4472	-0.0967	0.5464	-0.1061	0.1270	-0.0066	0.0620	0.0252	0.7766
X15	0.3506	0.1343	0.3021	-0.2417	0.1403	0.0884	0.1210	-0.0336	0.9112
X16	0.1741	-0.4694	0.3601	0.0772	-0.0333	-0.1882	-0.1175	0.0924	-0.1553
X17	0.1157	-0.0581	0.2462	-0.2049	0.4410	0.0484	0.2613	0.5626	0.2757
X18	0.1192	-0.1352	0.5276	-0.2057	0.2214	0.0904	0.1680	0.2561	0.3581
X19	1.0000	0.0786	0.2178	-0.5052	-0.0010	0.2733	0.1438	-0.6413	0.2578
X20	0.0786	1.0000	-0.1138	-0.1448	0.1462	0.0965	0.1277	-0.0273	0.2828
X21	0.2178	-0.1138	1.0000	-0.3273	0.1331	-0.2940	-0.0562	0.6096	0.0341
X22	-0.5052	-0.1448	-0.3273	1.0000	0.4980	0.2085	0.3636	-0.0551	-0.1843
X23	-0.0010	0.1462	0.1331	0.4980	1.0000	0.7911	0.9589	-0.1545	0.1965
X24	0.2733	0.0965	-0.2940	0.2085	0.7911	1.0000	0.9331	-0.7339	0.1527
X25	0.1438	0.1277	-0.0562	0.3636	0.9589	0.9331	1.0000	-0.4278	0.1742
X26	-0.6413	-0.0273	0.6096	-0.0551	-0.1545	-0.7339	-0.4278	1.0000	0.0103
X27	0.2578	0.2828	0.0341	-0.1843	0.1965	0.1527	0.1742	0.0103	1.0000

X1 – Girth
X2 – Girth increment
X3 – Leaf size
X4 – Specific leaf weight
X5 – Stomatal density
X6 – Bark thickness
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X8 – Dens. latex vessels
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X10 – Laticifer area index
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X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix C. Error correlation matrix for traits of 25 clones at the mature stage

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1.0000**	0.2735	0.1669	-0.1076	-0.2055	0.5987**	0.5021**	-0.1223	-0.1089
X2	0.2735	1.0000**	-0.0348	0.2790*	-0.1105	0.0222	-0.1872	-0.0641	-0.0099
X3	0.1669	-0.0348	1.0000	-0.3560*	-0.0756	0.1618	0.0588	0.0041	0.2961*
X4	-0.1076	0.2790	-0.3560*	1.0000**	0.0134	-0.0877	-0.0571	0.0866	-0.0332
X5	-0.2055	-0.1105	-0.0756	0.0134	1.0000**	-0.3009*	-0.0054	0.3291*	-0.2234
X6	0.5987**	0.0222	0.1618	-0.0877	-0.3009*	1.0000**	0.4663**	-0.3661*	0.0483
X7	0.5021**	-0.1872	0.0588	-0.0571	-0.0054	0.4663**	1.0000**	-0.1048	-0.0115
X8	-0.1223	-0.0641	0.0041	0.0866	0.3291*	-0.3661**	-0.1048	1.0000**	-0.2006
X9	-0.1089	-0.0099	0.2961*	-0.0332	-0.2234	0.0483	-0.0115	-0.2006	1.0000**
X10	0.5953**	-0.0361	0.2410	-0.1160	-0.1441	0.4614**	0.7581**	0.0320	0.4360**
X11	0.1858	-0.0814	0.1747	-0.0011	-0.0578	0.1343	0.1996	-0.0564	-0.1371
X12	0.2946*	-0.0163	0.0931	0.0050	-0.1029	0.2118	0.0873	-0.1214	-0.1409
X13	0.2329	0.1285	0.2228	0.1887	-0.1262	-0.0313	0.0678	-0.0609	0.0966
X14	0.6066**	0.2670	0.0925	-0.0335	-0.3091*	0.3725**	0.0903	-0.1698	-0.0301
X15	0.6528**	0.1890	-0.0774	-0.0037	-0.2774	0.3528*	0.2041	-0.2076	-0.0210
X16	0.1457	0.2130	0.1804	0.0332	-0.1115	0.1405	-0.0634	-0.0177	-0.0481
X17	0.3701**	0.3039*	0.1180	-0.1360	0.1611	0.2974*	0.3845**	-0.0427	-0.0431
X18	0.2829*	0.2133	0.1523	-0.1750	0.0780	0.3075*	0.2762	-0.2736	0.0281
X19	-0.1147	0.3067*	0.0025	-0.0392	0.1087	-0.0928	-0.2026	0.1627	0.1953
X20	0.0590	0.0641	-0.0139	-0.1832	-0.0413	0.0722	0.0989	-0.1662	0.1710
X21	-0.2184	0.2524	-0.2456	0.1809	0.0048	-0.0707	-0.0200	-0.3115*	0.1176
X22	-0.0909	0.0518	0.0095	0.0197	0.0052	0.0442	-0.1679	-0.1085	0.0889
X23	-0.0389	-0.1527	-0.0443	-0.2994*	-0.0119	-0.1972	-0.1652	0.3413*	-0.0983
X24	0.1374	0.0266	0.5271**	-0.3712**	-0.0328	-0.0004	0.1203	-0.0117	0.3294*
X25	0.0397	-0.0940	0.2290	-0.4117**	-0.0437	-0.1417	-0.0647	0.2736	0.1079
X26	-0.0854	-0.0992	-0.3174*	0.0311	-0.0860	-0.0335	-0.1592	0.2110	-0.3551*
X27	0.6418**	0.3088	-0.0774	-0.0034	-0.0789	0.1557	0.2287	0.0349	-0.0870

(contd...)

X1 – Girth
X2 – Girth increment
X3 – Leaf size
X4 – Specific leaf weight
X5 – Stomatal density
X6 – Bark thickness
X7 – No. latex vessel rows
X8 – Dens. latex vessels
X9 – Diameter. latex vessels

X10 – Laticifer area index
X11 - Leaf midrib thickness
X12 - Leaf lamina thickness
X13 - Leaf palisade layer thickness
X14 – Initial flow rate
X15 - Final volume of latex
X16 – Plugging index
X17 – Dry rubber content
X18 – Total solids content

X19- Latex thiols
X20 – Inorganic phoshorous.
X21 – Latex sucrose
X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix C. (contd...)

	X10	X11	X12	X13	X14	X15	X16	X17	X18
X1	0.5953**	0.1858	0.2946*	0.2329	0.6066**	0.6528**	0.1457	0.3701**	0.2829*
X2	-0.0361	-0.0814	-0.0163	0.1285	0.2670	0.1890	0.2130	0.3039*	0.2133
X3	0.2410	0.1747	0.0931	0.2228	0.0925	-0.0774	0.1804	0.1180	0.1523
X4	-0.1160	-0.0011	0.0050	0.1887	-0.0335	-0.0037	0.0332	-0.1360	-0.1750
X5	-0.1441	-0.0578	-0.1029	-0.1262	-0.3091*	-0.2774	-0.1115	0.1611	0.0780
X6	0.4614**	0.1343	0.2118	-0.0313	0.3725**	0.3528*	0.1405	0.2974*	0.3075*
X7	0.7581**	0.1996	0.0873	0.0678	0.0903	0.2041	-0.0634	0.3845**	0.2762
X8	0.0320	-0.0564	-0.1214	-0.0609	-0.1698	-0.2076	-0.0177	-0.0427	-0.2736
X9	0.4360**	-0.1371	-0.1409	0.0966	-0.0301	-0.0210	-0.0481	-0.0431	0.0281
X10	1.0000**	0.1310	0.0489	0.0991	0.1881	0.2729	-0.0208	0.3025*	0.1319
X11	0.1310	1.0000**	0.3257*	-0.0759	-0.0154	0.0513	-0.0033	0.0442	-0.1856
X12	0.0489	0.3257*	1.0000**	0.1876	0.4747**	0.4752**	0.0628	0.0346	-0.0239
X13	0.0991	-0.0759	0.1876	1.0000**	0.1754	0.0716	0.1653	0.0000	0.2300
X14	0.1881	-0.0154	0.4747**	0.1754	1.0000**	0.7701**	0.4335**	0.1055	0.0969
X15	0.2729	0.0513	0.4752**	0.0716	0.7701**	1.0000**	-0.1716	0.0740	-0.0278
X16	-0.0208	-0.0033	0.0628	0.1653	0.4335**	-0.1716	1.0000**	0.1053	0.2539
X17	0.3025*	0.0442	0.0346	0.0000	0.1055	0.0740	0.1053	1.0000**	0.6845**
X18	0.1319	-0.1856	-0.0239	0.2300	0.0969	-0.0278	0.2539	0.6845**	1.0000**
X19	-0.0332	-0.3188*	-0.0935	0.0347	-0.1259	-0.0878	-0.0499	-0.1940	-0.0083
X20	0.1660	0.0640	-0.1387	-0.1068	-0.1259	0.0084	-0.1869	0.0800	-0.1298
X21	-0.0975	0.0596	-0.3133*	-0.2040	-0.1566	-0.1142	-0.1052	0.0142	0.0000
X22	-0.1082	0.1180	0.0345	-0.2239	0.0871	0.0324	0.0834	-0.0858	-0.0495
X23	-0.0612	-0.2011	-0.0101	0.0117	-0.0891	-0.2528	0.2259	-0.2056	0.0035
X24	0.2760	-0.0167	-0.1980	0.1169	-0.0367	-0.1211	0.1483	0.0477	0.2062
X25	0.1074	-0.1816	-0.1469	0.0672	-0.0902	-0.2698	0.2608	-0.1199	0.1115
X26	-0.2473	0.0060	0.2232	-0.0630	0.0101	-0.0782	0.1281	-0.1847	-0.1691
X27	0.3542*	-0.0383	0.2189	0.1917	0.4775**	0.7011**	-0.2720	0.0874	-0.1144

(contd...)

X1 – Girth	X10 – Laticifer area index
X2 – Girth increment	X11 - Leaf midrib thickness
X3 – Leaf size	X12 - Leaf lamina thickness
X4 – Specific leaf weight	X13 - Leaf palisade layer thickness
X5 – Stomatal density	X14 – Initial flow rate
X6 – Bark thickness	X15 - Final volume of latex
X7 – No. latex vessel rows	X16 – Plugging index
X8 – Dens. latex vessels	X17 – Dry rubber content
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X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix C. (contd...)

	X19	X20	X21	X26	X22	X23	X24	X25	X27
X1	-0.1147	0.0590	-0.2184	-0.0909	-0.0389	0.1374	0.0397	-0.0854	0.6418 **
X2	0.3067 *	0.0641	0.2524	0.0518	-0.1527	0.0266	-0.0940	-0.0992	0.3088 *
X3	0.0025	-0.0139	-0.2456	0.0095	-0.0443	0.5271 **	0.2290	-0.3174 *	-0.0774
X4	-0.0392	-0.1832	0.1809	0.0197	-0.2994 *	-0.3712 **	-0.4117 **	0.0311	-0.0034
X5	0.1087	-0.0413	0.0048	0.0052	-0.0119	-0.0328	-0.0437	-0.0860	-0.0789
X6	-0.0928	0.0722	-0.0707	0.0442	-0.1972	-0.0004	-0.1417	-0.0335	0.1557
X7	-0.2026	0.0989	-0.0200	-0.1679	-0.1652	0.1203	-0.0647	-0.1592	0.2287
X8	0.1627	-0.1662	-0.3115 *	-0.1085	0.3413 *	-0.0117	0.2736	0.2110	0.0349
X9	0.1953	0.1710	0.1176	0.0889	-0.0983	0.3294 *	0.1079	-0.3551	-0.0870
X10	-0.0332	0.1660	-0.0975	-0.1082	-0.0612	0.2760	0.1074	-0.2473	0.3542 *
X11	-0.3188 *	0.0640	0.0596	0.1180	-0.2011	-0.0167	-0.1816	0.0060	-0.0383
X12	-0.0935	-0.1387	-0.3133 *	0.0345	-0.0101	-0.1980	-0.1469	0.2232	0.2189
X13	0.0347	-0.1068	-0.2040	-0.2239	0.0117	0.1169	0.0672	-0.0630	0.1917
X14	-0.1259	-0.1259	-0.1566	0.0871	-0.0891	-0.0367	-0.0902	0.0101	0.4775 **
X15	-0.0878	0.0084	-0.1142	0.0324	-0.2528	-0.1211	-0.2698	-0.0782	0.7011 **
X16	-0.0499	-0.1869	-0.1052	0.0834	0.2259	0.1483	0.2608	0.1281	-0.2720
X17	-0.1940	0.0800	0.0142	-0.0858	-0.2056	0.0477	-0.1199	-0.1847	0.0874
X18	-0.0083	-0.1298	0.0000	-0.0495	0.0035	0.2062	0.1115	-0.1691	-0.1144
X19	1.0000 **	0.3324 *	-0.0897	0.0053	0.2704	0.1918	0.3014	0.0516	0.1640
X20	0.3324 *	1.0000 **	0.0559	0.1213	0.0122	0.1251	0.0686	-0.0461	0.2983 *
X21	-0.0897	0.0559	1.0000 **	0.1658	-0.2585	-0.0748	-0.2219	-0.1076	-0.1395
X22	0.0053	0.1213	0.1658	1.0000 **	-0.0525	0.0416	-0.0295	-0.0201	-0.1200
X23	0.2704	0.0122	-0.2585	-0.0525	1.0000 **	0.1469	0.8529 **	0.5261 **	-0.0540
X24	0.1918	0.1251	-0.0748	0.0416	0.1469	1.0000 **	0.6336 **	-0.5866 **	-0.0789
X25	0.3014 *	0.0686	-0.2219	-0.0295	0.8529 **	0.6336 **	1.0000 **	0.0975	-0.0893
X26	0.0516	-0.0461	-0.1076	-0.0201	0.5261 **	-0.5866 **	0.0975	1.0000 **	-0.0321
X27	0.1640	0.2983 *	-0.1395	-0.1200	-0.0540	-0.0789	-0.0893	-0.0321	1.0000 **

X1 – Girth
X2 – Girth increment
X3 – Leaf size
X4 – Specific leaf weight
X5 – Stomatal density
X6 – Bark thickness
X7 – No. latex vessel rows
X8 – Dens. latex vessels
X9 – Diameter. latex vessels

X10 – Laticifer area index
X11 - Leaf midrib thickness
X12 - Leaf lamina thickness
X13 - Leaf palisade layer thickness
X14 – Initial flow rate
X15 - Final volume of latex
X16 – Plugging index
X17 – Dry rubber content
X18 – Total solids content

X19- Latex thiols
X20 – Inorganic phoshorous.
X21 – Latex sucrose
X22 – Latexmagnesium
X23 – Leaf chlorophyll a
X24 – Chlorophyll b
X25 – Tot.chlorophyll
X26 – Chl.a:b ratio
X27 – Average annual yield

Appendix D. (contd)

	14	15	16	17	18	19	20	21	22	23	24	25
1	45.031	35.338	31.761	32.196	47.276	49.245	34.481	45.850	49.114	36.217	68.281	25.081
2	64.439	33.772	42.963	27.008	42.956	49.702	26.190	56.707	27.085	29.571	74.577	46.652
3	63.073	21.057	32.054	13.691	38.176	19.273	23.422	47.145	32.848	38.459	40.223	28.993
4	58.093	19.649	23.262	16.223	31.736	31.841	14.378	46.515	24.854	35.973	49.095	26.996
5	50.329	53.364	52.717	48.387	53.893	111.074	46.578	95.955	55.310	37.768	144.402	59.132
6	66.768	41.920	35.577	54.013	55.953	82.250	50.211	33.407	66.435	41.859	115.210	69.756
7	52.560	18.260	24.193	20.796	47.509	42.211	31.080	41.306	22.784	14.495	72.357	22.835
8	43.498	38.970	34.937	16.802	10.435	33.539	16.610	46.109	33.876	56.051	39.944	24.026
9	77.090	82.744	72.619	87.620	58.690	137.409	52.547	92.089	92.718	87.170	147.040	99.856
10	44.050	42.004	23.890	18.886	32.269	57.479	22.210	42.375	36.593	34.609	81.552	25.186
11	32.874	27.230	28.883	8.061	28.471	37.385	22.050	33.991	33.672	23.765	57.288	15.502
12	60.942	44.800	42.517	44.489	45.155	97.391	46.003	72.394	47.723	42.197	130.529	63.190
13	56.162	66.515	47.018	56.681	54.880	115.137	52.631	59.610	47.396	31.854	141.418	58.802
14	0.000	72.900	52.705	40.581	27.140	103.529	43.050	59.250	73.159	37.532	124.434	37.059
15	72.900	0.000	25.210	27.957	45.050	53.641	26.610	38.420	22.336	38.181	73.381	41.938
16	52.705	25.210	0.000	26.322	31.043	53.789	26.850	32.699	37.164	33.793	83.166	23.729
17	40.581	27.957	26.322	0.000	25.614	31.352	15.624	47.646	28.854	36.981	53.854	17.285
18	27.140	45.050	31.043	25.614	0.000	56.691	17.672	40.064	38.469	50.007	61.578	29.704
19	103.529	53.641	53.789	31.352	56.691	0.000	48.014	66.227	44.603	76.962	20.048	35.501
20	43.050	26.610	26.850	15.624	17.672	48.014	0.000	46.762	28.106	42.353	52.070	30.816
21	59.250	38.420	32.699	47.646	40.064	66.227	46.762	0.000	48.132	46.310	80.588	48.801
22	73.159	22.336	37.164	28.854	38.469	44.603	28.106	48.132	0.000	38.500	58.333	37.135
23	37.532	38.181	33.793	36.981	50.007	76.962	42.353	46.310	38.500	0.000	110.400	38.203
24	124.434	73.381	83.166	53.854	61.578	20.048	52.070	80.588	58.333	110.400	0.000	58.997
25	37.059	41.938	23.729	17.285	35.501	30.816	30.816	48.801	37.135	38.203	58.997	0.000

Appendix D. D² values for mature clones

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.000	53.571	25.707	28.627	60.879	39.003	24.667	42.716	77.427	52.642	23.815	60.969	93.908
2	53.571	0.000	24.522	22.546	34.263	56.644	27.824	39.668	81.454	35.407	29.519	43.982	52.306
3	25.707	24.522	0.000	8.716	55.178	43.342	15.710	26.856	87.713	37.670	16.631	49.038	84.126
4	28.627	22.546	8.716	0.000	42.258	42.965	15.862	25.015	71.468	32.085	22.654	40.335	65.759
5	60.879	34.263	55.178	42.258	0.000	69.813	43.573	63.149	56.770	60.972	52.555	18.336	69.887
6	39.003	56.644	43.342	42.965	69.813	0.000	44.614	65.828	63.762	62.931	51.763	37.357	86.406
7	24.667	27.824	15.710	15.862	43.573	44.614	0.000	38.184	90.783	31.829	16.015	44.541	50.728
8	42.716	39.668	26.856	25.015	63.149	65.828	38.184	0.000	77.969	39.498	20.505	58.315	73.300
9	77.427	81.454	87.713	71.468	56.770	63.762	90.783	77.969	0.000	82.658	91.575	49.636	106.907
10	52.642	35.407	37.670	32.085	60.972	62.931	31.829	39.498	82.658	0.000	22.365	56.997	22.951
11	23.815	29.519	16.631	22.654	52.555	51.763	16.015	20.505	91.575	22.365	0.000	53.244	52.271
12	60.969	43.982	49.038	40.335	18.336	57.357	44.541	58.315	49.636	56.997	53.244	0.000	70.343
13	93.908	52.306	84.126	65.759	69.887	86.406	50.728	73.300	106.907	22.951	52.271	70.343	0.000
14	45.031	64.439	63.073	58.093	50.329	66.768	52.560	43.498	77.090	44.050	32.874	60.942	56.162
15	35.338	33.772	21.057	19.649	53.364	41.920	18.260	38.970	82.744	42.004	27.230	44.800	66.515
16	31.761	42.963	32.054	23.262	52.717	35.577	24.193	34.937	72.619	23.890	28.883	42.517	47.018
17	32.196	27.008	13.691	16.223	48.387	54.013	20.796	16.802	87.620	18.886	8.061	44.489	56.681
18	47.276	42.956	38.176	31.736	53.893	55.953	47.509	10.435	58.690	32.269	28.471	45.155	54.880
19	49.245	49.702	19.273	31.841	111.074	82.250	42.211	33.539	137.409	57.479	37.385	97.391	115.137
20	34.481	26.190	23.422	14.378	46.578	50.211	31.080	16.610	52.547	22.210	22.050	46.003	52.631
21	45.850	56.707	47.145	46.515	95.955	33.407	41.306	46.109	92.089	42.375	33.991	72.394	59.610
22	49.114	27.085	32.848	24.854	55.310	66.435	22.784	33.876	92.718	36.593	33.672	47.723	47.396
23	36.217	29.571	38.459	35.973	37.768	41.859	14.495	56.051	87.170	34.609	23.765	42.197	31.854
24	68.281	74.577	40.223	49.095	144.402	115.210	72.357	39.944	147.040	81.552	57.288	130.529	141.418
25	25.081	46.652	28.993	26.996	59.132	69.756	22.835	24.026	99.856	25.186	15.502	63.190	58.802

(contd...)

Appendix E. Phenotypic correlation matrix of 34 variables for clones at the immature stage

		First year parameters							Second year	
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
Sprt. week	Y1	1.0000**	-0.3268**	0.3218**	-0.2345*	-0.0028	-0.3750**	-0.3288**	-0.2625*	-0.4023**
Height	Y2	-0.3268**	1.0000**	-0.1521	0.6550**	0.5449**	0.3099**	0.8267**	0.6791**	0.5918**
Sc. diameter (1)	Y3	0.3218**	-0.1521	1.0000**	-0.1781	0.0495	-0.3556**	-0.0813	0.0463	-0.6557**
Whrls prd.(W1)	Y4	-0.2345*	0.6550**	-0.1781	1.0000**	0.7878**	0.5338**	0.7586**	0.4278**	0.4300**
Whrls ret.(W2)	Y5	-0.0028	0.5449**	0.0495	0.7878**	1.0000**	-0.1004	0.7044**	0.3753**	0.2203
Whrls shd(W3)	Y6	-0.3750**	0.3099**	-0.3556**	0.5338**	-0.1004	1.0000**	0.2584*	0.1758	0.3922**
Leaves prod.	Y7	-0.3288**	0.8267**	-0.0813	0.7586**	0.7044**	0.2584*	1.0000**	0.7016**	0.5681**
Sc. diameter (2)	Y8	-0.2625*	0.6791**	0.0463	0.4278**	0.3753**	0.1758	0.7016**	1.0000**	0.6961**
Dia. increment	Y9	-0.4023**	0.5918**	-0.6557**	0.4300**	0.2203	0.3922**	0.5681**	0.6961**	1.0000**
Whorls (W4)	Y10	0.2652*	0.3034**	0.1251	0.4447**	0.5763**	-0.0728	0.4211**	0.3318**	0.1438
Whorls (W5)	Y11	-0.2233	0.7244**	-0.0826	0.5037**	0.5040**	0.1216	0.6825**	0.6096**	0.4892**
Whorls (W6)	Y12	0.1524	0.0132	0.1731	-0.0702	0.1743	-0.3525**	0.1075	0.3332**	0.1259
Whorls (W7)	Y13	-0.2969**	0.6984**	-0.1008	0.4032**	0.4119**	0.0858	0.6445**	0.6307**	0.5198**
Whorls (W8)	Y14	0.0259	0.5582**	-0.0264	0.8411**	0.7990**	0.2617*	0.6887**	0.4453**	0.3331**
Leaf size	Y15	0.0712	-0.0338	-0.1763	0.2196	0.3228**	-0.0884	0.0360	0.0071	0.1355
SLW	Y16	-0.0073	0.1886	-0.1570	0.2587*	0.2388*	0.0901	0.1203	0.0876	0.1522
Stom. density	Y17	0.1000	-0.2243	0.1146	-0.2202	-0.1482	-0.1521	-0.1972	-0.1919	-0.2059
Bark thk.	Y18	-0.0760	0.2183	0.1010	0.1831	0.2244	-0.0123	0.3087**	0.4086**	0.2827*
No.LV rows	Y19	0.0068	-0.0328	0.1206	-0.1988	-0.0731	-0.2208	-0.0570	0.2088	0.1051
Density of LV	Y20	0.0005	-0.1424	-0.0210	0.0010	-0.0702	0.0980	-0.0812	-0.1525	-0.0994
Diameter of LV	Y21	-0.0244	0.0202	0.0155	0.0956	-0.0070	0.1641	-0.0137	0.0960	0.0551
Lat. area index	Y22	-0.0840	0.1830	0.1155	-0.0193	0.0201	-0.0587	0.1384	0.5343**	0.3271**
Midrib thick.	Y23	0.2277	0.0219	0.1764	0.1792	0.3142**	-0.1418	0.0741	0.0091	-0.0838
Lamina.thick.	Y24	0.1929	0.0312	-0.0327	0.2324*	0.3397**	-0.0910	-0.0329	-0.1634	-0.1189
Palisade thick.	Y25	0.0756	0.0393	0.0669	0.0899	0.1231	-0.0237	-0.1102	-0.0430	-0.1002
Latex thiols	Y26	-0.0354	-0.0935	0.2295	-0.2852*	-0.2375*	-0.1346	0.0002	0.1580	-0.0004
In. phoshorous	Y27	-0.0431	0.1085	0.0586	0.2064	0.2645*	-0.0297	0.2117	0.2190	0.1327
Latex sucrose	Y28	-0.0555	0.1211	-0.0265	-0.0596	-0.0164	-0.0737	0.0691	0.2499*	0.1831
Ltx.magnesium	Y29	0.1304	-0.0030	-0.1607	0.0070	0.0029	0.0072	-0.0534	0.0477	0.1647
Chlorophyll a	Y30	-0.0814	0.1452	0.0843	0.0792	-0.0047	0.1343	0.1988	0.3138**	0.1935
Chlorophyll b	Y31	-0.0759	0.1233	0.1339	0.1438	0.0038	0.2272	0.2066	0.2671*	0.1215
Tot chlorophyll	Y32	-0.0820	0.1397	0.1002	0.0973	-0.0066	0.1663	0.2036	0.3063**	0.1772
Chl a:b ratio	Y33	0.0623	0.0447	-0.0787	-0.1387	0.0401	-0.2791*	-0.0293	0.0657	0.1005
Juvenile yield	Y34	-0.0226	0.0516	0.1261	0.0794	0.0879	0.0076	0.1789	0.5086**	0.3016**

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix E. (contd...)

		Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18
Sprt. week	Y1	0.2652*	-0.2233	0.1524	-0.2969**	0.0259	0.0712	-0.0073	0.1000	-0.0760
Height	Y2	0.3034**	0.7244**	0.0132	0.6984**	0.5582**	-0.0338	0.1886	-0.2243	0.2183
Sc. diameter (1)	Y3	0.1251	-0.0826	0.1731	-0.1008	-0.0264	-0.1763	-0.1570	0.1146	0.1010
Whrls prd.(W1)	Y4	0.4447**	0.5037**	-0.0702	0.4032**	0.8411**	0.2196	0.2587*	-0.2202	0.1831
Whrls ret.(W2)	Y5	0.5763**	0.5040**	0.1743	0.4119**	0.7990**	0.3228**	0.2388*	-0.1482	0.2244
Whrls shd(W3)	Y6	-0.0728	0.1216	-0.3525**	0.0858	0.2617*	-0.0884	0.0901	-0.1521	-0.0123
Leaves prod.	Y7	0.4211**	0.6825**	0.1075	0.6445**	0.6887**	0.0360	0.1203	-0.1972	0.3087**
Sc. diameter (2)	Y8	0.3318**	0.6096**	0.3332**	0.6307**	0.4453**	0.0071	0.0876	-0.1919	0.4086**
Dia. increment	Y9	0.1438	0.4892**	0.1259	0.5198**	0.3331**	0.1355	0.1522	-0.2059	0.2827*
Whorls (W4)	Y10	1.0000**	0.3966**	0.5444**	0.2337*	0.8585**	0.1895	0.1548	-0.1192	0.2427*
Whorls (W5)	Y11	0.3966**	1.0000**	0.0617	0.9688**	0.5279**	-0.0298	-0.0475	-0.1756	0.1214
Whorls (W6)	Y12	0.5444**	0.0617	1.0000**	0.1029	0.2886*	0.1558	0.0920	0.1184	0.1780
Whorls (W7)	Y13	0.2337*	0.9688**	0.1029	1.0000**	0.3720**	-0.0591	-0.0791	-0.1271	0.0985
Whorls (W8)	Y14	0.8585**	0.5279**	0.2886*	0.3720**	1.0000**	0.2402*	0.2416*	-0.1980	0.2514*
Leaf size	Y15	0.1895	-0.0298	0.1558	-0.0591	0.2402*	1.0000**	0.3957**	-0.0745	0.2160
SLW	Y16	0.1548	-0.0475	0.0920	-0.0791	0.2416*	0.3957**	1.0000**	-0.2090	0.3375**
Stom. density	Y17	-0.1192	-0.1756	0.1184	-0.1271	-0.1980	-0.0745	-0.2090	1.0000**	-0.0820
Bark thk.	Y18	0.2427*	0.1214	0.1780	0.0985	0.2514*	0.2160	0.3375**	-0.0820	1.0000**
No.LV rows	Y19	0.0962	-0.1510	0.2121	-0.1580	-0.0557	0.1049	0.2258	-0.0754	0.5404**
Density of LV	Y20	-0.0674	-0.0684	-0.0928	-0.0588	-0.0401	-0.0889	-0.1354	-0.0293	-0.2567*
Diameter of LV	Y21	0.1104	0.2180	-0.1253	0.1864	0.1214	-0.1543	-0.0871	-0.0170	-0.0316
Lat. area index	Y22	0.2269	0.1722	0.2527*	0.1697	0.1260	0.0355	0.1792	-0.1407	0.5109**
Midrib thick.	Y23	0.2154	0.0275	0.0948	-0.0225	0.2327*	0.3887**	0.3937**	-0.1740	0.3838**
Lamina.thick.	Y24	0.1279	-0.1029	-0.0293	-0.1484	0.2103	0.4023**	0.4159**	-0.0906	0.0450
Palisade thick.	Y25	0.0127	-0.1459	0.0445	-0.1464	0.0592	0.4921**	0.4283**	-0.0040	0.0976
Latex thiols	Y26	-0.1502	-0.1288	0.1704	-0.0512	-0.2540*	-0.2032	0.1154	0.1657	0.3241**
In. phoshorous	Y27	0.2971**	0.1872	0.2844**	0.1788	0.2976**	0.1024	0.2045	0.1737	0.4470**
Latex sucrose	Y28	-0.0241	0.1173	0.1454	0.1636	-0.0486	-0.1454	-0.0934	0.0784	-0.0577
Ltx.magnesium	Y29	0.1554	-0.0936	0.2671*	-0.0953	0.0978	0.2508*	0.3294**	-0.0138	0.1645
Chlorophyll a	Y30	0.0190	0.0906	-0.0499	0.0875	0.0568	-0.3351**	-0.0354	-0.2004	-0.0188
Chlorophyll b	Y31	0.0987	0.0883	-0.0907	0.0544	0.1420	-0.3522**	-0.0743	-0.3379**	-0.0861
Tot chlorophyll	Y32	0.0384	0.0867	-0.0609	0.0757	0.0789	-0.3471**	-0.0471	-0.2455*	-0.0370
Chl a:b ratio	Y33	-0.1014	0.0267	0.1625	0.0874	-0.1406	0.1570	0.0948	0.4071**	0.2181
Juvenile yield	Y34	0.2096	0.1339	0.2928**	0.1472	0.1720	0.2109	0.1481	-0.0586	0.4128**

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix E. (contd...)

Traits		Y19	Y20	Y21	Y22	Y23	Y24	Y25	Y26
Sprt. week	Y1	0.0068	0.0005	-0.0244	-0.0840	0.2277	0.1929	0.0756	-0.0354
Height	Y2	-0.0328	-0.1424	0.0202	0.1830	0.0219	0.0312	0.0393	-0.0935
Sc. diameter (1)	Y3	0.1206	-0.0210	0.0155	0.1155	0.1764	-0.0327	0.0669	0.2295
Whrls prd.(W1)	Y4	-0.1988	0.0010	0.0956	-0.0193	0.1792	0.2324*	0.0899	-0.2852*
Whrls ret.(W2)	Y5	-0.0731	-0.0702	-0.0070	0.0201	0.3142**	0.3397**	0.1231	-0.2375*
Whrls shd(W3)	Y6	-0.2208	0.0980	0.1641	-0.0587	-0.1418	-0.0910	-0.0237	-0.1346
Leaves prod.	Y7	-0.0570	-0.0812	-0.0137	0.1384	0.0741	-0.0329	-0.1102	0.0002
Sc. diameter (2)	Y8	0.2088	-0.1525	0.0960	0.5343**	0.0091	-0.1634	-0.0430	0.1580
Dia. increment	Y9	0.1051	-0.0994	0.0551	0.3271**	-0.0838	-0.1189	-0.1002	-0.0004
Whorls (W4)	Y10	0.0962	-0.0674	0.1104	0.2269	0.2154	0.1279	0.0127	-0.1502
Whorls (W5)	Y11	-0.1510	-0.0684	0.2180	0.1722	0.0275	-0.1029	-0.1459	-0.1288
Whorls (W6)	Y12	0.2121	-0.0928	-0.1253	0.2527*	0.0948	-0.0293	0.0445	0.1704
Whorls (W7)	Y13	-0.1580	-0.0588	0.1864	0.1697	-0.0225	-0.1484	-0.1464	-0.0512
Whorls (W8)	Y14	-0.0557	-0.0401	0.1214	0.1260	0.2327*	0.2103	0.0592	-0.2540*
Leaf size	Y15	0.1049	-0.0889	-0.1543	0.0355	0.3887**	0.4023**	0.4921**	-0.2032
SLW	Y16	0.2258	-0.1354	-0.0871	0.1792	0.3937**	0.4159**	0.4283**	0.1154
Stom. density	Y17	-0.0754	-0.0293	-0.0170	-0.1407	-0.1740	-0.0906	-0.0040	0.1657
Bark thk.	Y18	0.5404**	-0.2567*	-0.0316	0.5109**	0.3838**	0.0450	0.0976	0.3241**
No.LV rows	Y19	1.0000**	-0.1762	-0.2445*	0.7671**	0.0611	-0.1015	0.1726	0.4177**
Density of LV	Y20	-0.1762	1.0000**	-0.0009	-0.0657	-0.2538*	-0.0509	-0.0581	-0.1775
Diameter of LV	Y21	-0.2445	-0.0009	1.0000**	0.3018**	0.1079	0.0415	-0.1276	0.0289
Lat. area index	Y22	0.7671**	-0.0657	0.3018**	1.0000**	0.0550	-0.1257	0.0838	0.3708**
Midrib thick.	Y23	0.0611	-0.2538*	0.1079	0.0550	1.0000**	0.5377**	0.3505**	-0.0272
Lamina.thick.	Y24	-0.1015	-0.0509	0.0415	-0.1257	0.5377**	1.0000**	0.7077**	-0.2341*
Palisade thick.	Y25	0.1726	-0.0581	-0.1276	0.0838	0.3505**	0.7077**	1.0000**	-0.1653
Latex thiols	Y26	0.4177**	-0.1775	0.0289	0.3708**	-0.0272	-0.2341*	-0.1653	1.0000**
In. phoshorous	Y27	0.1509	-0.0314	0.1551	0.2347*	0.1496	-0.0172	-0.0728	0.1581
Latex sucrose	Y28	0.0107	-0.1692	-0.0209	0.0753	-0.1587	-0.1247	-0.0795	0.0455
Ltx.magnesium	Y29	0.1790	-0.0398	-0.2070	0.0644	0.1685	0.1539	0.2546*	0.0375
Chlorophyll a	Y30	0.1273	0.0705	0.2264	0.3297**	-0.2042	-0.2801*	-0.2719*	0.2323*
Chlorophyll b	Y31	0.0774	0.1104	0.2062	0.2646*	-0.2433*	-0.2766*	-0.3218**	0.1912
Tot chlorophyll	Y32	0.1182	0.0817	0.2225	0.3178**	-0.2225	-0.2857*	-0.2915**	0.2315*
Chl a:b ratio	Y33	0.1085	-0.1368	-0.0451	0.0752	0.2176	0.1135	0.2217	0.0449
Juvenile yield	Y34	0.4622**	-0.0619	0.0743	0.6268**	0.1171	-0.0991	0.0797	0.3294**

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix E.(contd...)

Traits		Y27	Y28	Y29	Y30	Y31	Y32	Y33	Y34
Sprt. week	Y1	-0.0431	-0.0555	0.1304	-0.0814	-0.0759	-0.0820	0.0623	-0.0226
Height	Y2	0.1085	0.1211	-0.0030	0.1452	0.1233	0.1397	0.0447	0.0516
Sc. diameter (1)	Y3	0.0586	-0.0265	-0.1607	0.0843	0.1339	0.1002	-0.0787	0.1261
Whrls prd.(W1)	Y4	0.2064	-0.0596	0.0070	0.0792	0.1438	0.0973	-0.1387	0.0794
Whrls ret.(W2)	Y5	0.2645*	-0.0164	0.0029	-0.0047	0.0038	-0.0066	0.0401	0.0879
Whrls shd(W3)	Y6	-0.0297	-0.0737	0.0072	0.1343	0.2272	0.1663	-0.2791*	0.0076
Leaves prod.	Y7	0.2117	0.0691	-0.0534	0.1988	0.2066	0.2036	-0.0293	0.1789
Sc. diameter (2)	Y8	0.2190	0.2499*	0.0477	0.3138**	0.2671*	0.3063**	0.0657	0.5086**
Dia. increment	Y9	0.1327	0.1831	0.1647	0.1935	0.1215	0.1772	0.1005	0.3016**
Whorls (W4)	Y10	0.2971**	-0.0241	0.1554	0.0190	0.0987	0.0384	-0.1014	0.2096
Whorls (W5)	Y11	0.1872	0.1173	-0.0936	0.0906	0.0883	0.0867	0.0267	0.1339
Whorls (W6)	Y12	0.2844*	0.1454	0.2671*	-0.0499	-0.0907	-0.0609	0.1625	0.2928**
Whorls (W7)	Y13	0.1788	0.1636	-0.0953	⁻0.0875	0.0544	0.0757	0.0874	0.1472
Whorls (W8)	Y14	0.2976**	-0.0486	0.0978	0.0568	0.1420	0.0789	-0.1406	0.1720
Leaf size	Y15	0.1024	-0.1454	0.2508*	-0.3351**	-0.3522**	-0.3471**	0.1570	0.2109
SLW	Y16	0.2045	-0.0934	0.3294**	-0.0354	-0.0743	-0.0471	0.0948	0.1481
Stom. density	Y17	0.1737	0.0784	-0.0138	-0.2004	-0.3379**	-0.2455*	0.4071**	-0.0586
Bark thk.	Y18	0.4470**	-0.0577	0.1645	-0.0188	-0.0861	-0.0370	0.2181	0.4128**
No.LV rows	Y19	0.1509	0.0107	0.1790	0.1273	0.0774	0.1182	0.1085	0.4622**
Density of LV	Y20	-0.0314	-0.1692	-0.0398	0.0705	0.1104	0.0817	-0.1368	-0.0619
Diameter of LV	Y21	0.1551	-0.0209	-0.2070	0.2264	0.2062	0.2225	-0.0451	0.0743
Lat. area index	Y22	0.2347*	0.0753	0.0644	0.3297**	0.2646*	0.3178**	0.0752	0.6268**
Midrib thick.	Y23	0.1496	-0.1587	0.1685	-0.2042	-0.2433*	-0.2225	0.2176	0.1171
Lamina.thick.	Y24	-0.0172	-0.1247	0.1539	-0.2801*	-0.2766*	-0.2857*	0.1135	-0.0991
Palisade thick.	Y25	-0.0728	-0.0795	0.2546*	-0.2719*	-0.3218**	-0.2915**	0.2217	0.0797
Latex thiols	Y26	0.1581	0.0455	0.0375	0.2323*	0.1912	0.2315*	0.0449	0.3294**
In. phoshorous	Y27	1.0000**	0.0253	0.2536*	-0.0420	-0.0548	-0.0507	0.1136	0.4076**
Latex sucrose	Y28	0.0253	1.0000**	0.0615	0.2951**	0.1260	0.2497*	0.2871*	0.0616
Ltx.magnesium	Y29	0.2536*	0.0615	1.0000**	-0.1441	-0.2363*	-0.1743	0.2793*	0.2392*
Chlorophyll a	Y30	-0.0420	0.2951**	-0.1441	1.0000**	0.9011**	0.9915**	-0.1771	0.2619*
Chlorophyll b	Y31	-0.0548	0.1260	-0.2363*	0.9011**	1.0000**	0.9489**	-0.5687**	0.2720*
Tot chlorophyll	Y32	-0.0507	0.2497*	-0.1743	0.9915**	0.9489**	1.0000**	-0.2959**	0.2706*
Chl a:b ratio	Y33	0.1136	0.2871*	0.2793**	-0.1771	-0.5687**	-0.2959**	1.0000**	-0.0564
Juvenile yield	Y34	0.4076**	0.0616	0.2392*	0.2619*	0.2720*	0.2706*	-0.0564	1.0000**

* and **: Correlation significant at 5% and 1% respectively

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix F. Genotypic correlation matrix of 34 variables for clones at the immature stage

		First year parameters							Second year	
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
Sprt. week	Y1	1.0000	-0.6859	0.3449	-0.1526	0.0549	-0.4808	-0.4236	-0.2231	-0.4209
Height	Y2	-0.6859	1.0000	-0.4273	0.8475	0.5306	1.0501	0.8839	0.7654	0.8812
Sc. diameter (1)	Y3	0.3449	-0.4273	1.0000	-0.1417	-0.0987	-0.1563	-0.1408	0.0973	-0.5976
Whrls prd.(W1)	Y4	-0.1526	0.8475	-0.1417	1.0000	0.9227	0.6637	0.7236	0.4524	0.4456
Whrls ret.(W2)	Y5	0.0549	0.5306	-0.0987	0.9227	1.0000	0.3241	0.5647	0.4375	0.4252
Whrls shd(W3)	Y6	-0.4808	1.0501	-0.1563	0.6637	0.3241	1.0000	0.6800	0.2613	0.2685
Leaves prod.	Y7	-0.4236	0.8839	-0.1408	0.7236	0.5647	0.6800	1.0000	0.8181	0.7635
Sc. diameter (2)	Y8	-0.2231	0.7654	0.0973	0.4524	0.4375	0.2613	0.8181	1.0000	0.7338
Dia. increment	Y9	-0.4209	0.8812	-0.5976	0.4456	0.4252	0.2685	0.7635	0.7338	1.0000
Whorls (W4)	Y10	0.3831	0.5712	0.4067	0.5953	0.6942	0.1140	0.5769	0.5503	0.1794
Whorls (W5)	Y11	-0.6606	1.1516	-0.2324	⌐0.8210	0.6076	0.8357	0.9492	0.7127	0.7311
Whorls (W6)	Y12	0.4003	-0.0021	0.4751	-0.2501	0.1655	-0.9349	0.2266	0.5616	0.1888
Whorls (W7)	Y13	-0.8367	1.1337	-0.3295	0.7128	0.4810	0.8159	0.9584	0.7638	0.8406
Whorls (W8)	Y14	0.1317	0.7929	0.1510	0.8911	0.9041	0.4327	0.7274	0.5618	0.3486
Leaf size	Y15	0.2850	0.1488	-0.1952	0.2172	0.4554	-0.3506	0.1411	-0.0423	0.1463
SLW	Y16	0.2216	-0.2225	-0.3050	0.1064	0.4781	-0.6664	-0.1520	-0.3507	-0.0911
Stom. density	Y17	0.3195	-0.3694	0.6936	-0.4050	-0.0369	-0.9221	-0.4786	-0.2428	-0.6211
Bark thk.	Y18	0.0466	0.1839	0.2081	0.2973	0.4447	-0.1332	0.4425	0.3934	0.2689
No.LV rows	Y19	-0.1608	-0.1842	0.3306	-0.0930	0.0641	-0.3527	-0.0531	0.2551	0.0202
Density of LV	Y20	-0.4908	-0.5674	-0.4824	-0.3223	-0.6589	0.4875	-0.7672	-0.7993	-0.4247
Diameter of LV	Y21	0.1258	0.2075	0.3874	0.1664	0.0537	0.3042	0.0661	0.1639	-0.1316
Lat. area index	Y22	-0.2242	0.0772	0.4737	0.0697	0.1213	-0.0645	0.1443	0.5596	0.1442
Midrib thick.	Y23	0.5789	-0.0768	0.3518	0.2191	0.6380	-0.7002	0.1054	-0.0766	-0.2578
Lamina.thick.	Y24	0.4900	-0.1958	-0.0440	0.2541	0.4631	-0.2751	-0.1992	-0.4408	-0.3636
Palisade thick.	Y25	0.1933	-0.1043	0.1017	0.0812	0.1682	-0.1272	-0.2803	-0.1793	-0.2469
Latex thiols	Y26	0.0662	-0.6312	0.3924	-0.6124	-0.5376	-0.4597	-0.2816	-0.0673	-0.2093
In. phoshorous	Y27	-0.0091	-0.0534	0.0379	0.2889	0.3878	-0.0436	0.1633	0.0287	0.0892
Latex sucrose	Y28	-0.0678	0.1653	-0.1408	-0.1651	-0.1191	-0.1741	-0.0410	0.1146	0.2059
Ltx.magnesium	Y29	0.3566	-0.0583	-0.4069	0.0982	0.1260	-0.0036	-0.1498	-0.0921	0.2615
Chlorophyll a	Y30	-0.1538	-0.1172	0.2818	-0.0282	-0.1838	0.2874	0.1424	0.3308	0.0622
Chlorophyll b	Y31	-0.0970	-0.1460	0.3203	0.1126	-0.1669	0.6001	0.1952	0.2003	-0.0871
Tot chlorophyll	Y32	-0.1392	-0.1267	0.2969	0.0086	-0.1868	0.3835	0.1600	0.3013	0.0230
Chl a:b ratio	Y33	0.0107	0.1890	-0.0967	-0.2522	0.0642	-0.7434	-0.1010	0.2624	0.3204
Juvenile yield	Y34	0.2098	-0.3319	0.2885	0.1079	0.2472	-0.2149	0.0663	0.3996	0.1698

(contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year;
W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes
produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the
second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes
produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Traits		Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18
Sprt. week	Y1	0.3831	-0.6606	0.4003	-0.8367	0.1317	0.2850	0.2216	0.3195	0.0466
Height	Y2	0.5712	1.1516	-0.0021	1.1337	0.7929	0.1488	-0.2225	-0.3694	0.1839
Sc. diameter (1)	Y3	0.4067	-0.2324	0.4751	-0.3295	0.1510	-0.1952	-0.3050	0.6936	0.2081
Whrls prd.(W1)	Y4	0.5953	0.8210	-0.2501	0.7128	0.8911	0.2172	0.1064	-0.4050	0.2973
Whrls ret.(W2)	Y5	0.6942	0.6076	0.1655	0.4810	0.9041	0.4554	0.4781	-0.0369	0.4447
Whrls shd(W3)	Y6	0.1140	0.8357	-0.9349	0.8159	0.4327	-0.3506	-0.6664	-0.9221	-0.1332
Leaves prod.	Y7	0.5769	0.9492	0.2266	0.9584	0.7274	0.1411	-0.1520	-0.4786	0.4425
Sc. diameter (2)	Y8	0.5503	0.7127	0.5616	0.7638	0.5618	-0.0423	-0.3507	-0.2428	0.3934
Dia. increment	Y9	0.1794	0.7311	0.1888	0.8406	0.3486	0.1463	-0.0911	-0.6211	0.2689
Whorls (W4)	Y10	1.0000	0.5648	0.5023	0.4311	0.8951	0.2771	0.4078	-0.1723	0.5025
Whorls (W5)	Y11	0.5648	1.0000	0.1289	0.9812	0.7745	0.0010	-0.2628	-0.5738	-0.0170
Whorls (W6)	Y12	0.5023	0.1289	1.0000	0.1908	0.1449	0.4556	0.5846	0.8961	0.4508
Whorls (W7)	Y13	0.4311	0.9812	0.1908	1.0000	0.6390	-0.0216	-0.3520	-0.4537	-0.1233
Whorls (W8)	Y14	0.8951	0.7745	0.1449	0.6390	1.0000	0.2770	0.2893	-0.3220	0.4487
Leaf size	Y15	0.2771	0.0010	0.4556	-0.0216	0.2770	1.0000	0.8373	0.2393	0.3949
SLW	Y16	0.4078	-0.2628	0.5846	-0.3520	0.2893	0.8373	1.0000	1.3114	0.4912
Stom. density	Y17	-0.1723	-0.5738	0.8961	-0.4537	-0.3220	0.2393	1.3114	1.0000	0.0451
Bark thk.	Y18	0.5025	-0.0170	0.4508	-0.1233	0.4487	0.3949	0.4912	0.0451	1.0000
No.LV rows	Y19	0.1820	-0.3079	0.5037	-0.3560	0.0512	0.3629	0.4831	-0.0105	0.6911
Density of LV	Y20	-0.6583	-0.3446	-0.8042	-0.3315	-0.5506	-0.3526	-0.3970	-1.0443	-0.7498
Diameter of LV	Y21	0.1157	0.4290	-0.2486	0.4436	0.1577	-0.4959	-0.3932	0.0105	0.0767
Lat. area index	Y22	0.3412	0.0328	0.5222	0.0115	0.2313	0.1028	0.1958	-0.2201	0.7244
Midrib thick.	Y23	0.5627	0.1246	0.4329	0.0155	0.4394	0.5571	0.2545	0.0994	0.4232
Lamina.thick.	Y24	0.1706	-0.1612	-0.1949	-0.2744	0.2373	0.4573	0.3235	0.3732	-0.0093
Palisade thick.	Y25	0.0421	-0.3067	0.2306	-0.3298	0.0688	0.6486	0.3764	0.6174	0.0254
Latex thiols	Y26	-0.2558	-0.4665	0.3271	-0.4104	-0.4843	-0.2265	-0.0299	0.5650	0.3488
In. phoshorous	Y27	0.4774	0.1661	0.3293	0.0761	0.4299	0.2826	0.3186	0.8067	0.5570
Latex sucrose	Y28	-0.1178	0.0583	0.0853	0.1380	-0.1581	-0.2424	-0.3124	0.3618	-0.3276
Ltx.magnesium	Y29	0.2386	-0.1116	0.3416	-0.1599	0.1892	0.5584	0.5014	0.2875	0.1536
Chlorophyll a	Y30	0.0091	0.1075	0.0757	0.1650	-0.0105	-0.5428	-0.6880	0.0806	-0.0734
Chlorophyll b	Y31	0.1167	0.1250	-0.1793	0.1018	0.1284	-0.5979	-0.7690	-0.1508	-0.1887
Tot chlorophyll	Y32	0.0316	0.1123	-0.0033	0.1492	0.0226	-0.5690	-0.7218	0.0163	-0.1061
Chl a:b ratio	Y33	-0.1288	0.0196	0.5443	0.1592	-0.2126	0.2864	0.4178	0.5033	0.3352
Juvenile yield	Y34	0.5091	-0.0410	0.8874	-0.0608	0.3474	0.4807	0.0931	-0.0689	0.3923

(contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix F. (contd...)

Traits		Y19	Y20	Y21	Y22	Y23	Y24	Y25	Y26
Sprt. week	Y1	-0.1608	-0.4908	0.1258	-0.2242	0.5789	0.4900	0.1933	0.0662
Height	Y2	-0.1842	-0.5674	0.2075	0.0772	-0.0768	-0.1958	-0.1043	-0.6312
Sc. diameter (1)	Y3	0.3306	-0.4824	0.3874	0.4737	0.3518	-0.0440	0.1017	0.3924
Whrls prd.(W1)	Y4	-0.0930	-0.3223	0.1664	0.0697	0.2191	0.2541	0.0812	-0.6124
Whrls ret.(W2)	Y5	0.0641	-0.6589	0.0537	0.1213	0.6380	0.4631	0.1682	-0.5376
Whrls shd(W3)	Y6	-0.3527	0.4875	0.3042	-0.0645	-0.7002	-0.2751	-0.1272	-0.4597
Leaves prod.	Y7	-0.0531	-0.7672	0.0661	0.1443	0.1054	-0.1992	-0.2803	-0.2816
Sc. diameter (2)	Y8	0.2551	-0.7993	0.1639	0.5596	-0.0766	-0.4408	-0.1793	-0.0673
Dia. increment	Y9	0.0202	-0.4247	-0.1316	0.1442	-0.2578	-0.3636	-0.2469	-0.2093
Whorls (W4)	Y10	0.1820	-0.6583	0.1157	0.3412	0.5627	0.1706	0.0421	-0.2558
Whorls (W5)	Y11	-0.3079	-0.3446	0.4290	0.0328	0.1246	-0.1612	-0.3067	-0.4665
Whorls (W6)	Y12	0.5037	-0.8042	-0.2486	0.5222	0.4329	-0.1949	0.2306	0.3271
Whorls (W7)	Y13	-0.3560	-0.3315	0.4436	0.0115	0.0155	-0.2744	-0.3298	-0.4104
Whorls (W8)	Y14	0.0512	-0.5506	0.1577	0.2313	0.4394	0.2373	0.0688	-0.4843
Leaf size	Y15	0.3629	-0.3526	-0.4959	0.1028	0.5571	0.4573	0.6486	-0.2265
SLW	Y16	0.4831	-0.3970	-0.3932	0.1958	0.2545	0.3235	0.3764	-0.0299
Stom. density	Y17	-0.0105	-1.0443	0.0105	-0.2201	0.0994	0.3732	0.6174	0.5650
Bark thk.	Y18	0.6911	-0.7498	0.0767	0.7244	0.4232	-0.0093	0.0254	0.3488
No.LV rows	Y19	1.0000	-0.2659	-0.3088	0.8485	-0.0018	-0.2232	0.1825	0.5199
Density of LV	Y20	-0.2659	1.0000	-0.0554	-0.3500	-0.4823	-0.0187	0.0363	-0.5109
Diameter of LV	Y21	-0.3088	-0.0554	1.0000	0.1670	0.2509	0.1182	-0.1106	0.0834
Lat. area index	Y22	0.8485	-0.3500	0.1670	1.0000	0.0390	-0.2877	0.0993	0.4252
Midrib thick.	Y23	-0.0018	-0.4823	0.2509	0.0390	1.0000	0.5196	0.2872	-0.0701
Lamina.thick.	Y24	-0.2232	-0.0187	0.1182	-0.2877	0.5196	1.0000	0.6958	-0.3322
Palisade thick.	Y25	0.1825	0.0363	-0.1106	0.0993	0.2872	0.6958	1.0000	-0.2299
Latex thiols	Y26	0.5199	-0.5109	0.0834	0.4252	-0.0701	-0.3322	-0.2299	1.0000
In. phoshorous	Y27	0.2229	-0.2510	0.3845	0.3257	0.1847	-0.1078	-0.1426	0.0409
Latex sucrose	Y28	-0.0787	-0.4870	-0.0043	-0.0828	-0.2176	-0.1933	-0.1113	-0.1071
Ltx.magnesium	Y29	0.1123	0.0132	-0.4123	-0.1236	0.1411	0.0824	0.2916	-0.1158
Chlorophyll a	Y30	0.0141	0.2886	0.4125	0.3302	-0.3923	-0.5416	-0.5206	0.2239
Chlorophyll b	Y31	-0.0651	0.4371	0.3816	0.2164	-0.4563	-0.5594	-0.6121	0.1850
Tot chlorophyll	Y32	-0.0039	0.3442	0.4097	0.3090	-0.4220	-0.5591	-0.5565	0.2247
Chl a:b ratio	Y33	0.1707	-0.5370	0.0093	0.1857	0.3418	0.2158	0.3600	0.0424
Juvenile yield	Y34	0.4878	-0.0924	0.1922	0.6807	0.1467	-0.2223	0.0368	0.1855

(contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix F.(contd...)

Traits		Y27	Y28	Y29	Y30	Y31	Y32	Y33	Y34
Sprt. week	Y1	-0.0091	-0.0678	0.3566	-0.1538	-0.0970	-0.1392	0.0107	0.2098
Height	Y2	-0.0534	0.1653	-0.0583	-0.1172	-0.1460	-0.1267	0.1890	-0.3319
Sc. diameter (1)	Y3	0.0379	-0.1408	-0.4069	0.2818	0.3203	0.2969	-0.0967	0.2885
Whrls prd.(W1)	Y4	0.2889	-0.1651	0.0982	-0.0282	0.1126	0.0086	-0.2522	0.1079
Whrls ret.(W2)	Y5	0.3878	-0.1191	0.1260	-0.1838	-0.1669	-0.1868	0.0642	0.2472
Whrls shd(W3)	Y6	-0.0436	-0.1741	-0.0036	0.2874	0.6001	0.3835	-0.7434	-0.2149
Leaves prod.-	Y7	0.1633	-0.0410	-0.1498	0.1424	0.1952	0.1600	-0.1010	0.0663
Sc. diameter (2)	Y8	0.0287	0.1146	-0.0921	0.3308	0.2003	0.3013	0.2624	0.3996
Dia. increment	Y9	0.0892	0.2059	0.2615	0.0622	-0.0871	0.0230	0.3204	0.1698
Whorls (W4)	Y10	0.4774	-0.1178	0.2386	0.0091	0.1167	0.0316	-0.1288	0.5091
Whorls (W5)	Y11	0.1661	0.0583	-0.1116	0.1075	0.1250	0.1123	0.0196	-0.0410
Whorls (W6)	Y12	0.3293	0.0853	0.3416	0.0757	-0.1793	-0.0033	0.5443	0.8874
Whorls (W7)	Y13	0.0761	0.1380	-0.1599	0.1650	0.1018	0.1492	0.1592	-0.0608
Whorls (W8)	Y14	0.4299	-0.1581	0.1892	-0.0105	0.1284	0.0226	-0.2126	0.3474
Leaf size	Y15	0.2826	-0.2424	0.5584	-0.5428	-0.5979	-0.5690	0.2864	0.4807
SLW	Y16	0.3186	-0.3124	0.5014	-0.6880	-0.7690	-0.7218	0.4178	0.0931
Stom. density	Y17	0.8067	0.3618	0.2875	0.0806	-0.1508	0.0163	0.5033	-0.0689
Bark thk.	Y18	0.5570	-0.3276	0.1536	-0.0734	-0.1887	-0.1061	0.3352	0.3923
No.LV rows	Y19	0.2229	-0.0787	0.1123	0.0141	-0.0651	-0.0039	0.1707	0.4878
Density of LV	Y20	-0.2510	-0.4870	0.0132	0.2886	0.4371	0.3442	-0.5370	-0.0924
Diameter of LV	Y21	0.3845	-0.0043	-0.4123	0.4125	0.3816	0.4097	0.0093	0.1922
Lat. area index	Y22	0.3257	-0.0828	-0.1236	0.3302	0.2164	0.3090	0.1857	0.6807
Midrib thick.	Y23	0.1847	-0.2176	0.1411	-0.3923	-0.4563	-0.4220	0.3418	0.1467
Lamina.thick.	Y24	-0.1078	-0.1933	0.0824	-0.5416	-0.5594	-0.5591	0.2158	-0.2223
Palisade thick.	Y25	-0.1426	-0.1113	0.2916	-0.5206	-0.6121	-0.5565	0.3600	0.0368
Latex thiols	Y26	0.0409	-0.1071	-0.1158	0.2239	0.1850	0.2247	0.0424	0.1855
In. phoshorous	Y27	1.0000	-0.2761	0.0431	-0.0059	-0.0514	-0.0251	0.1258	0.4534
Latex sucrose	Y28	-0.2761	1.0000	-0.1612	0.4556	0.2340	0.3983	0.3233	-0.2989
Ltx.magnesium	Y29	0.0431	-0.1612	1.0000	-0.2537	-0.4112	-0.3056	0.3973	0.0780
Chlorophyll a	Y30	-0.0059	0.4556	-0.2537	1.0000	0.8878	0.9916	-0.0949	0.2537
Chlorophyll b	Y31	-0.0514	0.2340	-0.4112	0.8878	1.0000	0.9398	-0.5350	0.2732
Tot chlorophyll	Y32	-0.0251	0.3983	-0.3056	0.9916	0.9398	1.0000	-0.2207	0.2645
Chl a:b ratio	Y33	0.1258	0.3233	0.3973	-0.0949	-0.5350	-0.2207	1.0000	-0.0888
Juvenile yield	Y34	0.4534	-0.2989	0.0780	0.2537	0.2732	0.2645	-0.0888	1.0000

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix G. Environmental correlation matrix of 34 variables for clones at the immature stage

		First year parameters							Second year	
		Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
Sprt. week	Y1	1.0000**	-0.2069	0.3104*	-0.2821	-0.0318	-0.3491*	-0.2833	-0.2872	-0.3930**
Height	Y2	-0.2069	1.0000**	-0.0564	0.5995**	0.5605**	0.1404	0.8181**	0.6700**	0.4965**
Sc. diameter (1)	Y3	0.3104*	-0.0564	1.0000**	-0.1999	0.1267	-0.4295**	-0.0519	0.0160	-0.6872**
Whrls prd.(W1)	Y4	-0.2821	0.5995**	-0.1999	1.0000**	0.7093**	0.5097**	0.7823**	0.4110**	0.4210**
Whrls ret.(W2)	Y5	-0.0318	0.5605**	0.1267	0.7093**	1.0000**	-0.2449	0.7751**	0.3387*	0.1079
Whrls shd(W3)	Y6	-0.3491*	0.1404	-0.4295**	0.5097**	-0.2449	1.0000**	0.1300	0.1519	0.4474**
Leaves prod.	Y7	-0.2833	0.8181**	-0.0519	0.7823**	0.7751**	0.1300	1.0000**	0.6388**	0.4671**
Sc. diameter (2)	Y8	-0.2872	0.6700**	0.0160	0.4110**	0.3387	0.1519	0.6388**	1.0000**	0.6738**
Dia. increment	Y9	-0.3930**	0.4965**	-0.6872**	0.4210**	0.1079	0.4474**	0.4671**	0.6738**	1.0000**
Whorls (W4)	Y10	0.2027	0.2081	-0.0298	0.3500*	0.5103**	-0.1414	0.3389*	0.1909	0.1231
Whorls (W5)	Y11	-0.0306	0.5935**	-0.0147	.0.3438*	0.4573**	-0.0854	0.5658**	0.5625**	0.3754**
Whorls (W6)	Y12	0.0754	0.0168	0.0767	-0.0047	0.1817	-0.2282	0.0713	0.2604	0.1076
Whorls (W7)	Y13	-0.1016	0.5833**	-0.0155	0.2805	0.3910**	-0.0914	0.5355**	0.5921**	0.4010**
Whorls (W8)	Y14	-0.0371	0.4823**	-0.1358	0.8063**	0.7373**	0.2090	0.6718**	0.3610**	0.3242*
Leaf size	Y15	-0.0797	-0.1315	-0.1675	0.2245	0.2313	0.0265	-0.0381	0.0500	0.1301
SLW	Y16	-0.0990	0.3079*	-0.0969	0.3358*	0.1398	0.2913*	0.2299	0.3024*	0.2597
Stom. density	Y17	0.0463	-0.1982	-0.0370	-0.1787	-0.1859	-0.0188	-0.1309	-0.1907	-0.0985
Bark thk.	Y18	-0.1648	0.2548	0.0259	0.0900	0.0662	0.0430	0.2241	0.4251**	0.2989*
No.LV rows	Y19	0.1421	0.0508	-0.0473	-0.3055*	-0.1931	-0.1845	-0.0637	0.1690	0.1840
Density of LV	Y20	0.1457	-0.0521	0.1189	0.1140	0.1106	0.0218	0.1191	0.0699	0.0012
Diameter of LV	Y21	-0.1205	-0.0648	-0.2290	0.0425	-0.0479	0.1169	-0.0648	0.0436	0.1850
Lat. area index	Y22	0.0035	0.2420	-0.1170	-0.0859	-0.0472	-0.0605	0.1367	0.5158**	0.4555**
Midrib thick.	Y23	-0.1671	0.1257	-0.0120	0.1566	-0.0489	0.2751	0.0550	0.1476	0.1435
Lamina.thick.	Y24	-0.1379	0.2581	-0.0264	0.2484	0.2605	0.0238	0.1735	0.2408	0.1974
Palisade thick.	Y25	-0.0661	0.2099	0.0387	0.1301	0.0964	0.0612	0.0941	0.1835	0.0971
Latex thiols	Y26	-0.2034	0.4380**	0.0655	0.2088	0.1496	0.1046	0.4258**	0.6183**	0.3428*
In. phoshorous	Y27	-0.0792	0.2382	0.0840	0.1294	0.1685	-0.0277	0.2788	0.4452**	0.1875
Latex sucrose	Y28	-0.0533	0.1264	0.1066	0.0777	0.1074	-0.0242	0.2136	0.4796**	0.1886
Ltx.magnesium	Y29	-0.0654	0.0333	0.0589	-0.0925	-0.1168	0.0154	0.0302	0.2074	0.0810
Chlorophyll a	Y30	-0.0180	0.3858**	-0.1181	0.2218	0.1939	0.0684	0.2908*	0.3240*	0.3705**
Chlorophyll b	Y31	-0.0645	0.3355*	-0.0351	0.1895	0.1756	0.0463	0.2418	0.3621**	0.3494*
Tot chlorophyll	Y32	-0.0355	0.3727**	-0.0938	0.2142	0.1869	0.0666	0.2784	0.3400*	0.3704**
Chl a:b ratio	Y33	0.1395	-0.0643	-0.0738	-0.0006	0.0181	-0.0229	0.0501	-0.2115	-0.1675
Juvenile yield	Y34	-0.1873	0.2514	0.0113	0.0564	-0.0284	0.1123	0.2637	0.6062**	0.4086**

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix G . (contd...)

Traits		Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18
Sprt. week	Y1	0.2027	-0.0306	0.0754	-0.1016	-0.0371	-0.0797	-0.0990	0.0463	-0.1648
Height	Y2	0.2081	0.5935**	0.0168	0.5833**	0.4823**	-0.1315	0.3079	-0.1982	0.2548
Sc. diameter (1)	Y3	-0.0298	-0.0147	0.0767	-0.0155	-0.1358	-0.1675	-0.0969	-0.0370	0.0259
Whrls prd.(W1)	Y4	0.3500*	0.3438*	-0.0047	0.2805	0.8063**	0.2245	0.3358	-0.1787	0.0900
Whrls ret.(W2)	Y5	0.5103**	0.4573**	0.1817	0.3910**	0.7373**	0.2313	0.1398	-0.1859	0.0662
Whrls shd(W3)	Y6	-0.1414	-0.0854	-0.2282	-0.0914	0.2090	0.0265	0.2913*	-0.0188	0.0430
Leaves prod.	Y7	0.3389*	0.5658**	0.0713	0.5355**	0.6718**	-0.0381	0.2299	-0.1309	0.2241
Sc. diameter (2)	Y8	0.1909	0.5625**	0.2604	0.5921**	0.3610**	0.0500	0.3024*	-0.1907	0.4251**
Dia. increment	Y9	0.1231	0.3754**	0.1076	0.4010**	0.3242*	0.1301	0.2597	-0.0985	0.2989*
Whorls (W4)	Y10	1.0000**	0.3163*	0.5780**	0.1578	0.8363**	0.1232	0.0439	-0.1106	0.0427
Whorls (W5)	Y11	0.3163*	1.0000**	0.0425	0.9687**	0.4010**	-0.0516	0.0318	-0.0841	0.2164
Whorls (W6)	Y12	0.5780**	0.0425	1.0000**	0.0814	0.3622**	0.0277	-0.0402	-0.0184	0.0665
Whorls (W7)	Y13	0.1578	0.9687**	0.0814	1.0000**	0.2638	-0.0845	0.0045	-0.0628	0.2257
Whorls (W8)	Y14	0.8363**	0.4010**	0.3622**	0.2638	1.0000**	0.2092	0.2243	-0.1744	0.0796
Leaf size	Y15	0.1232	-0.0516	0.0277	-0.0845	0.2092	1.0000**	0.1564	-0.2086	0.0272
SLW	Y16	0.0439	0.0318	-0.0402	0.0045	0.2243	0.1564	1.0000**	-0.5455**	0.2670
Stom. density	Y17	-0.1106	-0.0841	-0.0184	-0.0628	-0.1744	-0.2086	-0.5455**	1.0000**	-0.1426
Bark thk.	Y18	0.0427	0.2164	0.0665	0.2257	0.0796	0.0272	0.2670	-0.1426	1.0000**
No.LV rows	Y19	0.0231	-0.0465	0.0861	-0.0547	-0.1642	-0.2056	0.0750	-0.1191	0.3644**
Density of LV	Y20	0.1242	0.0055	0.0486	0.0027	0.1451	0.0167	-0.0720	0.1348	-0.0725
Diameter of LV	Y21	0.1073	0.0997	-0.0812	0.0702	0.0927	0.1712	0.0728	-0.0284	-0.1332
Lat. area index	Y22	0.1477	0.2575	0.1554	0.2548	0.0430	-0.0282	0.1769	-0.1277	0.3135*
Midrib thick.	Y23	-0.2409	-0.0809	-0.1584	-0.0703	-0.0605	0.1052	0.6971**	-0.4712**	0.3571*
Lamina.thick.	Y24	0.0965	-0.0667	0.1016	-0.0842	0.2063	0.3427*	0.6707**	-0.4715**	0.1543
Palisade thick.	Y25	-0.0305	0.0069	-0.1100	-0.0188	0.0569	0.2376	0.6890**	-0.4962**	0.2677
Latex thiols	Y26	-0.0248	0.2819	0.1189	0.3359*	0.1066	-0.1905	0.3579*	-0.0418	0.3352*
In. phoshorous	Y27	0.1340	0.2292	0.3188*	0.2839	0.1603	-0.1454	0.1480	-0.0984	0.3067*
Latex sucrose	Y28	0.0944	0.2110	0.2488	0.2407	0.1051	0.0140	0.0944	-0.0676	0.4042**
Ltx.magnesium	Y29	0.0816	-0.0902	0.2793	-0.0667	-0.0026	-0.1709	0.2475	-0.1704	0.1828
Chlorophyll a	Y30	0.0331	0.0914	-0.1543	0.0473	0.1507	-0.0220	0.5329**	-0.4377**	0.0653
Chlorophyll b	Y31	0.0882	0.0686	-0.0552	0.0304	0.1666	-0.0098	0.4672**	-0.5367**	0.0556
Tot chlorophyll	Y32	0.0505	0.0776	-0.1177	0.0361	0.1573	-0.0205	0.5207**	-0.4780**	0.0656
Chl a:b ratio	Y33	-0.0842	0.0419	-0.0816	0.0516	-0.0535	-0.0628	-0.2012	0.5425**	0.0306
Juvenile yield	Y34	-0.0223	0.2531	0.0401	0.2707	0.0189	-0.0738	0.1894	-0.0628	0.4340**

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix G. (contd...)

Traits		Y19	Y20	Y21	Y22	Y23	Y24	Y25	Y26
Sprt. week	Y1	0.1421	0.1457	-0.1205	0.0035	-0.1671	-0.1379	-0.0661	-0.2034
Height	Y2	0.0508	-0.0521	-0.0648	0.2420	0.1257	0.2581	0.2099	0.4380 **
Sc. diameter (1)	Y3	-0.0473	0.1189	-0.2290	-0.1170	-0.0120	-0.0264	0.0387	0.0655
Whrls prd.(W1)	Y4	-0.3055 *	0.1140	0.0425	-0.0859	0.1566	0.2484	0.1301	0.2088
Whrls ret.(W2)	Y5	-0.1931	0.1106	-0.0479	-0.0472	-0.0489	0.2605	0.0964	0.1496
Whrls shd(W3)	Y6	-0.1845	0.0218	0.1169	-0.0605	0.2751	0.0238	0.0612	0.1046
Leaves prod.	Y7	-0.0637	0.1191	-0.0648	0.1367	0.0550	0.1735	0.0941	0.4258 **
Sc. diameter (2)	Y8	0.1690	0.0699	0.0436	0.5158 **	0.1476	0.2408	0.1835	0.6183 **
Dia. increment	Y9	0.1840	0.0012	0.1850	0.4555 **	0.1435	0.1974	0.0971	0.3428 *
Whorls (W4)	Y10	0.0231	0.1242	0.1073	0.1477	-0.2409	0.0965	-0.0305	-0.0248
Whorls (W5)	Y11	-0.0465	0.0055	0.0997	0.2575	-0.0809	-0.0667	0.0069	0.2819 *
Whorls (W6)	Y12	0.0861	0.0486	-0.0812	0.1554	-0.1584	0.1016	-0.1100	0.1189
Whorls (W7)	Y13	-0.0547	0.0027	0.0702	0.2548	-0.0703	-0.0842	-0.0188	0.3359 *
Whorls (W8)	Y14	-0.1642	0.1451	0.0927	0.0430	-0.0605	0.2063	0.0569	0.1066
Leaf size	Y15	-0.2056	0.0167	0.1712	-0.0282	0.1052	0.3427 *	0.2376	-0.1905
SLW	Y16	0.0750	-0.0720	0.0728	0.1769	0.6971 **	0.6707 **	0.6890 **	0.3579 *
Stom. density	Y17	-0.1191	0.1348	-0.0284	-0.1277	-0.4712 **	-0.4715 **	-0.4962 **	-0.0418
Bark thk.	Y18	0.3644 *	-0.0725	-0.1332	0.3135 *	0.3571 *	0.1543	0.2677	0.3352 *
No.LV rows	Y19	1.0000 **	-0.1618	-0.1791	0.6920 **	0.2053	0.1563	0.1693	0.2186
Density of LV	Y20	-0.1618	1.0000 **	0.0204	0.0398	-0.2015	-0.1029	-0.1781	0.0126
Diameter of LV	Y21	-0.1791	0.0204	1.0000 **	0.4155 **	-0.1243	-0.0844	-0.1885	-0.0734
Lat. area index	Y22	0.6920 **	0.0398	0.4155 **	1.0000 **	0.0924	0.1319	0.0731	0.3577 *
Midrib thick.	Y23	0.2053	-0.2015	-0.1243	0.0924	1.0000 **	0.6023 **	0.6021 **	0.1505
Lamina.thick.	Y24	0.1563	-0.1029	-0.0844	0.1319	0.6023 **	1.0000 **	0.7569 **	0.1657
Palisade thick.	Y25	0.1693	-0.1781	-0.1885	0.0731	0.6021 **	0.7569 **	1.0000 **	0.1276
Latex thiols	Y26	0.2186	0.0126	-0.0734	0.3577 *	0.1505	0.1657	0.1276	1.0000 **
In. phoshorous	Y27	0.0399	0.0862	-0.1215	0.1327	0.0671	0.2094	0.1160	0.5145 **
Latex sucrose	Y28	0.1878	-0.0096	-0.0493	0.3298 *	0.0306	0.0933	0.0317	0.6122 **
Ltx.magnesium	Y29	0.2839	-0.0798	0.0381	0.2970 *	0.2455	0.3397 *	0.1698	0.4889 **
Chlorophyll a	Y30	0.3311 *	-0.0482	-0.0184	0.3544 *	0.3379 *	0.4653 **	0.5077 **	0.2719
Chlorophyll b	Y31	0.3065 *	-0.0528	-0.0073	0.3378 *	0.3058 *	0.4458 **	0.4904 **	0.2253
Tot chlorophyll	Y32	0.3303 *	-0.0588	-0.0182	0.3510 *	0.3335 *	0.4679 **	0.5113 **	0.2668
Chl a:b ratio	Y33	-0.0118	0.1006	-0.1383	-0.0911	-0.1932	-0.2214	-0.2770	0.0554
Juvenile yield	Y34	0.4340 **	-0.0559	-0.0362	0.5784 **	0.0749	0.1243	0.1845	0.7167 **

* and **: Correlation significant at 5% and 1% respectively   (contd...)

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year; W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushes produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix G.(contd...)

Traits		Y27	Y28	Y29	Y30	Y31	Y32	Y33	Y34
Sprt. week	Y1	-0.0792	-0.0533	-0.0654	-0.0180	-0.0645	-0.0355	0.1395	-0.1873
Height	Y2	0.2382	0.1264	0.0333	0.3858**	0.3355*	0.3727**	-0.0643	0.2514
Sc. diameter (1)	Y3	0.0840	0.1066	0.0589	-0.1181	-0.0351	-0.0938	-0.0738	0.0113
Whrls prd.(W1)	Y4	0.1294	0.0777	-0.0925	0.2218	0.1895	0.2142	-0.0006	0.0564
Whrls ret.(W2)	Y5	0.1685	0.1074	-0.1168	0.1939	0.1756	0.1869	0.0181	-0.0284
Whrls shd(W3)	Y6	-0.0277	-0.0242	0.0154	0.0684	0.0463	0.0666	-0.0229	0.1123
Leaves prod.	Y7	0.2788	0.2136	0.0302	0.2908	0.2418	0.2784	0.0501	0.2637
Sc. diameter (2)	Y8	0.4452**	0.4796**	0.2074	0.3240	0.3621	0.3400*	-0.2115	0.6062**
Dia. increment	Y9	0.1875	0.1886	0.0810	0.3705	0.3494	0.3704*	-0.1675	0.4086**
Whorls (W4)	Y10	0.1340	0.0944	0.0816	0.0331	0.0882	0.0505	-0.0842	-0.0223
Whorls (W5)	Y11	0.2292	0.2110	-0.0902	0.0914	0.0686	0.0776	0.0419	0.2531
Whorls (W6)	Y12	0.3188*	0.2488	0.2793	-0.1543	-0.0552	-0.1177	-0.0816	0.0401
Whorls (W7)	Y13	0.2839*	0.2407	-0.0667	-0.0473	0.0304	0.0361	0.0516	0.2707
Whorls (W8)	Y14	0.1603	0.1051	-0.0026	0.1507	0.1666	0.1573	-0.0535	0.0189
Leaf size	Y15	-0.1454	0.0140	-0.1709	-0.0220	-0.0098	-0.0205	-0.0628	-0.0738
SLW	Y16	0.1480	0.0944	0.2475	0.5329**	0.4672**	0.5207**	-0.2012	0.1894
Stom. density	Y17	-0.0984	-0.0676	-0.1704	-0.4377**	-0.5367**	-0.4780**	0.5425**	-0.0628
Bark thk.	Y18	0.3067*	0.4042*	0.1828	0.0653	0.0556	0.0656	0.0306	0.4340**
No.LV rows	Y19	0.0399	0.1878	0.2839*	0.3311*	0.3065*	0.3303*	-0.0118	0.4340**
Density of LV	Y20	0.0862	-0.0096	-0.0798	-0.0482	-0.0528	-0.0588	0.1006	-0.0559
Diameter of LV	Y21	-0.1215	-0.0493	0.0381	-0.0184	-0.0073	-0.0182	-0.1383	-0.0362
Lat. area index	Y22	0.1327	0.3298*	0.2970*	0.3544*	0.3378*	0.3510*	-0.0911	0.5784**
Midrib thick.	Y23	0.0671	0.0306	0.2455	0.3379*	0.3058*	0.3335*	-0.1932	0.0749
Lamina.thick.	Y24	0.2094	0.0933	0.3397*	0.4653**	0.4458**	0.4679**	-0.2214	0.1243
Palisade thick.	Y25	0.1160	0.0317	0.1698	0.5077**	0.4904**	0.5113**	-0.2770	0.1845
Latex thiols	Y26	0.5145**	0.6122**	0.4889**	0.2719	0.2253	0.2668	0.0554	0.7167**
In. phoshorous	Y27	1.0000**	0.7100**	0.6301**	-0.1160	-0.0612	-0.1015	0.0878	0.3539*
Latex sucrose	Y28	0.7100**	1.0000**	0.5688**	-0.1198	-0.1250	-0.1219	0.1802	0.6888**
Ltx.magnesium	Y29	0.6301**	0.5688**	1.0000**	0.0789**	0.0863	0.0851	0.0110	0.4642**
Chlorophyll a	Y30	-0.1160	-0.1198	0.0789	1.0000**	0.9324**	0.9917**	-0.3969*	0.2875*
Chlorophyll b	Y31	-0.0612	-0.1250	0.0863	0.9324**	1.0000**	0.9689**	-0.6606**	0.2777
Tot chlorophyll	Y32	-0.1015	-0.1219	0.0851	0.9917**	0.9689**	1.0000**	-0.4926**	0.2911*
Chl a:b ratio	Y33	0.0878	0.1802	0.0110	-0.3969**	-0.6606**	-0.4926**	1.0000**	-0.0042
Juvenile yield	Y34	0.3539**	0.6888**	0.4642**	0.2875*	0.2777	0.2911*	-0.0042	1.0000**

* and **: Correlation significant at 5% and 1% respectively

W1: Whorls produced in the first year; W2: Whorls retained in the forst year; W3: Whorls shed in the first year W4: number of new flushes produced on the main stem in the second year; W5: Number of new flushes produced on the entire plant in the second year; W6: Number of new flushes retained on the main stem in the second year, W7: Number of new flushes retained on the entire plant in the second year ;W8: Number of flushe produced on the main stem in the two years; SLW: Specific leaf weight; Lvs: Latex vessel

Appendix H. D^2 values for immature clones

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.000	15.070	41.987	19.794	39.599	21.990	57.854	33.619	62.545	37.353	21.916	34.671	39.665
2	15.070	0.000	35.115	24.668	27.516	34.409	43.472	18.411	54.892	14.960	29.706	41.723	27.417
3	41.987	35.115	0.000	19.391	6.893	46.658	36.372	55.465	142.208	27.149	32.716	86.013	66.179
4	19.794	24.668	19.391	0.000	19.237	29.586	43.488	26.881	98.785	33.998	13.779	37.335	42.017
5	39.599	27.516	6.893	19.237	0.000	47.777	35.223	43.793	128.075	32.446	32.264	77.374	63.242
6	21.990	34.409	46.658	29.586	47.777	0.000	60.636	46.377	79.056	49.242	35.806	53.137	42.751
7	57.854	43.472	36.372	43.488	35.223	60.636	0.000	47.515	146.187	35.338	82.322	109.148	65.093
8	33.619	18.411	55.465	26.881	43.793	46.377	47.515	0.000	60.156	34.168	42.555	35.614	31.040
9	62.545	54.892	142.208	98.785	128.075	79.056	146.187	60.156	0.000	107.899	83.828	46.232	56.724
10	37.353	14.960	27.149	33.998	32.446	49.242	35.338	34.168	107.899	0.000	47.424	78.429	44.399
11	21.916	29.706	32.716	13.779	32.264	35.806	82.322	42.555	83.828	47.424	0.000	26.274	57.150
12	34.671	41.723	86.013	37.335	77.374	53.137	109.148	35.614	46.232	78.429	26.274	0.000	57.541
13	39.665	27.417	66.179	42.017	63.242	42.751	65.093	31.040	56.724	44.399	57.150	57.541	0.000
14	33.049	27.098	17.907	12.941	17.474	53.314	25.265	31.882	118.318	29.209	31.111	56.023	45.787
15	13.613	13.950	38.526	14.093	36.295	25.516	38.064	14.018	62.701	23.930	26.126	32.015	32.491
16	16.978	15.379	26.106	12.897	25.490	17.860	37.868	23.566	81.722	22.613	16.208	40.964	39.497
17	60.683	67.775	29.654	39.412	44.083	51.435	28.029	81.664	190.907	47.599	68.522	116.958	91.923
18	31.956	26.096	11.705	15.024	11.999	32.033	36.779	37.707	110.999	28.740	19.689	52.059	57.139
19	51.145	35.305	18.592	31.987	18.034	42.801	25.066	44.082	142.079	26.063	57.312	108.776	60.051
20	80.598	56.247	29.771	46.474	33.459	71.050	41.098	59.352	179.213	27.097	66.076	122.409	89.892
21	10.903	15.215	51.387	28.430	49.550	30.280	83.196	36.711	54.318	34.864	17.422	37.006	36.972
22	49.212	52.550	62.803	45.959	58.891	49.734	18.708	46.901	122.910	60.095	81.598	89.846	65.419
23	76.232	69.740	13.149	33.262	18.926	74.998	48.809	73.881	194.490	53.733	49.563	116.497	100.753
24	32.557	20.553	48.470	41.210	35.313	57.943	67.208	45.993	60.334	52.407	50.893	68.810	36.605
25	28.347	22.969	45.257	36.493	39.401	54.108	50.358	28.829	86.668	33.610	50.557	77.288	52.728

(contd....)

Appendix H. (contd.)

	14	15	16	17	18	19	20	21	22	23	24	25
1	33.049	13.613	16.978	60.683	31.956	51.145	80.598	10.903	49.212	76.232	32.557	28.347
2	27.098	13.950	15.379	67.775	26.096	35.305	56.247	15.215	52.550	69.740	20.553	22.969
3	17.907	38.526	26.106	29.654	11.705	18.592	29.771	51.387	62.803	13.149	48.470	45.257
4	12.941	14.093	12.897	39.412	15.024	31.987	46.474	28.430	45.959	33.262	41.210	36.493
5	17.474	36.295	25.490	44.083	11.999	18.034	33.459	49.550	58.891	18.926	35.313	39.401
6	53.314	25.516	17.860	51.435	32.033	42.801	71.050	30.280	49.734	74.998	57.943	54.108
7	25.265	38.064	37.868	28.029	36.779	25.066	41.098	83.196	18.708	48.809	67.208	50.358
8	31.882	14.018	23.566	81.664	37.707	44.082	59.352	36.711	46.901	73.881	45.993	28.829
9	118.318	62.701	81.722	190.907	110.999	142.079	179.213	54.318	122.910	194.490	60.334	86.668
10	29.209	23.930	22.613	47.599	28.740	26.063	27.097	34.864	60.095	53.733	52.407	33.610
11	31.111	26.126	16.208	68.522	19.689	57.312	66.076	17.422	81.598	49.563	50.893	50.557
12	56.023	32.015	40.964	116.958	52.059	108.776	122.409	37.006	89.846	116.497	68.910	77.288
13	45.787	32.491	39.497	91.923	57.139	60.051	89.892	36.972	65.419	100.753	36.605	52.728
14	0.000	23.641	23.505	39.641	17.796	33.780	44.390	48.744	40.800	29.657	46.848	45.982
15	23.641	0.000	11.759	51.271	24.934	40.515	48.401	21.786	31.903	58.964	42.551	29.242
16	23.505	11.759	0.000	35.397	10.728	25.794	38.030	17.518	38.972	43.312	46.997	29.022
17	39.641	51.271	35.397	0.000	28.915	36.671	40.149	81.428	42.005	38.773	99.251	66.821
18	17.796	24.934	10.728	28.915	0.000	27.752	34.190	39.481	46.205	23.922	52.441	45.762
19	33.780	40.515	25.794	36.671	27.752	0.000	23.918	56.268	46.713	27.633	52.122	32.344
20	44.390	48.401	38.030	40.149	34.190	23.918	0.000	76.851	75.340	26.081	94.987	56.925
21	48.744	21.786	17.518	81.428	39.481	56.268	76.851	0.000	80.293	85.733	35.195	28.198
22	40.800	31.903	38.972	42.005	46.205	46.713	75.340	80.293	0.000	71.540	77.898	62.116
23	29.657	58.964	43.312	38.773	23.922	27.633	26.081	85.733	71.540	0.000	87.866	70.613
24	46.848	42.551	46.997	99.251	52.441	52.122	94.987	35.195	77.898	87.866	0.000	30.987
25	45.982	29.242	29.022	66.821	45.762	32.344	56.925	28.198	62.116	70.613	30.987	0.000

MULTIVARIATE ANALYSIS OF YOUNG AND MATURE CLONES IN PARA RUBBER
(*Hevea brasiliensis* Muell. Arg.)

By

JAYASHREE MADHAVAN

ABSTRACT OF THESIS
SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE
DOCTOR OF PHILOSOPHY
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DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM

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ABSTRACT

A study on young and mature clones of rubber (*Hevea brasiliensis*) was undertaken with the objectives of estimating the variability, correlations, direct and indirect effects of various traits influencing yield, estimating the genetic divergence and the factors contributing to divergence, identifying those variables that remain stable in both stages of the crop, and to examine the extent to which mature yield could be predicted using immature attributes. A number of morphological, structural, physiological and biochemical parameters were observed at the two stages of growth.

Significant clonal differences at both stages were observed for almost all the traits. There was high genetic variability at the mature stage for most traits, especially girth increment, laticifer area index, initial flow rate, final volume of latex, latex biochemical parameters (except for total solids content) and yield. However number of stomata per unit area, density of latex vessels, diameter of latex vessels, total solids content and chlorophyll a:b ratio had very low variability as indicated by their genotypic coefficients of variation. It was shown that the traits yield, girth, laticifer area index, initial flow rate, final volume of latex, plugging index, latex thiols, inorganic phosphorous, sucrose, magnesium, chlorophyll b and total chlorophyll were most likely to respond to selection since there was a preponderance of additive gene action in the inheritance of these traits, as indicated

by their moderate to high estimates of heritability coupled with high genetic advance. High heritability coupled with low genetic advance observed for stomatal density, bark thickness, leaf midrib lamina and palisade layer thickness indicate that these are governed by non additive gene action.

Among the immature plants, high genetic variability was observed for immature yield, time taken to sprout, number of flushes shed by the end of the first year (W3), diameter increment, number of new flushes produced and those retained on the entire plant in the second year (W5 and 7), number of latex vessel rows, laticifer area index, latex thiols, inorganic phosphorous, sucrose and magnesium and juvenile yield. Leaf size, specific leaf weight, density and diameter of latex vessels and chlorophyll a:b ratio showed extremely low estimates of genotypic coefficient of variation. Higher heritability estimates were recorded for all the anatomical and biochemical traits except density of latex vessels, than for the morphological traits, indicating the greater influence of environment on the latter. High heritability combined with high genetic advance was recorded for most of the anatomical and biochemical parameters and yield (except density and diameter of latex vessels and chlorophyll a:b ratio which had very low genetic advance estimates) indicating the preponderance of additive gene action in these traits. Moderate to high heritability followed by low genetic advance were seen for the traits height, first year scion diameter bark thickness, diameter of latex vessels, which implies the inheritance of these traits is governed mainly by non additive gene action, and hence will not respond to selection.

At the mature phase, strong genotypic correlations of average annual yield were observed with final volume of latex and initial flow rate, girth, girth increment, number of latex vessel rows, laticifer area index, bark thickness and inorganic

phosphorous content, while at the immature stage, laticifer area index, scion diameter in the second year, number of latex vessel rows, bark thickness, inorganic phosphorous, thiol content, girth increment, number of new flushes produced and those retained on the main stem in the second year, latex magnesium, chlorophyll a, chlorophyll b, total chlorophyll, leaf size, and number of flushes produced on the main stem in the two years (W8), were positively associated with testap yield at both the phenotypic and genotypic levels. Biochemical parameters at both stages contributed relatively less than the other characters to variation in yield, except for inorganic phosphorous in the immature stage which showed moderate association with yield.

Path analysis at the mature phase revealed that initial flow rate and bark thickness could be used effectively as selection parameters for yield, as their direct effects were the highest. Inspite of the moderate to high correlations of girth, girth increment, number of latex vessel rows, final volume of latex, density and diameter of latex vessels, selection for these traits *per se* will not effectively improve yield, as their direct effects are low. A negligible residue was obtained in the present study, implying that almost all the variation in mature yield in the present study could be accounted for by these variables. At the immature stage, number of latex vessel rows was found to exert the highest positive direct effect on yield, while bark thickness had a very high negative direct effect on yield. A residue of 0.33 indicates that other variables contributing to variability in yield at this stage have not been included. These could be the physiological parameters initial flow rate and final volume of latex, which had strong correlations with mature yield.

Genetic divergence was assessed using the D^2 statistic and Tocher's method of clustering was employed to group the clones in the two stages. Seven and five clusters respectively were formed for the mature and immature groups of clones. A great deal of similarity was found in the clustering pattern of the clones at the two stages, inspite of the difference in age and the variables used to compute the genetic distance. Most of the clones fell into one major group (Cluster I) with 18 and 19 clones respectively, of which 16 clones were in common. The clustering patterns of the remaining clones were also similar, with many of them being independent or forming two clone clusters. This indicates that though most of the clones were genetically close as they fell into one cluster, the remaining clones included in different clusters having divergence can be exploited in hybridization programmes.

Factor analysis carried out in the two stages identified 10 factors at the mature stage which were principally associated with yield, stomatal density, latex biochemical components, initial flow rate, bark structural traits and chlorophyll content. The nine factors identified at the immature stage were mainly associated with vigour, yield, chlorophyll content and leaf structural traits.

The perfomance of the 25 clones at the two stages of growth was evaluated on the basis of indices formulated using discriminant function analysis. There was no correlation between the performance of the clones at the two stages.

Correlations between immature attributes and corresponding mature attributes reveal that latex biochemical traits thiols, inorganic phosphorous, sucrose and magnesium, bark structural traits number of latex vessel rows, laticifer area

index, stomatal density, density and diameter of latex vessels were relatively stable over the years, while morphological traits and yield appear to be the most affected with increase in age. Correlations between mature yield in the BI 2 panel and immature attributes of two year old plants revealed that the association with immature bark thickness and number of latex vessel rows were still retained at this age. Step wise regression of mature yield on immature attributes showed that number of latex vessel rows could explain only 21 per cent of the variability in mature yield. As no good fit was obtained, yield at this stage cannot be predicted using the first two years'attributes included in this study.

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