VARIABILITY, CORRELATIONS AND HETEROSIS FOR YIELD AND YIELD COMPONENTS IN CERTAIN HYBRID CLONES OF THE PARA RUBBER TREE, *HEVEA BRASILIENSIS* (Willd. ex Adr. de Juss.) Muell. Arg.

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BY

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JANUARY 1997

...to my beloved Mother

CERTIFICATE

Certified that this thesis entitled "VARIABILITY, CORRELATIONS AND HETEROSIS FOR YIELD AND YIELD COMPONENTS IN CERTAIN HYBRID CLONES OF THE PARA RUBBER TREE, *HEVEA BRASILIENSIS* (Willd. ex Adr. de Juss.) Muell. Arg." is an authentic record of the original research work carried out by Mrs. J. Licy under our joint supervision and guidance during the period October 1991 to January 1997.

It is further certified that no part of this work has previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles of any University or Society to her.

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CHAPTER 1

Introduction

The Para rubber tree, *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg., is the youngest of the domesticated major crops of the world. The original genetic material of *H. brasiliensis*, referred to as the "Wickham gene pool", was introduced to South East Asia by Sir Henry Wickham in 1876 from the Amazon river basin in Brazil, the centre of diversity of the genus. From this original material with an average yield of 200 -300 kg per hectare per year, substantial improvement in productivity, to around 3000 kg per hectare per year for the recently evolved clones has been achieved over a limited period. This ten fold advancement in productivity was achieved mainly through systematic breeding and selection. However, the genetic advance gained in the early breeding phases seems to have slowed down in the more recent phases of breeding (Tan, 1987; Ong and Tan, 1987; Simmonds, 1989), for which various reasons have been attributed. The perennial nature of the crop, seasonal nature of flowering, low fruit set, long duration of the breeding and selection cycle, the heterozygous nature of the species, the lack of any totally reliable early selection parameters etc. hamper quick development and release of proven cultivars.

In India, commercial planting in a 200 hectare plantation in 1902 marked the beginning of the rubber plantation (Plate 1) industry (Nair *et al.*, 1976) and crop improvement programmes were initiated in 1954-1955 with the inception of the Rubber Research Institute of India (RRII). Conventionally genetic improvement is achieved by introduction, selection and hybridization. Hybridization coupled with vegetative propagation and clonal selection is the most important method of *Hevea* breeding in India (Plate 2 and Plate 3). The approach involves artificial pollination between selected male and female clones, evaluation of the F1 hybrids and selection of promising recombinants. Only a small proportion of the female flower set fruit and a good number of flowers are shed during tender stage (Saraswathyamma, 1990). In *Hevea*, systematic breeding and selection has resulted in the development of a series of high yielding clones.

The early hybrid clones developed by the RRII belong to the RRII 100, 200 and 300 series (Annamma *et al.*, 1990b) Among clones of RRII 100 series, RRII 105 (Plate 4) is a very promising selection, (Nair and George, 1969; George *et al.*, 1980; Nazeer *et al.*, 1986) with wide popularity in the rubber planting sector. Clones RRII 203 and RRII 208 (Saraswathyamma *et al.*, 1987) and RRII 300 and RRII 308 (Premakumari *et al.*, 1984) are the best selections in the 200 and 300 series respectively. Commercial performance of eight popular clones from ten large estates in the major rubber growing tract of Kerala, revealed RRII 105 to be the highest yielder (Mercykutty *et al.*, 1995). Many other selections are in various stages of experimental evaluation. In the present hybridization programmes parent clones are selected based on various components contributing to yield.

1.1 Genetic studies

The genetic variability in a crop is of prime importance in its improvement. A knowledge of the available variability within the species for the desired character enables the breeder in determining the most potential parents. Hence the genetic potentialities of yield and yield contributing characters and their relationship should be properly assessed, for improving the crop.

1.1.1 Variability, heritability and genetic advance

For effective selection and utilization of genotypes for breeding programmes, a thorough study of genetic variability, heritability and genetic advance is essential. Fisher (1918) laid the foundation of biometrical genetics and developed the statistical parameters like mean, variance and co-variance. Charles and Smith (1939), Powers (1942) and Powers *et al.*(1950) separated genetic variance from total variance using estimates of enviornmental variance. Genotypic coefficient of variation indicates the relative magnitude of genetic diversity present in the material and helps to compare the genetic variability present for different characters.

The effectiveness of selection for any character does not depend on the phenotypic variability alone. It is of great interest to the breeder to determine how much of the phenotypic variability present in a character is heritable. The heritability estimate provides such a measure. The other parameter of utility is the genetic advance which is a measure of the expected genetic progress and enables to evaluate the selection procedure.

In the early part of this century Johanson (1909) demonstrated that phenotype (P) is the interaction of genotype (G) and the environment (E). He further attributed the variation in a segregating population to both heritable and nonheritable components.

According to Jain (1982) heritability in the broad sense is the ratio of the genotypic variance to the total variance. Expected genetic gain as proposed by Burton and Devane (1953) is the product of heritability, phenotypic standard deviation and selection differential. According to Johnson *et al.*(1955) the genetic advance is more useful in predicting the actual value of selection than heritability, though the latter value indicates the relative effectiveness of selection based on phenotypic expression of the character.

Substantial amount of work has been done to understand the genetic basis of commercially important characters of most of the perennial crops (Tan *et al.*, 1975; Tan, 1977; Kester *et al.*, 1977; Nambiar and Ravindran, 1974; Nambiar *et al.*, 1970; Nambiar and Nambiar, 1970; Bavappa and Ramachander, 1967; Ramachandar and Bavappa, 1967; Srinivasan and Subbalakshmi, 1981). Ramachander (1990) has highlighted on the problems and prospects of application of biometrical genetics in perennial crops.

Gilbert *et al.*(1973) were the first to report on the application of biometrical analysis to rubber progeny data. They concluded that inheritance of yield and girth are additive and so phenotypic selection and family prediction would be effective. Nga and Subramaniam (1974) reported high genetic variations for yield and girth. Analysing the data of Ross and Brookson (1966), Simmonds (1969) found that most of the differences between family yields could be accounted for by additive gene effect. Data on yield and girth of progenies resultant of hand pollinations had been attempted by Tan *et al.* (1975), Ho (1976),Tan (1975), Alika (1980), Liang *et al.* (1980), Licy *et al.*(1992) and Licy *et al.* (1993) for variance analysis. The studies in general indicated the preponderance of additive genetic variance.

Genetic variance, heritability and genetic advance from selection, with respect to rubber yield and morphological characters were studied by Alika (1985). Tan (1979a) reported on heritabilities of biometrical characters viz. dry rubber yield, virgin bark thickness and renewed bark thickness. While Liang *et al.* (1980) obtained moderate heritability for yield in seedling progenies involving eight cross combinations, Liu *et al.* (1980) obtained a low broad sense heritability estimate for yield, girth and bark thickness in rubber from a single pair mating design.

Markose (1984) obtained high phenotypic and genotypic coefficients of variation coupled with high heritability for dry rubber yield, volume of latex and number of latex vessel rows. Variability and association of certain bark anatomical traits in *Hevea* were studied by Premakumari *et al.* (1987). According to Simmonds (1989) heritabilities of economic characters in rubber are generally high and therefore progeny performances are more or less predictable.

1.1.2 Correlation

The study of correlation is a preliminary requirement in plant breeding programme. Information on the magnitude and direction of correlations that exist among different characters is a basic prerequisite that would enable deciding the proper breeding procedure to be adopted, the characters on which selection is to be based and weightage to be given to various yield components, so that the selection for yield would be most effective. The idea of correlation was first presented by Galton (1889) and later was elaborated by Fisher (1918) and Wright (1921). Burton (1952) introduced a convenient procedure for the calculation of the phenotypic and genotypic coefficients of correlation.

The factors affecting yield are the components of yield and also the factors limiting yield (Mayo, 1980). The rubber yield in *H. brasiliensis* is a manifestation of various morphological, physiological, anatomical and biochemical characters of the tree (Pollinere, 1966). Visibly the factors are ultimately manifested in the volume of latex on tapping and the quantum of rubber it contains (Sethuraj, 1977). Lee and Tan (1979) found a close association between latex volume and yield of rubber and suggested that the volume of latex was a dominant factor determining yield.

Attempts have been made to correlate productivity with morphological characteristics of the planting materials (Whitby, 1919; Gilbert *et al.*, 1973; Narayanan *et al.*, 1973; Lee and Tan, 1979; Liang *et al.*, 1980; Liu *et al.*, 1980; Pavia *et al.*, 1982; Hamzah and Gomez, 1982; Filho *et al.*, 1982; Licy and Premakumar 1988; Mydin, 1992 and Premakumari, 1992). Rubber yield was found to have positive correlation with girth, number of latex vessel rows and bark thickness (Dijkman and Ostendorf, 1929; Gilbert *et al.*, 1973; Lee and Tan, 1979; Liang *et al.*, 1980; Liu *et al.*, 1980 and Mydin *et al.*, 1992).

Yield and vigour in rubber are hardly separable according to Simmonds (1989). Vigorous growth of the plant enables early opening of the tree for tapping. Hence early vigour plays an important role with respect to exploitation. Normally the trees are brought under tapping when they attain a girth of 50 cm at a height of

125 cm from the bud union . On opening for tapping, photosynthate is partitioned between two competing sinks: latex offtake and tree growth. Accordingly, growth rate tends to decline under tapping and the breeder's task 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; Wicherley, 1975; 1976). According to Ramaer (1929) growth vigour is genetically controlled and this was confirmed by Ferwerda (1940) and De Jong (1941). There is significant clonal variation with regard to girth increment under tapping. Napitapulu (1973) found a positive correlation between yield and girth within clones but not between clones. Yield and girth increment under tapping tend to be negatively correlated (Ho, 1976). Nazeer *et al.* (1986) also reported similar associations between yield and girth increment rate.

The flow of latex starts only after injuring the bark and there by opening the latex vessels. During the process of tapping, thin shavings of the bark are removed simultaneously opening the latex vessels (Ridley, 1897). As a result latex contained in the laticifers exudes, which in turn is collected (Plate 4). Field latex usually contains 30 to 45 per cent rubber (Sethuraj and Nair, 1980). The dry rubber content (drc) varies in different clonal latices (Ng *et al.*, 1970). Grantham (1925) and Heusser and Holder (1931) found a negative correlation between yield and drc. It was reported that drc varies with clone, age, length of the tapping cut and frequency and time of tapping (Kang and Hashim, 1982).

There is an inherent clotting mechanism within the latex vessels which is responsible for the cessation of latex flow (Southorn, 1966) consequent to the plugging of the opened ends of the laticifers. Milford *et al.* (1969) proposed an index - the plugging index - for measuring the extent of plugging. A higher initial rate of flow *per se* can result in a lower plugging index (Sethuraj, 1992).

Yield in rubber has been found to be positively correlated to the initial flow rate (Paardekooper and Sarmo son, 1969) and negatively correlated to plugging index (Milford *et al.*, 1969). Saraswathyamma and Sethuraj (1975) reported seasonal variation in yield to be related to clonal variation in the plugging index. The initial flow rate and plugging index are thus two important physiological components determining latex yield (Sethuraj, 1977). A low plugging index and high initial flow rate contribute to high yield. Sethuraj (1981), through a theoretical analysis of yield components of *H. brasiliensis* represented the effect of the major yield components by the formula,

$$Y = \frac{F.l.Cr.}{p}$$

where Y = yield ;

F = initial flow rate per unit length of the tapping cut;

l = length of the tapping cut;

Cr = percentage rubber content and

p = plugging index.

These relationships indicate that the yield of rubber from a tree per tapping is proportional to the initial flow rate, length of the tapping cut and the rubber content of the latex and inversely proportional to the plugging index.

Anatomical components also play a major role in determining rubber yield (Panikkar, 1974). Latex is present in latex vessels which occur in almost all parts of the tree except the wood (Bobilioff, 1923; Aggelen-Bot, 1948; Schweizer, 1949). In the bark latex vessels are more concentrated in the region near the cambium (Bobilioff, 1923; Dijkman, 1951; De Jong and Warrier, 1965). The latex vessels are produced in discreet rows and appear as concentric rings in cross section. The vessels belonging to the same ring are tangentially interconnected (Plate 5). The laticifers are generally oriented in an anticlockwise direction, the angle of inclination varying from three to five degrees to the vertical.

Rubber yield was found to have positive correlation with bark thickness and number of latex vessel rows (Gomez *et al.*, 1972; Ho *et al.*, 1973; Narayan *et al.*, 1974). A positive correlation of initial rate of flow and number of latex vessel rows has also been reported (Sethuraj *et al.*, 1974).

The role and importance of biochemical components of rubber yield viz. total solid content (TSC), thiols, inorganic phosphorus (Pi), magnesium (Mg) and sucrose content in *Hevea* had been discussed by various workers (Jacob *et al.*, 1986; Eschbach *et al.*, 1984; Jacob, 1970; Jacob *et al.*, 1983; Subronto, 1978; Nair, 1992). Viscosity of latex depends on the total solids present. A high total solid content may limit yield by hindering flow (Brozozowska *et al.*, 1979; Milford *et al.*, 1969; Buttery and Boatman, 1976). On the other hand a low TSC is indicative of weak latex regeneration *in situ* (Eschbach *et al.*, 1984; Prevot *et al.*, 1984). The effect of magnesium is reported to be two fold. It can activate some latex enzymes (D' Auzac, 1975; Jacob, 1970; Jacob *et al.*, 1981; Jacob *et al.*, 1983) and secondly it can also destabilise latex by neutralising the negative charges on latex particles, and may thus reduce or even stop latex flow (Southorn and Yip, 1968).

Inorganic phosphorus (Pi) in latex is a measure of energy metabolism. A high Pi value shows that the laticiferous system is very active (Lynen, 1969). As a result there is a highly significant positive correlation between Pi and productivity for many clones. Thiols, besides being able to neutralise toxic oxygen produced during cell metabolism, are able to activate some key enzymes, increasing metabolic activity and hence the regeneration of latex (Jacob *et al.*, 1986). Since sucrose is the primary product of photosynthesis, a high sucrose content in latex indicates either high metabolic production of sucrose or low metabolic utilization of sucrose content and production can be either positive or negative depending on the circumstances (Tupy and Primot, 1976; Prevot *et al.*, 1984). Nair (1992) reported that an active metabolism associated with high Pi, good sugar supply capacity implying high sucrose content, stable latex, characterized by low magnesium and high Pi and thiol content and medium total solid content necessary for good flow are conditions favouring high latex production. Bricard and Nicolas (1989) carried out studies to determine the reliability of the above biochemical parameters and observed that all the above characters exhibited high reliability.

1.1.3 Heterosis

The term 'heterosis' is defined as the superiority of an F_1 hybrid over its parents and utilization of hybrid vigour as a means of maximising the yield of agricultural crops has become one of the most important techniques in plant breeding. The genetic basis of heterosis as defined by Mather (1955) are: (I) Hybrid vigour is a direct property of heterozygosity and (ii) Hybrid vigour in the F_1 is because of contribution of superior genes by both the parents.

India is the fourth biggest natural rubber producer today, with a total production of 506,910 tonnes (Rubber Board, 1997). However, based on the present rate of development, the projected demand for natural rubber by the turn of the century would be much higher than the production. Hence research and development programmes are aimed at increasing natural rubber production to the highest possible level. Exploitation of heterosis holds tremendous scope in rubber and vegetative propagation enables fixation of the heterotic attributes obtained in the F_1 generation. Miller and Lee (1964) in their study on cotton opined that heterosis is associated primarily with the differences in the base performance of the parental varieties *per se* rather than with differences in the amount of heterosis expressed by different crosses. Only scanty reports on work in this line are available in rubber. Very high estimates of heterosis for latex yield was observed by Olapade (1988). Mydin *et al.* (1990) obtained high estimates of hybrid vigour for juvenile girth in certain hybrid *Hevea* clones. Licy *et al.* (1992) observed moderate to high estimates of heterosis for yield and yield attributes in the present population under study during evaluation at an early age of four and a half years after field planting. Similar observations were recorded by Licy *et al.* (1993) in a population of 14 hybrid clones in the early phase of evaluation.

1.2 Early selection

The major limiting factor hindering rapid progress in recommending newer planting materials for planting, in a perennial crop like rubber, is the long clonal testing period. Lack of fully reliable early selection methods also poses a hindrance towards quick identification of promising clones. Realising the importance of juvenile selection, early workers developed a number of techniques, of which the modified Hamaker-Morris-Mann method (1932-'38) is the widely adopted one. A test incision method developed at RRII (Annamma *et al.*, 1989) facilitates quantification of juvenile yield at the age of one year.

Studies on correlation between nursery yield and mature yield revealed low to moderate association between the two parameters (Ong *et al.*, 1986). Thus with the available early prediction methods, nursery yield can be taken only as a fair indicator of mature yield. A study on early evaluation incorporating clones of high, medium and low yield potentials revealed performance index at an age of two years to be good enough for selection of clones at an early age (Varghese *et al.*, 1993). However, further investigations are required for development of fully reliable early prediction methods so as to effect a possible reduction in the yield testing period which would favour a more or less quick release of cultivars.

1.3 Multiclone concept and clonal composites

One of the notable contributions of RRII had been the development of RRII 105 (Plate 4), the high yielding clone, extremely popular with the small and large growers. But it has come to a stage that more than 90% of the planters plant only this clone, leading to a situation of 'monoclonal development' during the last decade which has the potential danger of narrowing down the genetic variability leading to disease and pest epidemics. In *Hevea*, recent reports indicate instances of less serious diseases becoming more severe. The most serious problem reported is severe damage of RRIC 103, one of the most popular high yielder in Sri Lanka, due to *Corynespora* attack (Varghese et al., 1990). With the objective of preventing such a possible danger, RRII has proposed a strategy for encouraging multiclone planting from 1991 onwards. In this context any alternate clone with an yield potential of at least comparable to that of RRII 105 is worth evolving to constitute components of a multiclone population. *Hevea* being a highly heterozygous and predominantly open pollinated tree species, offers wide range of variability among clones and genetically divergent parents could be used in hybridization programmes to produce highly heterotic progenies to satisfy the above need.

The present investigations were taken up on the above background of this crop species with the following objectives in view:

(1) to find out the extent of variability for yield and its components in a set of hybrid clones;

(2) to estimate genetic parameters like heritability and genetic advance;

(3) to determine the nature and magnitude of association among yield and its components;

(4) to evaluate the extent of heterosis and

(5) to find out the possibilities of early identification and selection of potential hybrid clones resulting in a possible reduction in the period required for field evaluation and release of clones.

The final objective of the studies has been to identify a set of clones, comparable with or superior to, in performance of RRII 105, the most popular high yielding clone, as components of a clonal composite population, aimed at an over all boost in production and productivity.

Plate 1. An estate view of a mature rubber plantation

(a) (b) (c)

Plate 2. (a) A twig of *Hevea* showing the mature inflorescence

(b) A female flower showing the ovary and stigma and a male flower showing the anther column

(c) The technique of hybridization (hand pollination) in *Hevea*

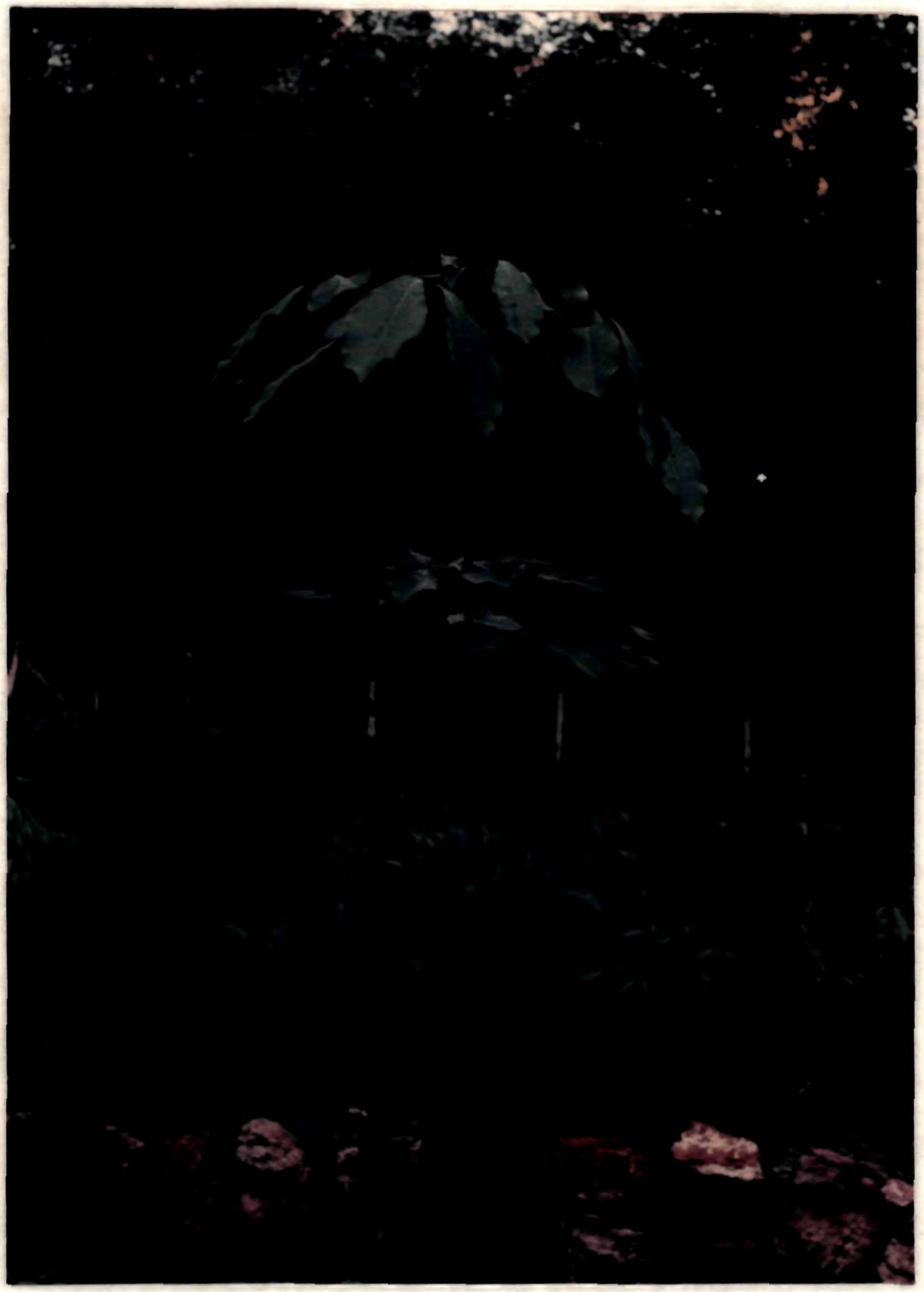
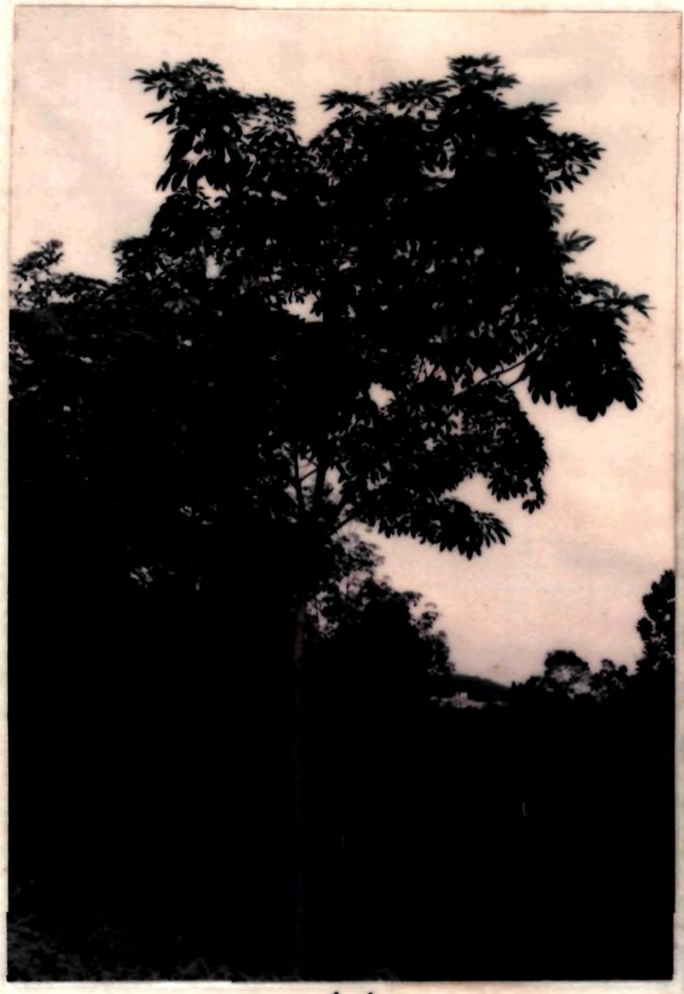


Plate 3. A two whorled polybag plant of RRII 105 resultant of vegitative propagation (bud grafting)



(a)

(b)

Plate 4. (a) An young tree of the clone RRII 105
(b) Trunk of a mature tree under tapping with the latex being collected in the cup

(a)

(b)

Plate 5. (a) Radial longitudinal section of *Hevea* bark showing the latex vessel rows

(b) Tangential longitudinal section of *Hevea* bark showing the interconnections of latex vessels

CHAPTER 2

Materials and Methods

2.1 Location

The field trial was conducted at the Experiment Station of the Rubber Research Institute of India, (9° 32'N 76° 36'E) at Kottayam, Kerala State, India. The land was previously planted with rubber which was replanted with the experimental materials of the present study. The terrain is generally hilly and slopy.

2.2 Experimental materials

Twenty five clones of *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg, which constituted twenty three hybrid clones resultant of a biparental cross of RRII 105 and RRIC 100, and the two parental clones, maintained by the Botany Division of the Rubber Research Institute of India, at the Experiment Station at Kottayam were utilised for the study (Table 1). However, from among the 25 clones, only 11 clones were selected for studies pertaining to biochemical parameters. Brief description of the parental clones is given below.

Table 1. Experimental materials

Sl.No	Clone	Place of origin	Parentage
1.	82/3 *	Rubber Research Institute of India, Kottayam, India	RRII 105 x RRIC 100
2.	82/4	- do -	- do -
3.	82/5	- do -	- do -
4.	82/7	- do -	- do -
5.	82/8	- do -	- do -
6.	82/10 *	- do -	- do -
7.	82/11	- do -	- do -
8.	82/14 *	- do -	- do -
9.	82/15	- do -	- do -
10.	82/17 *	- do -	- do -
11.	82/18	- do -	- do -
12.	82/19	- do -	- do -
13.	82/20	- do -	- do -
14.	82/21	- do -	- do -
15.	82/22 *	- do -	- do -
17.	82/24	- do -	- do -
16.	82/23	- do -	- do -
18.	82/25	- do -	- do -
19.	82/26	- do -	- do -
20.	82/27 *	- do -	- do -
21.	82/28 *	- do -	- do -
22.	82/29 *	- do -	- do -
23.	82/30 *	- do -	- do -
24.	RRII 105 *	- do -	Tjir1 x Gl1
25.	RRIC 100 *	Rubber Research Institute of Sri Lanka, Sri Lanka.	RRIC 52 x PB 86

* Clones studied for biochemical parameters.

RRII 105:

A hybrid clone of *H. brasiliensis* currently enjoying maximum popularity in the country. Parents are Tjir 1 and Gl 1. Vigour before and after tapping, average. Virgin and renewed bark thickness good. Yield very good. The average yield obtained over the first 11 years of tapping in commercial planting is 1970 kg ha $^{-1}$ year $^{-1}$. Latex is white with high drc. The clone has a fair degree of tolerance to abnormal leaffall disease, but is highly susceptible to pink disease. Occurrence of tapping panel dryness is high and hence tapping under half spiral, third daily (1/2 s d/3) is recommended. Free from serious wind damage if branch development is kept balanced.

RRIC 100:

This is a medium yielding hybrid clone developed by the Rubber Research Institute of Sri Lanka. Parents are RRIC 52 x PB 86. The clone has fairly high vigour (Fernando and Wijesinghe, 1970), slightly tolerant to abnormal leaf fall and powdery mildew. In India, the clone recorded an yield of 37.41 g tree $^{-1}$ tapping $^{-1}$over three years in the large scale trial (Joseph and Premakumari, 1987) and estimated yield for eleven years in the large scale clone trial is 2275 kg ha $^{-1}$ year $^{-1}$. (Joseph, 1996).

2.3 Experimental methods

The field experiment for the study was laid out in 1985, as a small scale evaluation trial of hybrid clones, adopting a randomised block design with three replications and four trees per plot. The spacing was 3.4 x 6.7 m. All cultural operations were carried out uniformly as recommended by the Rubber Board. The trees were opened for tapping following the half spiral 3rd daily (1/2 s d/3) system in 1993. Observations on the following characters were recorded.

2.3.1 Yield and major yield components ✓

(i) Dry rubber yield

Dry rubber yield per tree per tapping was recorded on all tapping days for a consecutive period of three years from January 1993 to December 1995. Yield was recorded by cup coagulation where by the latex was coagulated in the collection cup using one per cent formic acid. The coagula were then partially dried under shade for a week followed by drying in the smoke house for about one month. The dried lumps were weighed using a pan balance. As the lumps retain moisture even after prolonged drying, an allowance of 10 per cent was made from the recorded weight to compensate for the residual moisture (Markose, 1984).

Annual mean values, mean values for the stress period during summer season (February to May) and peak yield period (September to December) over the three years were computed separately.

(ii) Volume of latex

The total volume of latex obtained from each tree per tapping was recorded on a bimonthly interval during the period of observations. Two trees each from each replication was selected for recording latex volume.

(iii) Initial rate of latex flow

Initial flow of latex for the first five minutes of tapping was recorded at bimonthly intervels. Rate of latex flow per unit length of the tapping cut was estimated as

$$\frac{\text{Initial volume for the first five minutes(ml min}^{-5}\text{) x 50}}{\text{Length of tapping cut (cm)}}$$

(iv) Dry rubber content

The percentage dry rubber content (drc) of latex obtained from each tree was determined at bimonthly intervals from January 1993 to December 1995. Latex samples of known volume (20 ml) from two trees each from each replication were coagulated and the coagulum, after passing through rollers, was oven dried at 55°C for one week. The dried samples were then weighed and drc was determined as per cent rubber content on a dry weight by volume basis (Sethuraj, 1981).

(v) Plugging index

Plugging index was computed at bimonthly intervals from January 1993 to December 1995. Two trees each from each replication were selected for recording the observations. Plugging index was computed employing the formula proposed by Milford *et al.* (1969):

$$\text{Plugging index} = \frac{\text{Mean initial flow rate (ml/min.)}}{\text{Total volume of latex (ml)}} \times 100$$

(vi) Girth at opening

Girth of the trunk at a height of 150 cm from the bud union was measured at the commencement of first year, second year and third year of tapping.

(vii) Girth increment rate under tapping

Increase in girth from the first to third year of tapping was determined, from which the mean girth increment per year was worked out.

(viii) Virgin bark thickness

Thickness of the virgin bark on the untapped portion of the trunk, at the opposite side of the tapping panel at a height of 150 cm from the bud union was measured prior to opening the trees for tapping and during the three years of tapping at the same height using a Schleiper's gauge.

(ix) Number of latex vessel rows in virgin bark

Virgin bark samples were collected during the opening year of tapping (1993) and at the end of the third year of tapping (1995), from two trees each from each replication and fixed and preserved in 90:5:5 Formalin Aceto Alcohol. Radial longitudinal sections of the bark were taken at and stained in Sudan IV. Number of latex vessel rows was recorded from observations of three sections from each bark samples under light microscopy.

(x) Renewed bark thickness

In order to evaluate the performance of the clones in the early phase, the clones were subjected to tapping during 1990 ie. four and a half years after field planting, for a period of one year. Renewed bark thickness of bark with six years' bark renewal was measured using a Schleiper's guage during January 1996.

(xi) Number of latex vessel rows in renewed bark

During January 1996, renewed bark samples from the trunk portion which was tapped during 1990 was collected which constituted samples of six years' bark renewal. Samples were collected from two trees each from each replication and the number of latex vessel rows was recorded as mentioned above.

2.3.2 Biochemical subcomponents

Materials for analysing biochemical subcomponents of latex yield comprised of nine hybrid clones from among the present materials under study and the parental clones (Table 1).

The biochemical parameters studied were total solid content (TSC), thiols, inorganic phosphorus (Pi), sucrose and magnesium (Mg) present in the latex. The above parameters were recorded during the third year of tapping.

Latex samples from two trees from each replication were collected in ice cooled beakers. inorganic phosphorus and magnesium were extracted from a known amount of latex with 2.5 per cent trichloro acetic acid. For the determination of total solid content one g of latex sample was dried to constant weight. Thiols were measured by the method of Boyne and Ellmam (1972). Inorganic phosphorus was determined by the method of Taussky and Shorr (1953). Magnesium was estimated by atomic absorption spectrophotometry using the methods suggested by RRIM (1973). The concentration of magnesium was obtained using atomic absorption spectrophotometer model No.GBC 902. The method of Scott and Melvin (1953) was followed for the estimation of sucrose. The whole procedure was repeated twice and the pooled mean of all the observations were taken for the computations. The data was utilised for estimating genetic parameters as well as for correlations studies.

2.3.3 Early evaluation

In order to assess the early performance of the clones under study, the clones were subjected to tapping at an immature age of four and a half years after field planting for a period of one year during 1990. Data on all the above characters, except x and xi were recorded and utilised for evaluation of early versus mature performance of the clones.

2.4 Statistical analysis ✓

The mean data computed for each character from the three replications were subjected to statistical analysis. The estimates of Mean, Variance and Standard error were worked out by adopting the standard methods suggested by Panse and Sukhatme (1985).

2.4.1 Genetic variability

2.4.1.1 Analysis of variance

Analysis of variance for randomized block design was done according to the usual procedure. Pooled mean values over the first three years of tapping were utilized for most of the characters. For structural and biochemical parameters data collected during the third year of regular tapping was used.

Analysis of variance was carried out in order to :

(i) test whether there exist significant differences among clones, with respect to various traits,

(ii) estimate the components of variance and covariance,

(iii) compute the genotypic and phenotypic correlation coefficients, and

(iv) test whether there exists significant difference in the heterotic response among clones for the various traits.

The significance test was carried out by referring to the standard 'F' Table given by Fisher and Yates (1963).

2.4.2 Genetic parameters

2.4.2.1 Phenotypic and genotypic variance

Phenotypic and genotypic variances were estimated using the formulae given by Singh and Choudhary (1985)

$$\text{Genotypic variance } (\sigma^2 g) = \frac{\text{MSS treatment - MSS error}}{\text{Number of replications}}$$

$$\text{Phenotypic variance } (\sigma^2 p) = \sigma^2 g + \sigma^2 e$$

where $\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

$\sigma^2 e$ = Error variance

2.4.2.2 Coefficient of variability

Both genotypic and phenotypic coefficients of variability were computed by the method proposed by Burton and Devane (1953):-

(i) Genotypic coefficient of variability (GCV)

$$GCV = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$$

where, $\sigma^2 g$ is the genotypic variance and

$\bar{x}$, the mean of the population.

(ii) Phenotypic coefficient of variability (PCV)

$$PCV = \frac{\sqrt{\sigma^2 p}}{\bar{x}} \times 100$$

where, $\sigma^2 p$ is the phenotypic variance and

$\bar{x}$, the mean of the population.

2.4.2.3 Heritability (H^2)

Heritability (H^2) in the broad sense is the fraction of the total variance which is heritable and was estimated according to Jain (1982).

$$H^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

2.4.2.4 Genetic advance under selection (GA)

Genetic advance was estimated as percentage according to Allard (1960):

$$\text{Genetic advance (GA)} = \frac{K\,H^2\,\sigma p\,(x)}{\bar{x}}$$

where H^2 = Heritability estimate

p = Phenotypic standard deviation

K = Selection differential which is equal to 2.06 at 5% intensity of selection

$\bar{x}$ = Mean of the character x

2.4.3 Correlations

2.4.3.1 Simple correlation

Simple correlation coefficients between all possible early and mature characters were estimated as detailed below. As per definition simple correlations were estimated as:-

$$r_{xy} = \frac{\text{Cov}\,(xy)}{\sqrt{V(x)\,V(y)}}$$

where r_{xy} = simple correlation coefficient between characters x and y

Cov (xy) = Covariance of characters x and y

V(x) = Variance of character x

V(y) = Variance of character y

3.4.3.2 Genotypic and phenotypic correlations

Genotypic (r_g) and phenotypic (r_p) correlation coefficients among all possible characters were estimated using variance and covariance components as suggested by Singh and Choudhary (1985). Mean values of different characters at the third year of tapping were utilized for the computations. The formulae for their estimation are given below:-

Genotypic correlation coefficient

$$r_{xy}(g) = \frac{Cov\ xy\ (g)}{\sqrt{\sigma^2 x(g)\ \sigma^2 y(g)}}$$

where Cov xy (g) = genotypic covariance of character x and y

$\sigma^2 x (g)$ = genotypic variance of character x

$\sigma^2 y (g)$ = genotypic variance of character y

Similarly, phenotypic correlation coefficient

$$r_{xy}(p) = \frac{Cov\ xy\ (p)}{\sqrt{\sigma^2 x(p)\ \sigma^2 y(p)}}$$

where Cov xy (p) = phenotypic covariance of characters x and y

$\sigma^2 x (p)$ = phenotypic variance of charcter x

$\sigma^2 y (p)$ = phenotypic variancaoc character y

The significance of the correlation coefficients were tested according to Fisher and Yates (1963).

2.4.3.3 Regression coefficient

From the variance and covariance analysis simple regression coefficients were worked out.

$$b_{(y/x)} = \frac{\Sigma yx}{\sqrt{\Sigma x^2}}$$

where, $b_{(y/x)}$ is the regression coefficient of character y on character x

and Σx^2 is the sum of squares of character x.

2.4.4 Heterosis

Percentage of heterosis over the mid parent (MP) and better parent (BP) and over the standard clone RRII 105 (in cases where the better parent was not RRII 105) were calculated by the method of Turner (1953a and 1953b) and Hayes *et al.* (1955):-

$$\text{Mid parent value (MP)} = \frac{P_1 + P_2}{2}$$

where P_1 and P_2 are the female and male parents respectively.

$$\text{Percentage of heterosis over MP} = \frac{F_1 - MP}{MP} \times 100$$

$$\text{Percentage of heterosis over BP} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{Standard heterosis} = \frac{F_1 - \text{Mean of standard clone}}{\text{Mean of standard clone}} \times 100$$

The following standard errors were used to test the significance of heterosis.

$$SE\ (MP) = \sqrt{\frac{3\ Me}{2r}}$$

$$SE\ (BP)\ \text{and}\ SE\ (\text{standard variety}) = \sqrt{\frac{2\ Me}{r}}$$

where, Me = error mean sum of square

r = number of replications

CHAPTER 3

Experimental Results

The results of the present investigation are presented under the following main headings.

1. Genetic variability
2. Estimates of genetic parameters
3. Association of characters
4. Forecasting future performance and early selection and
5. Heterosis

3.1 Genetic variability

3.1.1 Analysis of variance

The analysis of variance was carried out for all the characters viz. dry rubber yield (annual, summer and peak), volume of latex, rate of latex flow, dry rubber content , plugging index, girth at opening, girth increment rate, number of latex vessel rows in virgin bark and in renewed bark, thickness of virgin and renewed bark, total solid content, thiols, inorganic phosphorus, magnesium and sucrose present in latex. The results are presented in Table2 and Table 3.

Table 2. Analysis of variance among clones for yield and major yield components

Sl.No.	Characters	Mean squares			F
		Replications	Clones	Error	(clones)
1.	Annual mean dry rubber yield.	147.03	1016.44	115.58	8.79**
2.	Summer yield	267.83	761.05	102.56	7.42**
3.	Peak yield	314.79	1630.41	171.76	9.49**
4.	Volume of latex	1242.97	9001.69	1132.33	7.95**
5.	Rate of latex flow	1.01	248.59	19.72	12.61**
6.	Dry rubber content	7.40	20.41	5.15	3.97**
7.	Plugging index	0.18	1.79	0.26	7.02**
8.	Girth at opening	48.79	35.59	15.69	2.27**
9.	Girth increment rate	2.37	3.05	0.80	3.83**
10.	Virgin bark thickness	2.63	0.58	0.32	1.83*
11.	Number of latex vessel rows in virgin bark	28.96	28.04	6.78	4.13**
12.	Renewed bark thickness	3.86	0.89	0.41	2.21**
13.	Number of latex vessel rows in renewed bark	14.48	40.03	5.90	6.78**

* Significant at $P < 0.05$ ** Significant at $P < 0.01$

Table 3. Analysis of variance among clones for biochemical subcomponents

Sl.No.	Characters	Mean squares			F
		Replications	Clones	Error	(clones)
1.	Total solid content	7.02	29.88	7.33	4.07**
2.	Thiols	2861.44	5052.44	1099.57	4.59**
3.	Inorganic phosphorus	9283.06	642231.59	114448.94	5.61**
4.	Magnesium	70183.65	761214.13	80794.24	9.42**
5.	Sucrose	0.505	20.23	4.09	4.95**

** Significant at $P < 0.01$

The differences among the genotypes, which include both the parents and hybrids were highly significant for all the characters studied. Except virgin bark thickness which was significant only at 5% level, all other characters were significant at 1% level indicating sufficient variability for selection. Highly significant clonal variation was observed for biochemical parameters also(Table 3).

3.1.2 Mean performance of clones

3.1.2.1 Yield and major yield components

(i) Dry rubber yield (Annual mean)

The annual mean dry rubber yield (pooled mean over the first three years of tapping) of clones is presented in Table 4. Among the hybrid clones, clone 82/14 exhibited the highest dry rubber yield of 88.20 g $tree^{-1}$ $tapping^{-1}$ whereas clone 82/19 exhibited the lowest yield of 20.21 g tree^{-1} tapping^{-1}, with the general mean being 51.57 g tree $^{-1}$ tapping^{-1}. Thirteen clones viz. 82/3, 82/4, 82/7, 82/10, 82/14, 82/17, 82/21, 82/22, 82/24, 82/25, 82/27, 82/29 and 82/30 recorded yield above the general mean of which nine clones yielded above RRII 105, the standard clone which is also the female parent. Clones 82/11, 82/18, 82/23, 82/26 and 82/28 were found to be on par with RRIC 100, the male parent. Five clones viz. 82/5, 82/8, 82/15, 82/19 and 82/20 were identified as low yielders (Table 4).

(ii) Summer yield

In the case of yield during summer season (stress period), the range of variation observed was from 11.14 g tree^{-1} tapping $^{-1}$ (clone 82/15) to 69.30 g tree^{-1} tapping^{-1} (clone 82/14) with a general mean of 36.42 g tree^{-1} tapping^{-1}. While 10 clones viz. 82/3, 82/10, 82/14, 82/17, 82/21, 82/22, 82/25, 82/27, 82/29 and 82/30 were found to excel RRII 105, two clones viz. 82/4 and 82/24 yielded just above the general mean. Five clones viz. 82/7, 82/18, 82/23, 82/24 and 82/8 were found to be medium yielders and on par with RRIC 100 (Table 4).

(iii) Peak yield

During the peak yielding period the yield ranged from 26.82 g tree^{-1} tapping $^{-1}$ (clone 82/19) to 104.32 g tree^{-1} tapping^{-1} (clone 82/14). Thirteen hybrid clones exhibited an yield above the general mean of 64.18 g tree^{-1} tapping $^{-1}$. While RRII 105 exhibited an yield of 76.06 g tree^{-1} tapping $^{-1}$ eight clones, viz. 82/3, 82/7, 82/17, 82/14, 82/21, 82/22, 82/29 and 82/30 gave an yield of above 76 g tree^{-1} tapping $^{-1}$. Two clones viz. 82/18 and 82/20 were found to be on par with RRIC 100 and the clones 82/5, 82/8, 82/15 and 82/19 were found to be low yielders during peak yielding period (Table 4), the yield ranging from 26.82 g tree $^{-1}$ tapping $^{-1}$ to 33.28 g tree $^{-1}$ tapping^{1}.

Table 4. Yield and rate of flow during the first three years of tapping

Sl.No.	Clone	Dry rubber yield (g tree $^{-1}$ tapping $^{-1}$) Annual**	Summer**	Peak**	Volume of latex** (ml tree $^{-1}$ tapping $^{-1}$)	Rate of flow** (ml min $^{-5}$cm^{-1} x 50)
1.	82/3	64.00	44.69	78.14	199.83	28.80
2.	82/4	56.73	38.78	71.86	199.47	32.76
3.	82/5	30.88	21.39	33.28	96.83	24.28
4.	82/7	66.14	33.47	96.47	173.31	22.52
5.	82/8	26.45	17.03	31.57	105.74	21.61
6.	82/10	56.61	42.99	65.17	188.70	44.76
7.	82/11	37.37	16.75	56.85	120.43	31.59
8.	82/14	88.20	69.30	104.32	280.12	43.55
9.	82/15	20.50	11.14	27.25	63.65	22.40
10.	82/17	60.95	44.72	86.15	209.63	40.19
11.	82/18	39.39	30.80	45.76	132.30	31.21
12.	82/19	20.21	14.07	26.82	91.70	15.50
13.	82/20	32.24	18.06	36.75	94.49	16.19
14.	82/21	61.70	46.21	79.46	173.70	32.85
15.	82/22	78.76	63.36	94.73	237.49	39.47
16.	82/23	44.12	27.61	55.27	138.37	31.92
17.	82/24	54.50	31.27	68.89	174.90	30.58
18.	82/25	53.55	36.80	64.54	183.64	32.01
19.	82/26	42.29	43.05	52.51	154.77	29.96
20.	82/27	62.96	46.02	75.25	222.48	35.43
21.	82/28	44.42	30.66	54.56	132.97	37.74
22.	82/29	78.83	67.25	93.46	237.16	31.40
23.	82/30	71.77	47.89	88.25	223.84	53.00
24.	RRII 105	58.55	41.47	76.06	185.76	45.51
25.	RRIC 100	38.15	25.74	41.13	121.40	28.54
General Mean		51.57	36.42	64.18	165.71	32.15
CD (0.05)		17.64	16.62	21.51	55.23	7.29

** Clonal variation significant at $P < 0.01$

(iv) Volume of latex

The volume of latex per tapping exhibited wide variation ranging from 63.65 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/15) to 280.12 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/14) with a general mean of 165.71 ml $tree^{-1}$ $tapping^{-1}$ (Table 4). Only one clone, the top yielder, 82/14, was found to be significantly superior to RRII 105 where as another set of eight clones viz. 82/3, 82/4, 82/10, 82/17, 82/22, 82/27, 82/29 and 82/30 performed above RRII 105 with a latex volume yield range of 188.70 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/10) to 237.49 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/22). The clones 82/7, 82/21, 82/24, 82/25 and 82/26 exhibited latex volume yield above 150 ml $tree^{-1}$ $tapping^{-1}$ and were found to be on par with RRII 105 which exhibited a latex volume yield of 185.76 ml $tree^{-1}$ $tapping^{-1}$. RRIC 100 exhibited a volume yield of 121.40 ml $tree^{-1}$ $tapping^{-1}$, and four clones 82/11, 82/18, 82/22 and 82/28 were found to be on par, with a latex volume yield ranging from 120.43 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/11) to 138.37 ml $tree^{-1}$ $tapping^{-1}$ (clone 82/23). The rest of the clones were found to be low yielding with respect to latex volume (Table 4).

(v) Rate of latex flow

Highly significant clonal variation was observed for the rate of latex flow. Among the hybrid clones, 82/30 exhibited the maximum flow rate of 53.00 ml min^{-5} cm^{-1} x 50 whereas clone 82/19 showed the minimum flow rate of 15.50 ml min^{-5} cm^{-1} x 50, the general mean being 32.15 ml min^{-5} cm^{-1} x 50 (Table 4). Four clones viz. 82/10, 82/14, 82/17 and 82/22 exhibited latex flow rate of above 38 and were found to be on par with RRII 105. Four other clones viz. 82/4, 82/21, 82/27 and 82/28 exhibited a flow rate above the general mean of 32.15 ml min^{-5} cm^{-1} x 50. While

RRIC 100 gave a latex flow rate of 28.54 ml min^{-5} cm^{-1} x 50, nine other clones viz. 82/3, 82/5, 82/11, 82/18, 82/23, 82/24, 82/25, 82/26 and 82/29 were observed to be on par with RRIC 100. The remaining five clones viz. 82/7, 82/8, 82/15, 82/19 and 82/20 were found to have low rate of latex flow (Table 4).

(vi) Dry rubber content

Highly significant clonal variation for dry rubber content was noticed among the 25 clones (Table 2) under study. Mean dry rubber content of the clones are presented in Table 5. The dry rubber content among the clones ranged from 27.10 per cent for the clone 82/19 to 36.74 per cent for the clone 82/11. Nine clones viz. 82/3, 82/11, 82/15, 82/17, 82/18, 82/21, 82/22, 82/23 and 82/30 exhibited a drc above that of RRII 105 which exhibited a drc of 33.46 per cent. While the clones 82/5, 82/10 and 82/28 were found to be on par with RRII 105, with above 32 per cent drc, the rest of the clones were found to be on par with RRIC 100 (Table 5).

(vii) Plugging index

As can be observed from the mean performance of clones (Table 5), the range of variation for plugging index was from 2.33 (clone 82/29) to 5.03 (clone 82/15), the general mean being 3.41. Fourteen hybrid clones were found to have values ranging from 2.33 (clone 82/29) to 3.42 (clone 82/17) compared to 3.60 of RRII 105, a character favouring higher yield. Five clones were found to be on par with RRII 105 with respect to plugging index. The clones, 82/5, 82/8, 82/11 and 82/15 showed high PI values.

Table 5. Dry rubber content, plugging index, girth at opening and girth increment rate in clones in the mature phase

Sl. No.	Clone	Dry rubber content**	Plugging index**	Girth at opening(cm)**	Girth increment rate(cm year $^{-1}$)**
1.	82/3	34.00	2.63	54.54	2.31
2.	82/4	31.00	2.87	58.69	2.59
3.	82/5	32.07	4.67	57.54	2.87
4.	82/7	28.19	2.63	56.34	4.19
5.	82/8	31.60	4.46	56.84	4.79
6.	82/10	32.58	3.81	53.52	2.96
7.	82/11	36.74	4.92	51.38	3.50
8.	82/14	30.64	2.59	57.49	3.05
9.	82/15	34.68	5.03	50.39	3.43
10.	82/17	34.63	3.42	54.73	1.86
11.	82/18	34.21	3.70	51.30	1.09
12.	82/19	27.10	3.32	51.04	3.60
13.	82/20	30.63	3.26	57.24	3.95
14.	82/21	36.65	2.97	50.64	1.24
15.	82/22	34.27	2.82	52.40	2.35
16.	82/23	33.53	3.75	50.59	3.09
17.	82/24	31.06	2.88	49.59	3.25
18.	82/25	28.51	2.77	52.08	2.02
19.	82/26	30.02	2.92	49.68	2.74
20.	82/27	29.88	2.47	52.79	1.39
21.	82/28	32.60	4.02	52.40	1.57
22.	82/29	28.81	2.33	62.77	3.28
23.	82/30	35.26	3.90	53.42	1.51
24.	RRII 105	33.46	3.60	49.04	3.49
25.	RRIC100	31.15	3.59	50.78	1.28
	General mean	32.13	3.41	53.49	2.70
	CD(0.05)	3.72	0.83	6.50	1.46

** Clonal variation significant at $P < 0.01$

thickness was found to be 7.83 mm. Twenty one out of the twenty three hybrid clones exhibited thickness above the general mean.

Table 6. Bark thickness and number of latex vessel rows in clones in the mature phase

Sl. No.	Clone	Virgin bark(3^{rd}Yr.)		Bark of six years' renewal	
		Barkthick-ness(mm)*	No.oflatex vesselrows**	Renewed bark thickness(mm)**	No.oflatex vesselrows**
1.	82/3	7.50	18.25	7.29	13.50
2.	82/4	7.88	14.72	6.95	17.55
3.	82/5	7.79	13.83	7.29	13.55
4.	82/7	8.04	15.39	8.25	16.73
5.	82/8	8.67	18.05	8.92	17.17
6.	82/10	7.84	19.58	8.54	17.38
7.	82/11	7.28	17.05	7.33	16.61
8.	82/14	8.61	21.76	7.85	19.83
9.	82/15	7.18	12.05	6.74	9.49
10.	82/17	8.09	20.49	8.34	18.93
11.	82/18	8.00	16.00	7.42	13.13
12.	82/19	7.21	9.33	6.92	8.94
13.	82/20	7.29	14.16	7.29	15.94
14.	82/21	8.39	20.44	7.55	15.91
15.	82/22	8.18	21.66	7.67	24.86
16.	82/23	7.52	15.44	7.70	14.03
17.	82/24	7.75	16.55	7.58	16.67
18.	82/25	8.21	17.44	7.63	15.33
19.	82/26	7.58	17.22	7.33	16.39
20.	82/27	8.18	16.72	7.34	14.01
21.	82/28	7.40	15.77	7.18	14.72
22.	82/29	7.89	22.00	7.68	21.64
23.	82/30	7.92	18.32	7.38	11.83
24.	RRII 105	8.17	15.21	8.00	19.38
25.	RRIC100	7.11	15.55	6.61	12.88
	General mean	7.83	16.92	7.55	15.90
	CD (0.05)	0.93	4.27	1.04	3.99

*** Clonal variation significant at $P < 0.05$ ** Clonal variation significant at $P < 0.01$**

(xi) Number of latex vessel rows in virgin bark

There was significant clonal variation for number of latex vessel rows in the virgin bark in the third year of tapping (Table 2). From the mean performance (Table 6), it is found that the range of variation for number of latex vessel rows is from 9.33 (clone 82/19) to 22.00 (clone 82/29) with a general mean of 16.92. Number of latex vessel rows exhibited by 12 clones were above the general mean. Of the remaining hybrid clones, ten clones were found to be on par with RRII 105 and only one clone ie. 82/19, was found to be very low in latex vessel row number.

(xii) Renewed bark thickness

Thickness of the renewed bark was measured at the portion of the trunk exploited for evaluating the early performance during 1990. The recording was done in 1996 by which time the bark had regenerated for six years. The clonal variation observed in the case of renewed bark thickness was significant (Table 2). The mean performance of renewed bark thickness among the 25 clones are presented in Table 6. The clones varied from 6.61 mm (RRIC 100) to 8.92 mm (clone 82/8) with a general mean of 7.55 mm. While 20 clones were found to be on par with RRII 105, the remaining three hybrid clones were found to be on par with RRIC 100.

(xiii) Number of latex vessel rows in renewed bark

Significant clonal variation for number of latex vessel rows was observed among the clones under study (Table 2). The mean performance of the clones are presented in Table 6. The clones exhibited a range of 8.94 (clone 82/19) to 25.86 (clone 82/22) with a general mean of 15.90. Thirteen hybrid clones were found to exhibit latex vessel rows above the general mean and were on par with RRII 105. Of the remaining clones eight hybrid clones were found to be on par with RRIC 100. Two clones viz. 82/15 and 82/19 were found to be poor with regard to the number of latex vessel rows in the renewed bark.

3.1.2.2 Biochemical subcomponents

Latex samples collected during the peak yielding period at the third year of tapping were utilized for studies on biochemical subcomponents of latex yield. Mean performance for biochemical subcomponents are presented in Table 7.

(i) Total solid content (TSC)

Among the 11 clones studied which include most of the high yielding hybrid clones and the parental clones, the highest TSC was observed for clone 82/30 which exhibited a mean value of 50.22 g% in contrast to RRII 105 which showed the lowest TSC of 40.38 g% and the general mean being 44.54 g%. Out of the nine hybrid clones six clones recorded value above the general mean.

(ii) Thiols

Thiol content in latex was highest for clone 82/3 (220.50 $\mu g\ g^{-1}$) and lowest in clone 82/30 (102.10 $\mu g\ g^{-1}$) while the general mean exhibited was 160.29 $\mu g\ g^{-1}$. The thiol content in five clones viz. 82/3, 82/14, 82/27, 82/29 and RRIC 100 was above the general mean (Table 7).

Table 7. Biochemical subcomponents of latex at the third year of tapping

Sl. No.	Clone	Total solid content** (g%)	Thiols** (µg g^{-1})	Inorganic phosphorus** (µg g^{-1})	Sucrose** (mg g^{-1})	Magnesium** (µg g^{-1})
1.	82/3	45.43	220.50	1185.51	11.86	425.54
2.	82/10	45.03	134.39	717.43	12.58	2106.22
3.	82/14	40.60	220.00	1853.31	5.59	1362.51
4.	82/17	46.29	156.43	1463.31	9.16	837.82
5.	82.22	47.10	147.96	1768.88	7.95	1108.33
6.	82/27	42.02	207.08	2043.77	8.04	1311.51
7.	82/28	47.66	118.00	887.77	6.48	776.02
8.	82/29	42.80	167.22	1632.81	6.81	836.11
9.	82/30	50.22	102.10	788.88	5.61	1224.71
10.	RRII 105	40.38	123.32	1525.40	10.30	1984.06
11.	RRIC 100	42.37	166.16	960.86	4.88	1089.97
	General mean	44.54	160.29	1347.99	8.11	1187.53
	C.D. (0.01)	6.29	77.03	785.86	4.69	660.28

** Significant at $P < 0.01$

(iii) Inorganic phosphorus (Pi)

Clone 82/27 exhibited maximum inorganic phosphorus content in latex (2043.77 µg g^{-1}), followed by clone 82/14 (1853.31 µg g^{-1}), 82/22 (1768.88 µg g^{-1}) and clone 82/29 (1632.81µg g^{1}). Six clones viz. 82/14, 82/17, 82/22, 82/27, 82/29 and RRII 105 were found to perform above the general mean of 1347.99 µg g^{-1}. The clones 82/10, 82/28 and 82/30 were found to exhibit low Pi content.

(iv) Sucrose

Sucrose content was highest in clone 82/10 (12.58 mg g^{-1}) and lowest in clone RRIC 100 (4.88 mg g^{-1}), whereas the general mean was 8.11 mg g^{-1}. Four clones viz. 82/3, 82/10, 82/17 and RRII 105 were found to have sucrose above the general mean of 8.11 mg g^{-1} and were on par with each other.

(v) Magnesium

The range of variation for magnesium content in latex was from 425.54 µg g^{-1} for clone 82/3 to 2106.22 µg g^{-1} for the clone 82/10. The clones 82/10, 82/14, 82/27, 82/30 and RRII 105 recorded values above the general mean of 1187.53 µg g^{-1}, while the clones 82/3, 82/17, 82/28 and 82/28 exhibited lower levels of magnesium content in latex (Table 7).

3.2 Estimates of genetic parameters

The mean, range, genotypic and phenotypic coefficients of variation in respect of all the characters studied are presented in Table 8 and Table 9. The histograms representing the variability are presented in Figures 1 to 10.

Table 8. Mean, range and estimates of genetic parameters for yield and major yield components

Sl. No.	Characters	Mean	S.E	Range	Coefficient of variation (%)		Heritability (%)	Genetic advance % over mean
					Genotypic	Phenotypic		
1.	Annual mean dry rubber yield (g tree^{-1} tapping^{-1})	51.57	6.21	20.21 - 88.20	33.73	39.54	72.21	58.66
2.	Summer yield (g tree^{-1} tapping^{-1})	36.42	5.85	11.14 - 69.30	40.68	50.03	68.16	70.09
3	Peak yield (g tree^{-1} tapping^{-1})	64.18	7.57	26.82 - 104.32	34.36	39.97	73.89	60.10
4.	Volume of latex (ml tree^{-1} tapping^{-1})	165.71	19.43	63.65 - 280.12	30.91	36.98	69.85	52.57
5.	Rate of latex flow (ml min^{-5} cm^{-1} x 50)	32.15	2.26	15.50 - 53.00	27.17	30.48	79.46	49.59
6.	Dry rubber content	32.13	1.31	27.10 - 36.74	7.02	9.96	49.71	10.05
7.	Plugging index	3.41	0.29	2.33 - 5.03	20.94	25.73	66.23	34.94
8.	Girth at opening (cm)	53.49	2.29	49.04 - 62.77	4.81	10.19	29.69	5.40
9.	Girth increment rate (cm year^{-1})	2.70	0.52	1.09 - 4.79	32.09	46.11	48.39	45.56
10.	Virgin bark thickness (mm)	7.83	0.33	7.11 - 8.67	3.79	8.15	21.62	3.69
11	No. of latex vessel rows in virgin bark	16.92	1.50	9.33 - 22.00	15.74	22.01	51.2	23.12
12.	Renewed bark thickness (mm)	7.55	0.37	6.61 - 8.92	5.35	9.97	28.75	5.91
13.	No. of latex vessel rows in renewed bark	15.90	1.40	8.94 - 25.86	21.22	26.14	65.86	35.55

Table 9. Mean, range and estimates of genetic parameters for biochemical subcomponents

Sl. No.	Characters	Mean	S.E	Range	Coefficient of variation (%)		Heritability (%)	Genetic advance % over mean
					Genotypic	Phenotypic		
1.	Total solid content ($\mu g\ g^{-1}$)	44.54	1.56	40.38 - 50.22	6.16	8.65	50.64	9.09
2.	Thiols ($\mu g\ g^{-1}$)	160.29	19.14	102.10 - 220.50	22.65	30.67	54.51	34.75
3.	Inorganic Phosphorus ($\mu g\ g^{-1}$)	1347.99	195.32	717.43 - 2043.77	31.12	39.98	60.59	50.23
4.	Magnesiun ($\mu g\ g^{-1}$)	1187.53	164.11	425.54 - 2106.22	40.10	46.70	73.73	71.19
5.	Sucrose ($mg\ g^{-1}$)	8.11	1.17	4.88 - 12.58	28.60	37.94	56.81	44.55

Volume of latex showed the highest range of variation from 63.65 ml tree $^{-1}$ tapping $^{-1}$ to 280.12 ml tree $^{-1}$ tapping $^{-1}$ (Fig. 4) with a mean of 165.71 ml tree $^{-1}$ tapping $^{-1}$. It was followed by yield during peak period ranging from 26.82 g tree $^{-1}$ tapping $^{-1}$ to 104.32 g tree $^{-1}$ tapping $^{-1}$ (Fig. 3) with a mean of 64.18 g tree $^{-1}$ tapping $^{-1}$, annual mean dry rubber yield ranging from 20.21 g tree $^{-1}$ tapping $^{-1}$ to 88.20 (Fig. 1) with a mean of 51.57 g tree $^{-1}$ tapping $^{-1}$ and yield during summer period (stress period) ranging from 11.14 g tree $^{-1}$ tapping $^{-1}$ to 69.30 g tree $^{-1}$ tapping $^{-1}$ (Fig. 2) with a mean of 36.42 g tree $^{-1}$ tapping $^{-1}$. In the case of rate of latex flow, the range of variation was from 15.50 ml min^{-5} cm^{-1} x 50 to 53.00 ml min^{-5} cm^{-1} x 50 with a mean of 32.15 ml min^{-5} cm^{-1} x 50 (Fig.5). Dry rubber content ranged from 27.10 to 36.74 and exhibited a mean of 32.13 (Fig. 6). Girth at opening ranged from 49.04 cm to 62.77 cm showing a mean of 53.49 cm. While number of latex vessels rows in virgin bark ranged from 9.33 to 22.00 (Fig.9) with a mean of 16.92, that in renewed bark ranged from 8.94 to 25.86 (Fig. 10) exhibiting a mean of 15.90. The lowest range was found in virgin bark thickness which ranged from 7.11 mm to 8.67 mm with a mean of 7.83 mm , followed by renewed bark thickness ranging from 6.61 mm to 8.92 mm with a mean of 7.55 mm, plugging index ranging from 2.33 to 5.03 (Fig. 7) with a mean of 3.41 and girth increment rate which ranged from 1.09 cm year $^{-1}$to 4.79 cm year $^{-1}$(Fig. 8) with a mean of 2.70 cm year $^{-1}$.

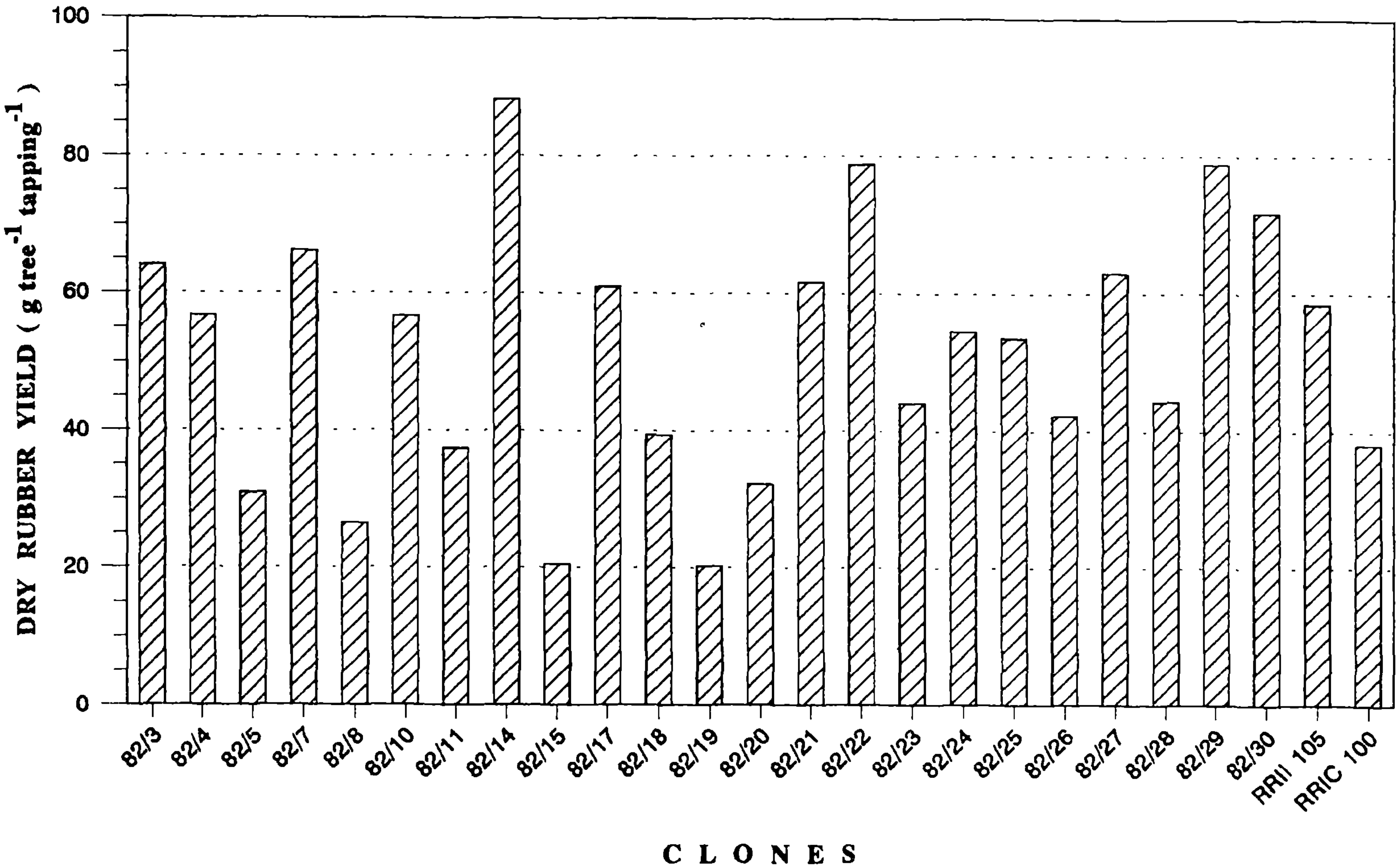


Fig. 1. Clonal variation for annual mean dry rubber yield.

Fig. 2. Clonal variation for dry rubber yield during summer season.

(viii) Girth at opening

The mean girth of clones are presented in Table 5. The clones exhibited a mean girth of 53.49 cm at opening for tapping, the range being 49.04 cm (RRII 105) to 62.77 cm (clone 82/29). As evident from the table all the clones exhibited superior performance over RRII 105 in terms of vigour. However, only the clones, 82/4, 82/5, 82/7, 82/8, 82/14, 82/17, 82/20 and 82/29 were found to be significantly superior to RRII 105.

(ix) Girth increment rate

The variability in mean rate of girth increment per year subsequent to tapping is represented in Table 5. The range of variation with respect to girth increment rate was from 1.09 cm $year^{-1}$ (clone 82/18) to 4.79 cm $year^{-1}$(clone 82/8). Fourteen clones, including both the parental clones RRII 105 and RRIC 100 exhibited a girth increment rate above the general mean (2.70 cm $year^{-1}$). Of these, the clones 82/7, 82/8, 82/11, 82/19 and 82/20 were found to be slightly superior to RRII 105 which recorded a girth increment rate of 3.49 cm $year^{-1}$. The remaining 10 clones were found to be on par with RRIC 100, the male parent, which had a girth increment rate of 1.28 cm $year^{-1}$.

(x) Virgin bark thickness

The clonal variation with regard to virgin bark thickness observed during the third year of tapping was significant only at 5 per cent level (Table2). As elucidated in Table 6, the clone 82/8 exhibited the maximum bark thickness of 8.67 mm, whereas RRIC 100 exhibited the minimum thickness of 7.11 mm. The general mean for bark

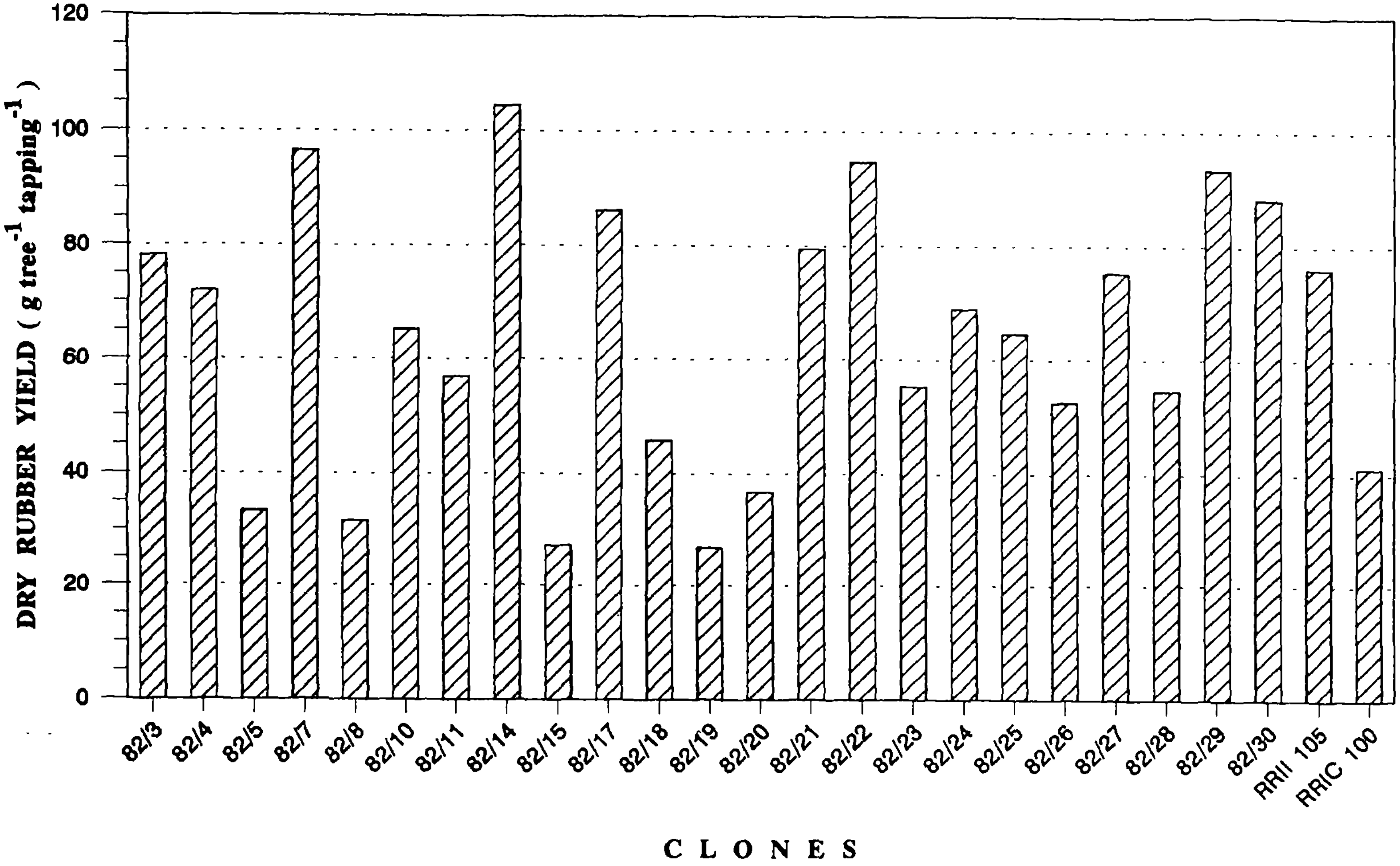


Fig. 3. Clonal variation for dry rubber yield during peak yielding period.

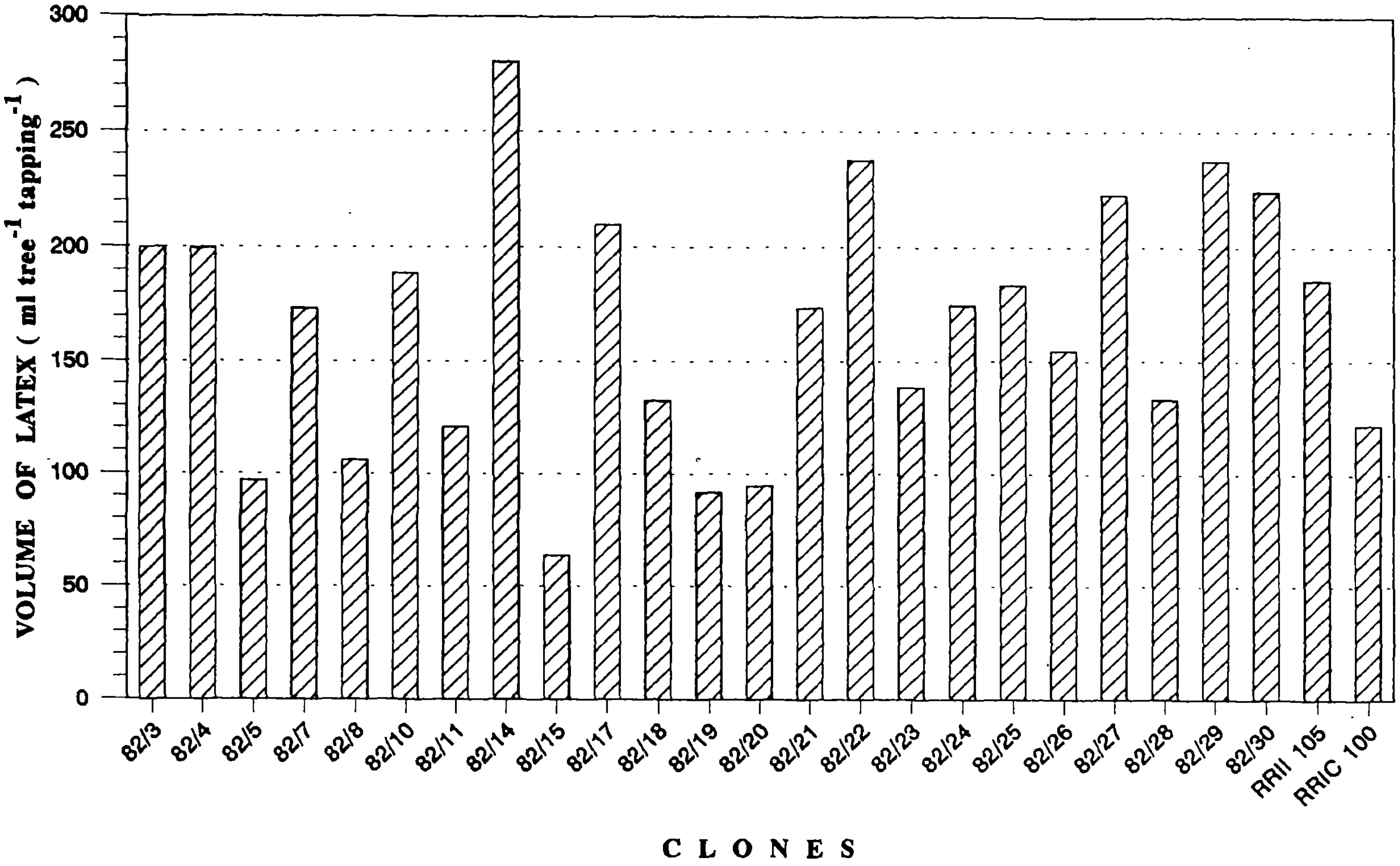


Fig. 4. Clonal variation for latex volume yield.

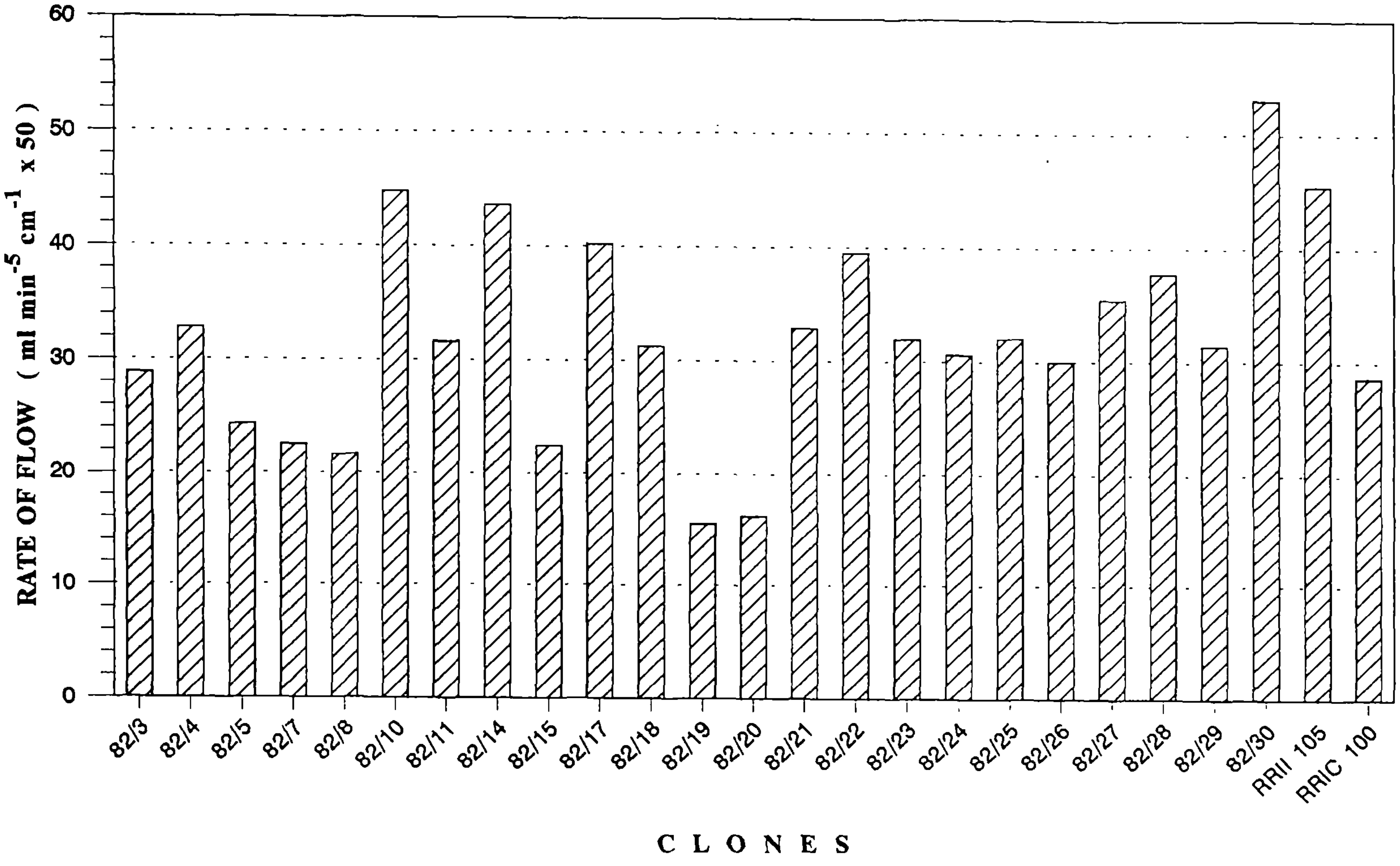


Fig. 5. Clonal variation for initial rate of latex flow.

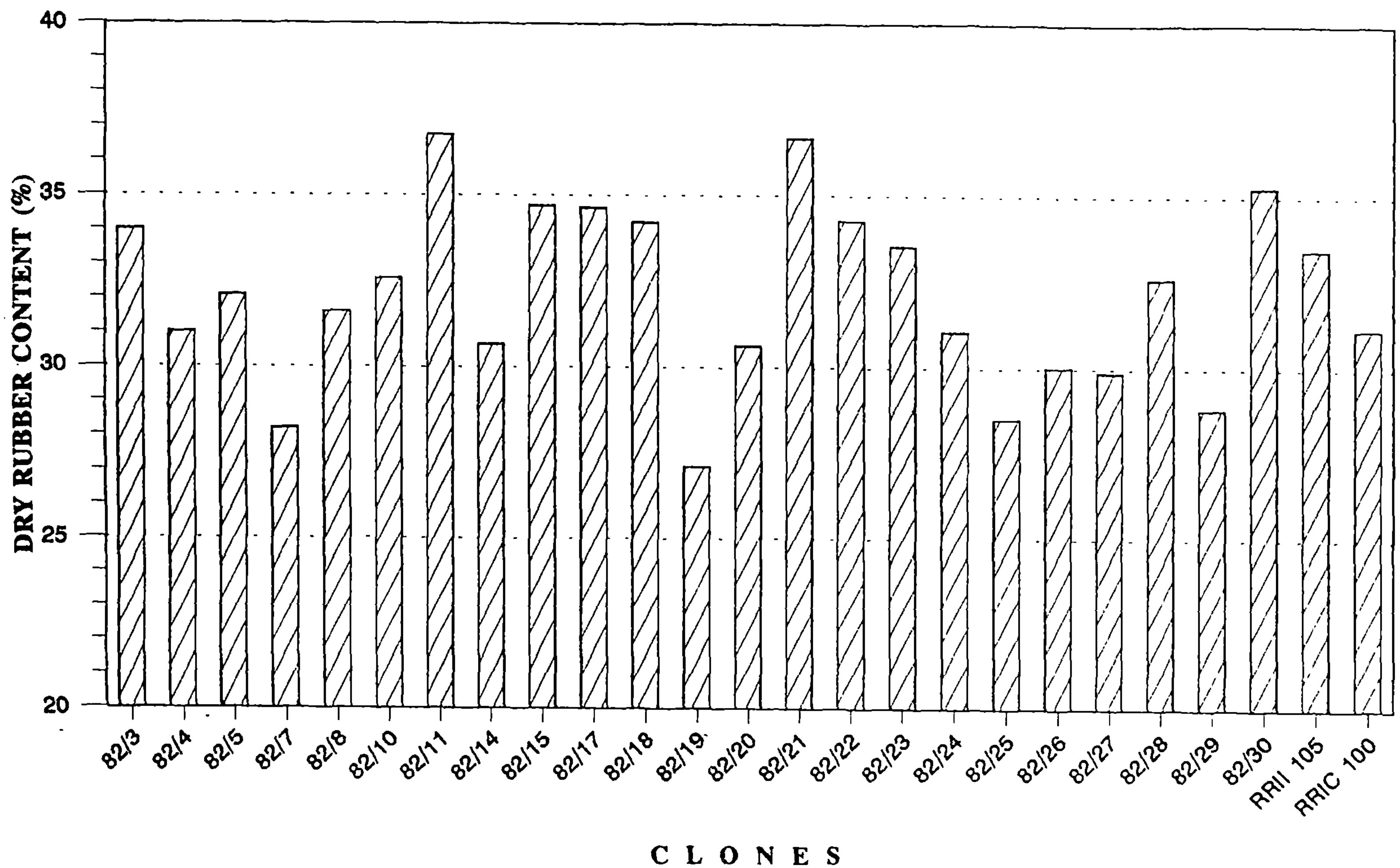


Fig. 6. Clonal variation for dry rubber content.

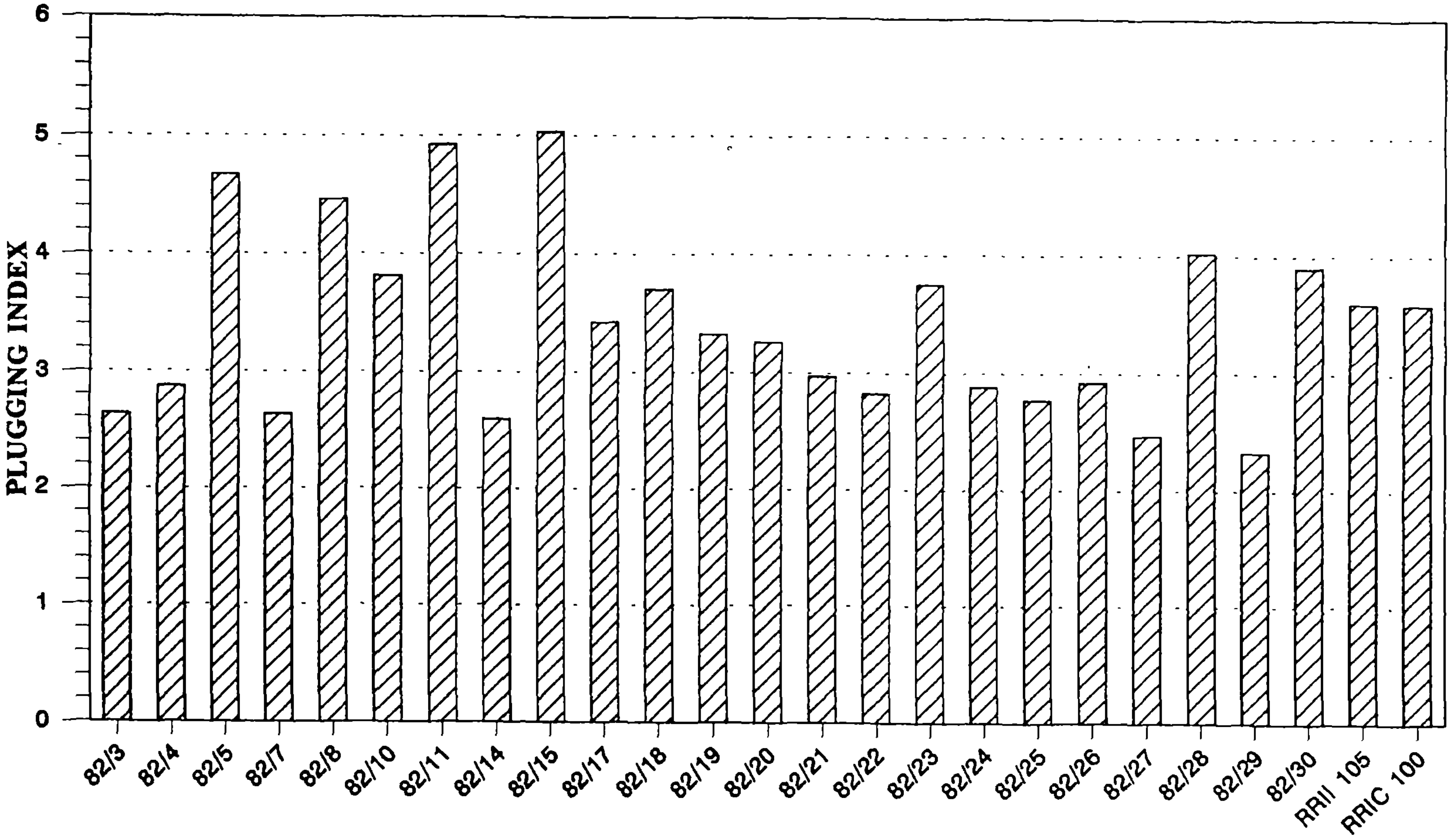


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Fig. 7. Clonal variation for plugging index.

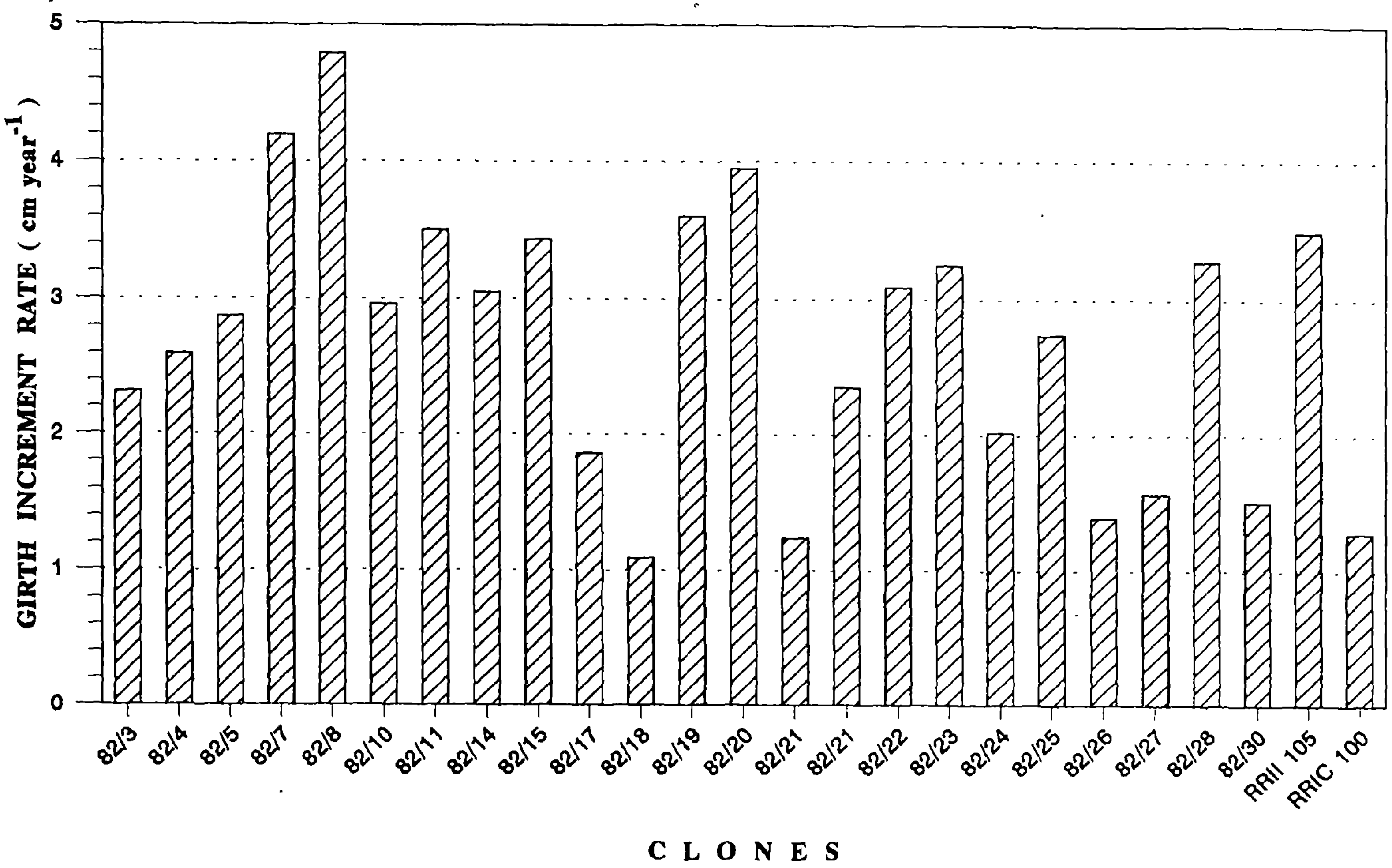


Fig. 8. Clonal variation for girth increment rate.

Fig. 9. Clonal variation for number of latex vessel rows in virgin bark.

Fig. 10. Clonal variation for number of latex vessel rows in the renewed bark.

Significant clonal variation was observed in the case of biochemical parameters too (Table 3). Among the biochemical parameters studied in eleven clones, magnesium content in latex exhibited the highest range of 425.54 μg g^{-1} to 2106.22 μg g^{-1} with a mean of 1187.53 μg g^{-1} which was followed by inorganic phosphorus ranging from 717.43 μg g^{-1} to 2043.77 μg g^{-1} with a mean of 1347.99 μg g^{-1}. Sucrose exhibited the lowest range of 4.88 mg/g to 12.58 mg/g with a mean of 8.11 mg/g followed by total solid content ranging from 40.38 g% to 50.22 g% with a mean of 44.54 g% and thiolss which ranged from 102.10 μg g^{-1} to 220.50 μg g^{-1} with a mean of 160.29 μg g^{-1} (Table 9).

3.2.1 Genotypic and phenotypic coefficients of variation

Estimates of genotypic coefficient of variation ranged from 3.79 to 40.68 for the 13 major characters studied. Summer yield recorded the highest GCV (40.68) followed by peak yield (34.36), annual mean dry rubber yield (33.65), girth increment rate (32.09), volume of latex (30.91), rate of latex flow (27.17), number of latex vessel rows in the renewed bark (21.22), plugging index (20.94), number of latex vessel rows in virgin bark (15.74), dry rubber content (7.02), renewed bark thickness (5.35), girth at opening (4.81) and virgin bark thickness (3.79) (Table 8).

Phenotypic coefficient of variation was higher than genotypic coefficient variation for all the characters studied. The highest phenotypic coefficient of variation was also recorded for summer yield (50.03), followed by girth increment rate (46.11), peak yield (39.97), annual mean dry rubber yield (39.54), volume of latex (36.98), rate of latex flow (30.48), number of latex vessel rows in renewed bark (26.14), plugging index (25.73), number of latex vessel rows in virgin bark (22.01), girth at opening (10.19), renewed bark thickness (9.97), dry rubber content (9.96) and virgin bark thickness (8.15) (Table 8 and Fig. 11 and Fig. 12).

Among the biochemical parameters studied, magnesium recorded the highest GCV (40.10), followed by inorganic phosphorus (31.12), sucrose (28.60), thiols (22.65) and total solid content which exhibited the lowest value of 6.16. In the case of PCV also, similar trend was observed wherein magnesium gave the highest PCV of 46.70 followed by inorganic phosphorus (39.98), sucrose (37.94), thiols (30.67) and total solid content (8.65) (Table 9 and Fig. 13).

3.2.2 Heritability (broad sense)

Heritability (broad sense) and genetic advance as per cent of mean (at 5 per cent intensity of selection) in respect of all the characters studied are presented in Table 8 and Table 9. The histograms representing the genetic parameters are shown in Figures 11 to 13.

Heritability estimates for yield and the 12 major yield components were found to be high for rate of latex flow (79.46), peak yield (73.89), annual mean dry rubber yield (72.49), volume of latex (69.85), summer yield (68.16), plugging index (66.23), number of latex vessel rows in renewed bark (65.86), number of latex vessel rows in virgin bark (51.12), dry rubber content (49.71) and girth increment rate (48.39). The estimated value of heritability was least (21.62) for the character virgin bark thickness (Table 8).

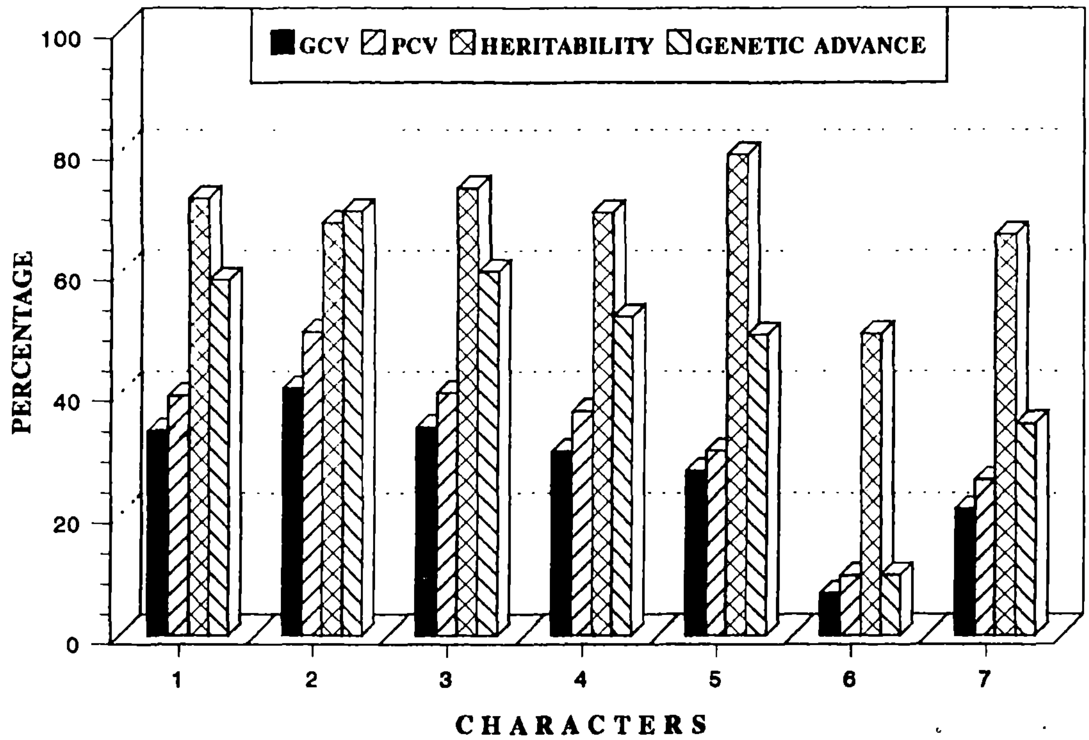


Fig. 11. Genotypic and phenotypic coefficients of variation, heritability and genetic advance (percent over mean) for yield and physiological parameters

1. Annual mean yield
2. Dry rubber yield (summer)
3. Peak yield
4. Volume of latex
5. Rate of latex flow
6. Dry fubber content
7. Plugging index

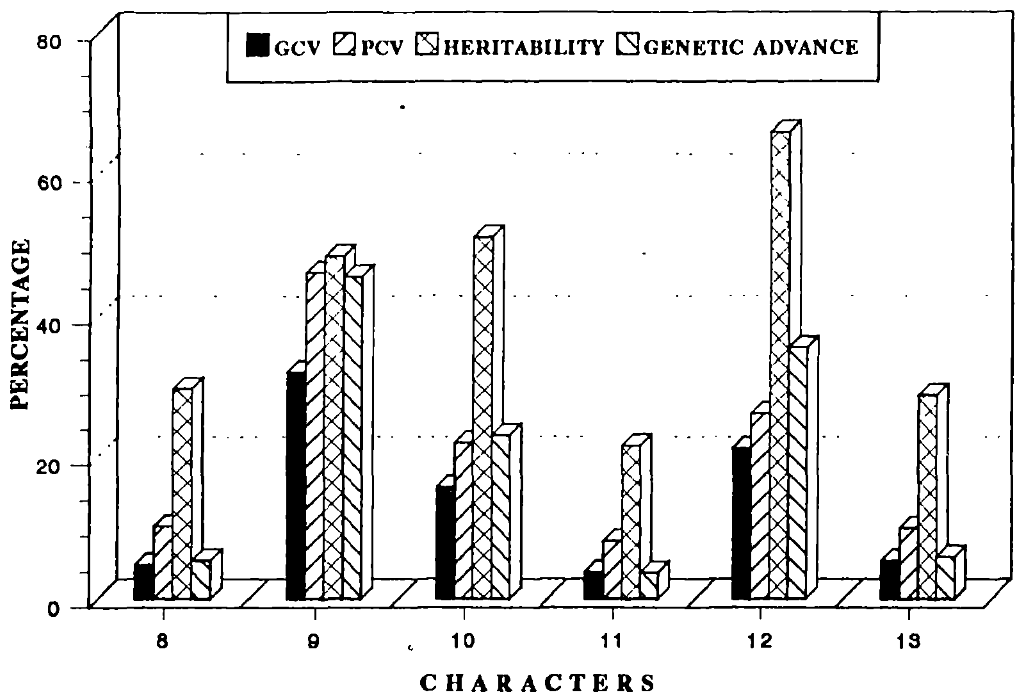


Fig.12. Genotypic and phenotypic coefficients of variation, heritability and genetic advance (percent over mean) for morphological and structural attributes.

8. Girth at opening
9. Girth increment rate
10. Number of latex vessel rows in virgin bark
11. Virgin bark thickness
12. No. of latex vessel rows in renewed bark
13. Renewed bark thickness

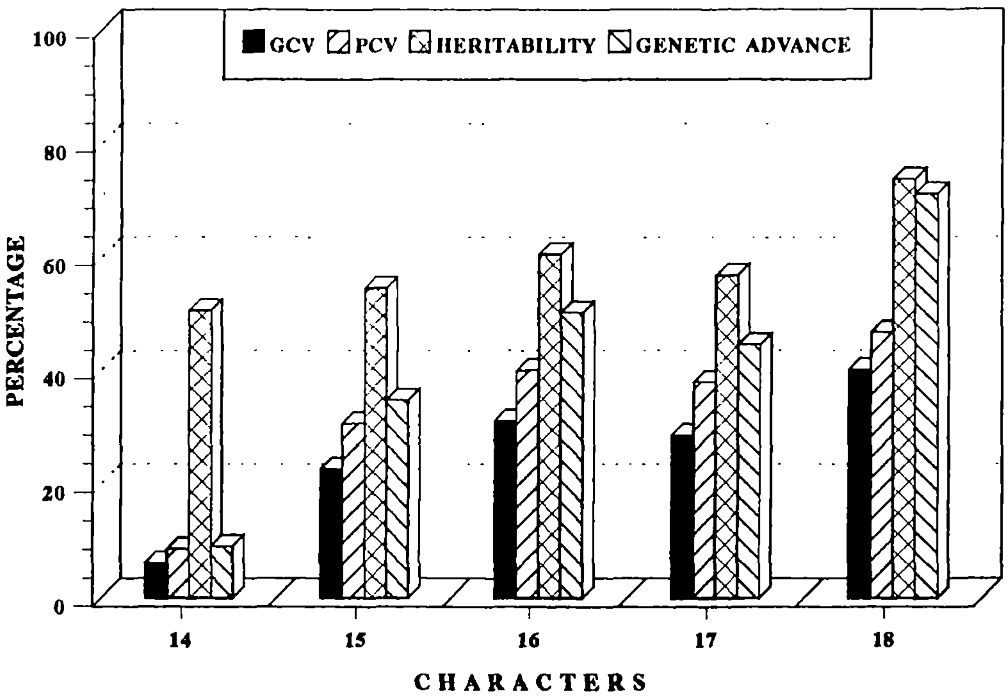


Fig. 13. Genotypic and phenotypic coefficients of variation, heritability and genetic advance (percent over mean) for biochemical attributes.

14. Total solid content
15. Thiols
16. Inorganic phosphorus
17. Sucrose
18. Magnesium

In the case of biochemical parameters all the five characters recorded high heritability values (Table 9). Magnesium revealed the highest estimate (73.73) followed by inorganic phosphorus (60.59), sucrose (56.81), thiols (54.51) and total solid content (50.64) .

3.2.3 Genetic advance

The study of genetic advance as percentage of mean, for yield and yield components considered, revealed that summer yield had the highest genetic advance (70.09) followed by peak yield (60.10), mean annual dry rubber yield (58.63), volume of latex (52.57), rate of latex flow (49.59) and girth increment rate on tapping (45.56). Number of latex vessel rows in renewed bark, plugging index and number of latex vessel rows in virgin bark exhibited intermediate values (35.55, 34.94 and 23.12 respectively) whereas the values were low for dry rubber content (10.05), renewed bark thickness (5.91), girth at opening (5.40) and virgin bark thickness (3.69) (Table 8).

Among the biochemical subcomponents magnesium recorded the highest value (71.19) followed by inorganic phosphorus (50.23), sucrose (44.55) and thiols (34.75). Total solid content revealed the lowest estimate of 9.09 (Table 9).

3.3 Association of characters

Data on characters, recorded during the third year of tapping were utilized for correlation studies. The genotypic correlation coefficients for dry rubber yield and the physiological, anatomical and growth attributes of yield are presented in Table 10. The phenotypic correlation coefficients are presented in Table 11.

Table 10. Genotypic correlation coefficients betwen yield and major yield components

	Dry rubber yield			Volume of latex	Rate of flow	Dry rubber content	Plugging index	Girth at opening	Girth increment rate	Virgin bark		Renewed bark	
	Annual (Y)	Summer (X1)	Peak (X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	LVR (X9)	BT (X10)	LVR (X11)	BT (X12)
Y	1.000	0.918	0.989	0.940	0.528	0.051	-0.626	0.098	-0.171	0.763	0.756	0.628	0.341
X1		1.000	0.879	0.883	0.433	0.123	-0.647	-0.008	-0.348	0.818	0.838	0.640	0.221
X2			1.000	0.910	0.529	0.049	-0.573	0.170	-0.071	0.755	0.695	0.650	0.359
X3				1.000	0.536	-0.014	-0.812	0.057	-0.128	0.775	1.034	0.637	0.514
X4					1.000	0.626	0.130	-0.340	-0.376	0.547	0.508	0.342	0.438
X5						1.000	0.471	-0.438	-0.425	0.489	-0.038	0.204	-0.138
X6							1.000	-0.079	0.018	-0.400	-0.763	-0.347	-0.292
X7								1.000	0.909	0.038	0.067	0.375	0.434
X8									1.000	-0.292	-0.096	0.180	0.465
X9										1.000	1.002	0.838	0.738
X10											1.000	0.966	0.770
X11												1.000	0.730
X12													1.000

BT - Bark thickness, LVR - Number of latex vessel rows

Table 11. Phenotypic correlation coefficients between yield and major yield components

	Dry rubber yield			Volume of latex	Rate of flow	Dry rubber content	Plugging index	Girth at opening	Girth increment rate	Virgin	bark	Renewed	bark
	Annual	Summer	Peak							LVR	BT	LVR	BT
	(Y)	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)	(X10)	(X11)	(X12)
Y	1.000	0.883**	0.946**	0.854**	0.528**	0.095	-0.520**	0.197	-0.099	0.607**	0.401**	0.473**	0.338**
X1		1.000	0.780**	0.785**	0.474**	0.196	-0.506**	0.120	-0.248*	0.657**	0.427**	0.454**	0.198
X2			1.000	0.806**	0.487**	0.093	-0.482**	0.246*	0.012	0.536**	0.366**	0.507**	0.346**
X3				1000	0.576**	0.025	-0.615**	0.156	-0.083	0.581**	0.373**	0.494**	0.316**
X4					1.000	0.365**	-0.018	-0.184	-0.247*	0.509**	0.249*	0.287*	0.221
X5						1.000	0.392**	-0.265*	-0.255*	0.279*	0.044	0.143	0.068
X6							1.000	-0.13	0.048	-0.292*	-0.228*	-0.311**	-0.100
X7								1.000	0.622**	0.068	0.237*	0.240*	0.334**
X8									1.000	-0.197	0.013	0.115	0.309**
X9										1.000	0.363**	0.593**	0.347**
X10											1.000	0.238*	0.641**
X11												1.000	0.360**
X12													1.000

* Significant at 5% level **Significant at 1% level ; BT - Bark thickness, LVR - Number of latex vessel rows

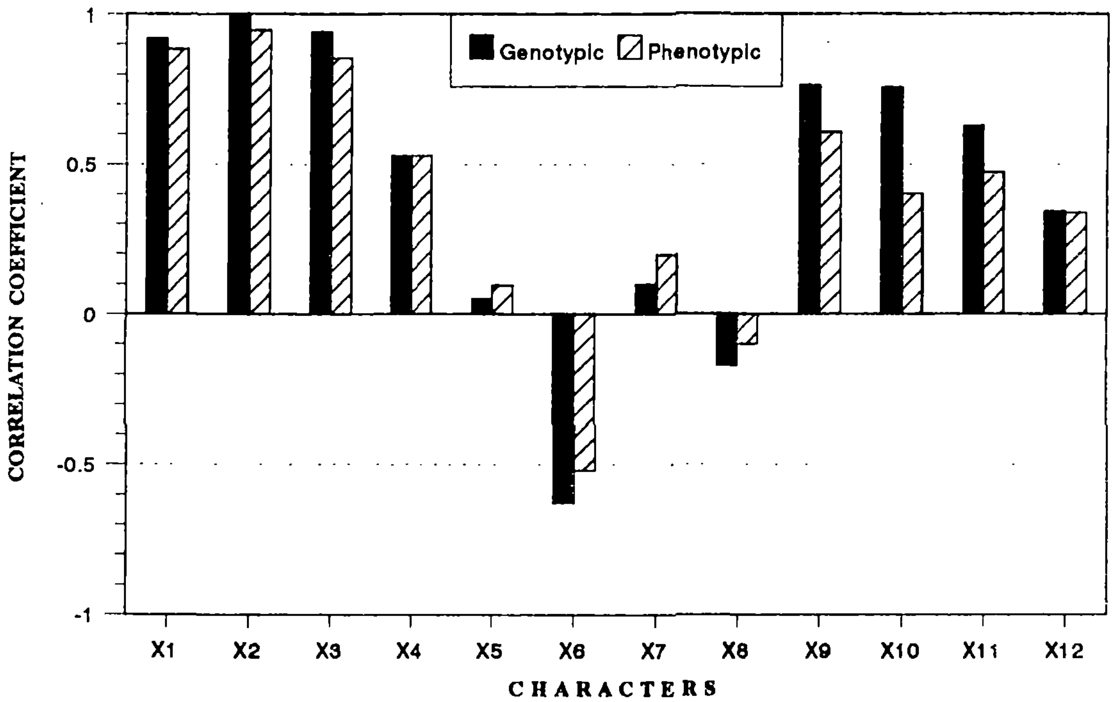


Fig.14. Genotypic and phenotypic correlation coefficients between annual dry rubber yield and its attributes in the third year of tapping.

X1	Summer yield	X2	Peak yield
X3	Volume of latex	X4	Rate of latex flow
X5	Dry rubber content	X6	Plugging index
X7	Girth at opening	X8	Girth increment rate
X9	Number of latex vessel rows in virgin bark	X10	Virgin bark thickness
X11	Number of latex vessel rows in renewed bark	X12	Renewed bark thickness

A comparison of genotypic and phenotypic correlation coefficients of dry rubber yield with 12 yield attributes are given in Figure 14.

3.3.1 Correlation of dry rubber yield with physiological components

At the genotypic level, correlations of annual mean dry rubber yield with dry rubber yield during the summer (stress) and peak periods, volume of latex and rate of latex flow were high and positive (0.918, 0.989, 0.940 and 0.528 respectively), while the relationship with plugging index was favourably negative and high (-0.626) (Table 10). The correlation with dry rubber content was low and positive (0.051) (Fig. 14).

At the phenotypic level also annual mean dry rubber yield exhibited highly significant positive correlation with yield during the summer and peak periods (0.883 and 0.946 respectively), volume of latex and rate of latex flow (0.854 and 0.528 respectively) whereas the association with drc was low and positive (0.095). In the case of association with plugging index, dry rubber yield revealed highly significant favourable negative association (-0.520). Similar trend was observed in the case of genotypic and phenotypic associations of dry rubber yield during summer and peak periods with the rest of the characters, with the exception of a negative association of summer yield with girth (Table 11 and Fig. 14).

3.3.2 Correlation of dry rubber yield with growth and structural attributes

While annual mean dry rubber yield recorded low positive genotypic correlation with girth (0.098) and negative association with girth increment rate (-0.171), its association with virgin bark thickness was high and positive (0.756) and with renewed bark thickness was moderate and positive (0.341). The association of dry rubber yield with number of latex vessel rows both in virgin and renewed bark was also high and positive (0.763 and 0.628 respectively) (Table 10 and Fig. 14).

At the phenotypic level also annual mean dry rubber yield exhibited more or less similar trend as was the case with genotypic correlation, exhibiting highly significant positive association with summer yield, peak yield, volume of latex and rate of latex flow, low positive association with girth (0.197) and negative association with girth increment rate (-0.099). The associations of dry rubber yield with thickness of both virgin and renewed bark were highly significant and positive (0.401 and 0.338 respectively); so also the associations with number of latex vessel rows both in virgin and renewed bark were highly significant and positive (0.607 and 0.473 respectively) (Table 11 and Fig. 14).

3.3.3 Inter-relationships among physiological, structural and growth attributes

At the genotypic level, volume of latex recorded high positive correlation with rate of latex flow (0.536), number of latex vessel rows both in virgin and renewed bark (0.775 and 0.637 respectively), virgin bark thickness (1.034) and with renewed bark thickness (0.514). The association of dry rubber content and girth with volume of latex was low and positive whereas girth increment rate exhibited negative and plugging index revealed high negative association. Rate of latex flow exhibited high to moderate positive association with drc, number of latex vessel rows in both virgin and renewed bark, thickness of both virgin and renewed bark and low positive association with plugging index. However, the association with girth and girth increment rate was negative. In the case of drc, the association with plugging index and number of latex vessel rows in virgin and renewed bark were positive whereas the rest of the characters exhibited negative association. Except with girth increment rate which revealed a positive association, all other characters exhibited a negative relationship with plugging index. Girth recorded high positive association with girth increment rate and moderate positive association with virgin and renewed bark thickness and low positive association with number of latex vessel rows, in both virgin and renewed bark. The association of number of latex vessel rows in virgin bark and virgin bark thickness was negative with girth increment rate while it was positive in the case with thickness of renewed bark. Number of latex vessel rows in the virgin bark exhibited high positive association with virgin and renewed bark thickness and also with number of latex vessel rows in the renewed bark. Similar was the case of association of virgin bark thickness with renewed bark thickness and the number of latex vessel rows in renewed bark. Renewed bark thickness and the number of latex vessel rows in renewed bark were highly and positively correlated (Table 10).

At the phenotypic level, volume of latex recorded high positive association with rate of latex flow, number of latex vessel rows in virgin and in renewed bark, virgin bark thickness and renewed bark thickness and significant positive association with drc, while plugging index exhibited highly significant negative association with latex volume. The association was negative in the case of girth increment rate with latex volume (Table 11).

Dry rubber content, number of latex vessel rows and bark thickness exhibited significant positive association with rate of latex flow whereas plugging index, girth and girth increment rate revealed negative association. In the case of dry rubber content, pegging index and number of latex vessel rows in the virgin bark recorded positive significant association while the association of number of latex vessel rows and bark thickness was positive but not significant. Girth and girth increment rate revealed negative association with drc. The association of plugging index with all other characters was negative except with that of girth increment rate. Girth exhibited significant and positive association with girth increment rate, bark thickness and number of latex vessel rows in renewed bark whereas the association with number of latex vessel rows in virgin bark was low and positive. The association of girth increment rate with number of latex vessel rows in virgin bark was negative while it was low and positive with virgin bark thickness and number of latex vessel rows in renewed bark and significant and positive with renewed bark thickness. Latex vessel rows in the virgin and the renewed bark and the thickness of virgin and renewed bark exhibited highly significant inter-relationships among each other.

3.3.4 Correlation among latex volume and biochemical subcomponents

At the genotypic level, thiols exhibited the highest positive correlation with latex yield (1.144) followed by inorganic phosphorus (0.948) and sucrose (0.530). Total solid content and magnesium revealed negative association with latex yield. Except sucrose, all the other characters showed negative association with total solid content. While thiols showed high positive correlation with inorganic phosphorus (0.562) its association with sucrose was low (0.005) and that with magnesium was negative (-0.490). Magnesium and sucrose were negatively correlated with inorganic phosphorus while they were positively associated between each other (0.254) (Table 12).

Table 12. Genotypic correlation coefficients between latex volume yield and biochemical subcomponents

	Volume of latex	Total Solid content	Thiols	Inorganic phosphorus	Magnesium	Sucrose
Volume of latex	1.000	-0.298	1.144xx	0.948xx	-0.372xx	0.530xx
Total solid content		1.000	-0.499xx	-0.505xx	-0.351xx	0.061
Thiols			1.000	0.562xx	-0.490xx	0.005
Inorganic phosphorus				1.000	-0.126	-0.158
Magnesium					1.000	0.254x
Sucrose						1.000

At the phenotypic level, thiols, inorganic phosphorus and magnesium showed low positive association with latex yield while the association of total solid content and sucrose with latex yield was negative. All the characters exhibited negative association with total solid content. Inorganic phosphorus and magnesium exhibited highly significant positive association with thiols while sucrose exhibited a low positive association. Similarly, while magnesium revealed highly significant positive association with inorganic phosphorus (0.450), sucrose revealed a low positive association (0.118). The association between magnesium and sucrose was significant and positive (0.383) (Table 13).

Table 13. Phenotypic correlation coefficients between latex volume yield and biochemical subcomponents

	Volume of latex	Total Solid content	Thiols	Inorganic Phosphorus	Magnesium	Sucrose
Volume of latex content	1.000	-0.265	0.008	0.189	0.106	-0.156
Total solid content		1.000	-0.629**	-0.691**	-0.399*	-0.325
Thiols			1.000	0.621**	0.528**	0.251
Inorganic phosphorus				1.000	0.450**	0.118
Magnesium					1.000	0.383*
Sucrose						1.000

* Significant at P < 0.05 ** Significant at P < 0.01

3.4 Forecasting future performance and early selection

3.4.1 Early versus mature character associations

Evaluation of mature performance over the first three years of tapping in comparison to early performance during the immature phase of four and a half years after field planting (Tables 14-16) was carried out with a view to evolving parameters for early detection of potential hybrid clones. While assessing the character associations, both yield contributing traits and the biochemical subcomponents were considered.

Table 14. Yield of clones in the early phase of four and a half years

Sl. No.	Clone	Dry rubber yield (g tree $^{-1}$ tapping $^{-1}$)			Volume of latex** (ml tree $^{-1}$ tapping $^{-1}$)
		Annual**	Summer**	Peak **	
1.	82/3	13.83	3.03	27.85	50.53
2.	82/4	10.66	2.26	20.74	~~25.33~~
3.	82/5	8.30	2.62	13.86	16.08
4.	82/7	15.89	2.26	32.72	43.22
5.	82/8	4.48	1.27	7.80	4.42
6.	82/10	14.82	5.05	25.24	14.50
7.	82/11	4.60	1.45	10.18	9.50
8.	82/14	18.08	4.66	36.13	55.50
9.	82/15	4.35	1.43	7.49	7.08
10.	82/17	13.55	3.46	26.48	35.66
11.	82/18	10.81	2.43	23.22	28.08
12.	82/19	5.70	1.98	10.42	9.42
13.	82/20	8.52	2.26	14.28	12.25
14.	82/21	11.64	3.39	24.87	25.67
15.	82/22	17.62	5.26	36.80	60.83
16.	82/23	9.86	2.33	20.06	25.50
17.	82/24	12.42	2.22	25.24	28.50
18.	82/25	11.38	2.91	23.75	33.33
19.	82/26	8.77	1.69	18.01	26.33
20.	82/27	15.40	3.59	32.14	52.17
21.	82/28	11.53	3.42	20.80	34.08
22.	82/29	19.90	4.43	40.57	61.83
23.	82/30	13.86	2.87	28.53	39.08
24.	RRIC 100	9.35	3.21	16.06	26.00
25.	RRII 105	9.85	2.54	18.93	29.25
General mean		11.41	2.88	22.49	30.16
CD (0.05)		4.44	1.34	9.63	30.30

** Clonal variation significant at $P < 0.01$

Table 15. Rate of flow, dry rubber content and plugging index in clones in the early phase of four and a half years

Sl.No.	Clone	Rate of flow** (ml min $^{-5}$ cm $^{-1}$x50)	Plugging index **	Dry rubber content**
1.	82/3	18.34	3.53	45.55
2.	82/4	17.76	7.15	38.87
3.	82/5	14.14	9.70	46.67
4.	82/7	14.65	3.51	34.37
5.	82/8	5.61	12.46	38.02
6.	82/10	14.62	9.47	46.27
7.	82/11	11.53	12.61	41.25
8.	82/14	30.09	6.30	34.35
9.	82/15	8.91	13.68	43.55
10.	82/17	24.20	5.52	44.50
11.	82/18	17.12	5.81	34.18
12.	82/19	9.31	8.20	40.67
13.	82/20	7.04	5.71	36.80
14.	82/21	21.77	8.37	43.37
15.	82/22	32.97	5.11	39.35
16.	82/23	17.70	6.26	42.67
17.	82/24	13.49	5.97	39.32
18.	82/25	22.55	6.34	37.08
19.	82/26	16.31	7.02	40.72
20.	82/27	17.27	3.30	35.48
21.	82/28	15.72	6.07	44.17
22.	82/29	26.23	2.50	34.15
23.	82/30	33.93	9.38	45.10
24.	RRIC 100	16.70	4.85	37.31
25.	RRII 105	15.91	7.03	39.22
	General mean	17.75	7.03	40.12
	CD (0.05)	9.56	3.78	7.92

** Significant at $P < 0.01$

Table 16. Growth and structural attributes in clones in the early phase of four and a half years

Sl.No.	Clone	Girth at opening** (cm)	Girth increment rate** (cm $year^{-1}$)	Bark thickness** (mm)	No. of latex vessel rows**
1.	82/3	41.02	4.34	5.21	6.00
2.	82/4	44.75	6.79	5.75	5.39
3.	82/5	46.31	6.95	5.77	6.78
4.	82/7	42.59	5.38	5.84	5.16
5.	82/8	41.38	7.25	6.34	6.33
6.	82/10	41.46	5.29	5.67	6.67
7.	82/11	37.64	5.33	5.17	4.89
8.	82/14	43.25	4.38	5.54	5.89
9.	82/15	40.84	6.46	5.74	4.28
10.	82/17	39.25	4.34	5.50	8.22
11.	82/18	40.47	4.17	5.67	4.39
12.	82/19	41.17	5.38	5.88	3.67
13.	82/20	42.99	6.56	5.60	5.61
14.	82/21	37.92	3.47	5.19	4.78
15.	82/22	37.08	4.50	5.29	7.89
16.	82/23	37.75	3.63	5.46	4.11
17.	82/24	38.47	5.53	5.47	5.31
18.	82/25	39.50	4.58	5.75	4.24
20.	82/27	42.09	4.13	6.08	5.83
21.	82/28	41.59	4.42	5.59	4.89
22.	82/29	44.03	5.63	5.42	6.78
23.	82/30	39.33	4.25	5.09	5.39
24.	RRIC 100	38.77	3.58	5.67	4.50
25.	RRII 105	36.56	4.78	5.63	7.17
	General mean	40.55	5.06	5.58	5.50
	CD (0.05)	4.13	1.42	0.51	2.04

** Significant at P < 0.01

3.4.1.1 Yield and major yield components

Simple correlation coefficients among early (Tables 14 to 16) and mature characters are presented in Table 17.

Dry rubber yield in all the three periods (annual, summer and peak) in the early phase revealed highly significant association with dry rubber yield, summer yield, volume of latex, rate of latex flow, plugging index, number of latex vessel rows in virgin bark and virgin bark thickness, with the exception of a non-significant positive association of summer yield during the early phase with virgin bark thickness in the mature phase. While annual mean dry rubber yield and peak yield in the early phase exhibited negative association with drc in the mature phase, the association of early summer yield with drc in the mature phase was positive though not significant. The association of girth at opening in the mature phase with annual mean dry rubber yield in the early phase was significant and positive, the association with early summer yield and peak yield was positive and not significant. Girth increment rate in the mature phase revealed negative association with dry rubber yield in all the three seasons in the early phase. Volume of latex and rate of latex flow in the early phase exhibited significant positive association with most of the characters in the mature phase and significant favourable association with plugging index and negative association with girth increment rate. Dry rubber content and plugging index in the early phase exhibited negative association with most of the characters and positive association with rate of latex flow, in the mature phase. Girth at opening in the early phase showed positive association with dry rubber yield, volume of latex, girth at opening, girth increment rate and virgin bark thickness in the mature phase while the association with the rest of the characters in the mature phase was negative. Similarly the association of girth increment rate with all the characters in the mature phase was negative except with plugging index, girth at opening and girth increment rate. Number of latex vessel rows in the early phase revealed significant positive association with dry rubber yield, volume of latex, girth at opening and bark thickness in the mature phase while the association with rate of latex flow, drc and girth increment rate in the mature phase was positive but not significant and with plugging index was negative. Bark thickness in the early phase exhibited a negative association with most of the characters in the mature phase and a positive association with plugging index, girth at opening, girth increment rate and bark thickness in the mature phase (Table 17).

The association of early characters with the same characters in all the three consecutive years in the mature phase of tapping was also worked out. The results are presented in Table 18. Dry rubber yield in the early phase exhibited highly significant association with dry rubber yield in the first year, second year, third year and with pooled mean over the first three years of tapping (r=0.913, 0.918, 0.811 and 0.918 respectively). Similarly, highly significant association was observed in the case of summer yield and peak yield. Volume of latex in the early phase revealed highly significant association with that observed in all the three years and pooled mean over the three years in the mature phase (r=0.796, 0.881, 0.709 and 0.844 respectively). Highly significant positive association of rate of latex flow in the early phase with rate of latex flow in the mature phase was observed as evidenced by the correlation coefficients (r=0.671, 0.741, 0.567 and 0.718 respectively). Dry rubber content in the early phase exhibited highly significant positive association with that in the first year (r=0.572), second year (r=0.392), third year (r=0.478) and pooled mean over the three years (r=0.541).

Table 17. **Early versus mature character correlations for yield and yield components**

Early characters		Mature characters: Mean over 3 years									3rd yr. of tapping	
		Y	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Annual dry rubber yield	(Y)	0.918**	0.890**	0.863**	0.877**	0.530**	-0.157	-0.724**	0.391*	-0.296	0.696**	0.443*
Summer yield	(X1)	0.721**	0.786**	0.620**	0.709**	0.571**	0.011	-0.458*	0.260	-0.386	0.683**	0.342
Peak yield	(X2)	0.929**	0.899**	0.894**	0.894**	0.521**	-0.126	-0.751**	0.340	-0.386	0.706**	0.479*
Total volume of latex	(X3)	0.872**	0.863**	0.829**	0.844**	0.461*	-0.131	-0.727**	0.289	-0.357	0.620**	0.383
Rate of latex flow	(X4)	0.827**	0.849**	0.799**	0.821**	0.718**	0.182	-0.449*	0.115	-0.517**	0.695**	0.427*
Dry rubber content	(X5)	-0.213	-0.201	-0.192	-0.216	0.202	0.541**	0.493*	-0.253	-0.151	-0.083	-0.298
Plugging index	(X6)	-0.555**	-0.543**	-0.520**	-0.529**	0.088	0.416*	0.829**	0.222	0.315	-0.271	-0.095
Girth at opening	(X7)	0.175	0.204	0.109	0.199	-0.084	-0.413*	-0.234	0.651**	0.102	-0.014	0.172
Girth increment rate	(X8)	-0.433*	-0.417*	-0.421*	-0.411*	-0.503*	-0.275	0.324	0.465*	0.999**	-0.349	-0.071
No.of latexvessel rows	(X9)	0.466*	0.497*	0.445*	0.474*	0.371	0.154	-0.138	0.404*	0.106	0.556**	0.449*
Bark thickness	(X10)	-0.393	-0.396*	-0.411*.	-0.317	-0.414*	-0.521**	0.120	0.200	0.322	-0.407*	0.209

* Significant at 5% level **Significant at 1% level

Table 18. Yearwise early versus mature correlations between yield and yield components

Character pairs	1st year of tapping	2nd year of tapping	3rd year of tapping	Mean over 3 years
Early Y Vs mature Y	0.913**	0.918**	0.811**	0.918**
,, X1 Vs ,, X1	0.841**	0.821**	0.735**	0.786**
,, X2 Vs ,, X2	0.886**	0.855*	0.793**	0.894**
,, X3 Vs ,, X3	0.796**	0.881**	0.709**	0.844**
,, X4 Vs ,, X4	0.671**	0.741**	0.567**	0.718**
,, X5 Vs ,, X5	0.572**	0.392*	0.478*	0.541**
,, X6 Vs ,, X6	0.787**	0.846**	0.612**	0.829**
,, X7 Vs ,, X7	0.651**	—	—	—
,, X8 Vs ,, X8	0.584**	0.582**	0.701**	0.999**
,, X9 Vs ,, X9	0.696**	—	0.556**	—
,, X10Vs ,, X10	0.456*	—	0.209	—

* Significant at 5% level   ** Significant at 1% level

Y - Annual dry rubber yield   X1 - Summer yield

X2 - Peak yield   X3 - Total volume of latex

X4 - Rate of latex flow   X5 - Dry rubber content

X6 - Plugging index   X7 - Girth at opening

X8 - Girth increment rate   X9 - No. of latex vessel rows

X10- Bark thickness

Plugging index and girth increment rate revealed significant positive association with the same characters in the first year (r=0.787 and 0.584 respectively), second year (r=0.846, 0.582 respectively), third year (r=0.612 and 0.701 respectively) and pooled mean over three years (r=0.829, 0.999 respectively) in the mature phase. Highly significant positive association was observed between girth at the time of opening the trees during the early phase and girth at regular opening at the mature phase (r=0.651). Number of latex vessel rows and bark thickness observed in the early phase also revealed significant positive association with the same characters in the first year (r=0.696, 0.456 respectively). Number of latex vessel rows in the early phase also exhibited highly significant positive association with that in the third year of tapping (r=0.556). The association of bark thickness in the early phase with that in the third year of mature tapping was positive though not significant (r=0.209).

3.4.1.2 Biochemical sub components.

The early versus mature character associations for biochemical subcomponents of latex are presented in Table 19. Total solid content in the early phase revealed significant positive association with total solid content and non significant positive association with sucrose. Its association with thiols, inorganic phosphorus and magnesium in the mature phase was negative. Thiols in the early phase exhibited signficant association with that in the mature phase. Thiols in the early phase exhibited positive association with total solid content and inorganic phosphorus in the mature phase and the associations with the rest of the characters were negative. Inorganic phosphorus in the early phase showed significant correlation with the same character in the mature phase. While the association of inorganic phosphorus in the early phase was positive with thiols and magnesium in the mature phase, its associations with the remaining characters viz. total solid content and sucrose were negative. The associations of sucrose in the early phase with thiols, inorganic phosphorus and sucrose in the mature phase were positive while it exhibited negative relationships with total solid content and magnesium. Magnesium in the early phase showed significant positive association with magnesium in the mature phase. Its correlations with total solid content and sucrose were positive while the same with thiols and inorganic phosphorus was negative. Highly significant early versus mature association was observed with respect to biochemical parameters viz. total solid content (0.408), thiols (0.429), inorganic phosphorus (0.637) and magnesium (0.610). However, the association in the case of sucrose was positive (0.265), though not significant.

Table 19. Early versus mature character correlations for biochemical sub components

Sl.No.	Characters in early phase	Characters in mature phase				
		Total solid content	Thiols	Inorganic phosphorus	Sucrose	Magnesium
1.	Total solid content	0.409*	-0.188	-0.433*	0.019	-0.186
2.	Thiols	-0.398*	0.429*	0.225	0.479*	-0.083
3.	Inorganic phosphorus	-0.005	0.293	0.637*	-0.149	0.016
4.	Sucrose	-0.046	0.114	0.166	0.265	-0.082
5.	Magnesium	0.226	-0.543**	-0.196	0.227	0.610*

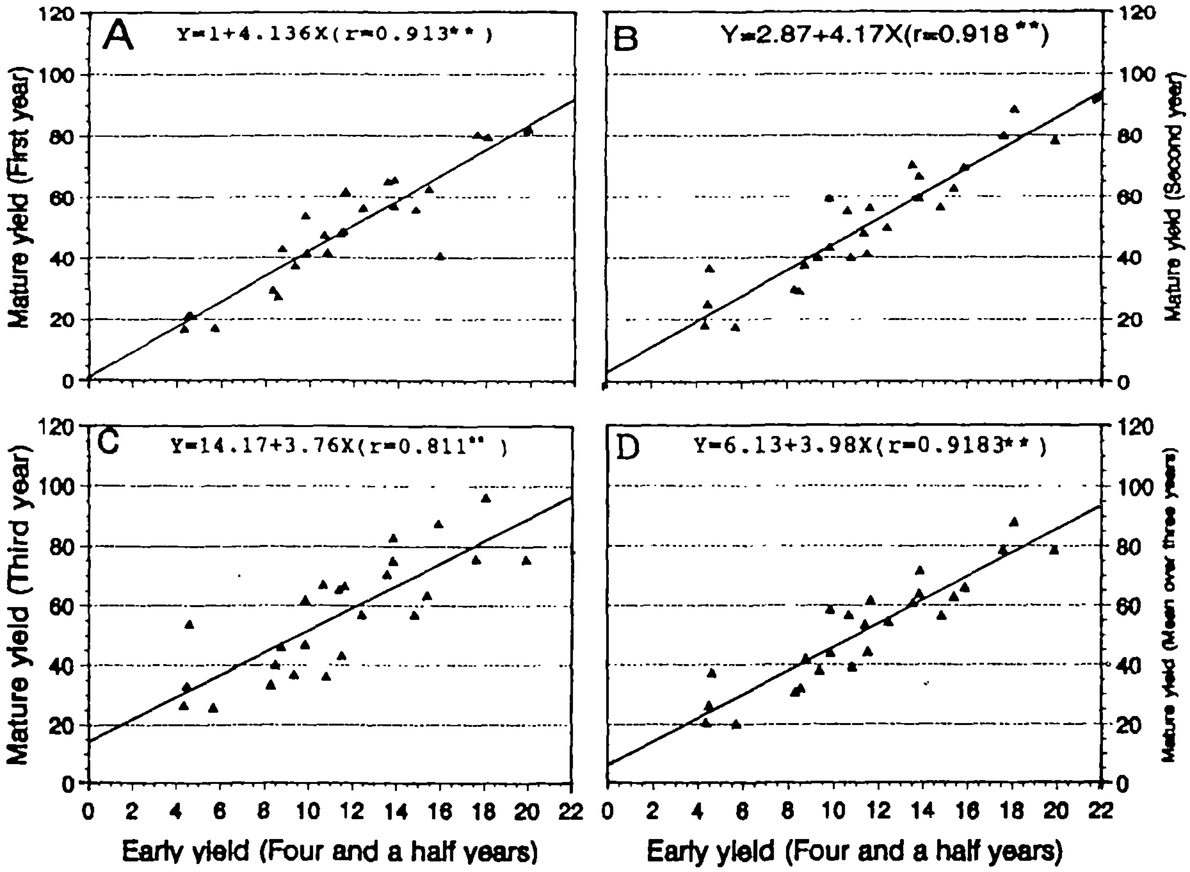
*Significant at P < 0.05 ** Significant at P < 0.01

3.4.2 Regression analysis

The degree of dependence of mature yield on early yield was examined by regression analysis. Suitable regression equations were computed and regression lines were fitted (Fig. 15 A,B,C,D) to observe the dependability of the first three consecutive years of mature yield as well as of pooled mean over the three years, on early yield. The equations are shown in the respective order:-

(i) $Y = 1 + 4.14\ X$	where Y is the mature yield in the first year of tapping and X, the early yield.
(ii) $Y = 2.87 + 4.17\ X$	where Y is the mature yield during the second year of tapping and X, the early yield.
(iii) $Y = 14.17 + 3.76\ X$	where Y is the mature yield during the third year of tapping and X, the early yield.
(iv) $Y = 13.3 + 3.98\ X$	where Y is the mature yield over the first three years of tapping and X, the early yield.

Using the above equations it is possible to estimate mature yield based on early yield. It is observed from Fig. 15 A,B,C,D that the mature yield is in accordance with the early yield in most cases.



Yield in g tree^{-1} tapping^{-1}

Fig. 15. Relationship between early yield and first year mature yield (A), second year mature yield (B), third year mature yield (C) and mean over three years (D) in hybrid clones

3.5 Heterosis

Heterosis was studied for yield and major yield components. The mean values of the hybrids were compared with the values of the mid parent (MP) and of the better parent (BP). In most cases, RRII 105, the standard clone, is the better parent. In cases where RRII 105 is not the better parent, standard heterosis was estimated separately. The results are presented in Tables 20 to 24 and Figures 16 to 22.

3.5.1 Estimates of heterosis for yield and major yield components

(i) Annual mean dry rubber yield

The extent of heterosis exhibited by the hybrids ranged from -58.20 per cent for the clone 82/19 to 82.42 per cent for the clone 82/14 over their corresponding mid parent values. The heterosis over the corresponding mid parent values were significant in six out of the twenty three hybrid clones. The heterosis of the hybrids over their corresponding better parent values ranged from -65.48 per cent for the clone 82/19 to 50.64 per cent for the clone 82/14. Nine hybrid clones viz. 82/3, 82/7, 82/14, 82/17, 82/21, 82/22, 82/27, 82/29 and 82/30 exhibited positive heterosis over the better parent, which is also the standard clone RRII 105 (Fig. 17) of which three clones viz. 82/14, 82/22 and 82/29 showed significant superiority (Table 20) with heterosis ranging from 22.58 to 50.64%.

(ii) Summer yield

Heterosis for summer yield ranged from -66.85 (clone 82/15) to 106.25 (clone 82/14) per cent over the mid parent. The range of variation over the better parent, RRII 105, was from -73.13 (clone 82/15) to 67.11(clone 82/14) per cent. The highest value of 67.11 for the clone 82/14 was followed by the clone 82/29 with a heterosis of 62.16 and the clone 82/22 with a heterosis of 52.79 per cent over their corresponding better parent. Ten hybrid clones viz. 82/3, 82/10, 82/14, 82/17, 82/21, 82/22, 82/26, 82/27, 82/29 and 82/30 revealed positive heterosis over the better parent (Fig. 17) the values being significant in the case of the above three clones (Table 20).

(iii) Peak yield

In the case of yield during peak period, heterosis over mid parent ranged from -54.23 (clone 82/19) to 78.02 (clone 82/14) per cent. Eight clones were found to be significantly superior to the mid parent. Heterosis over better parent (RRII 105) ranged from -64.74 (clone 82/19) to 37.15 (clone 82/14) per cent (Table 20). Only one clone, 82/14, exhibited significant superiority over the better parent whereas seven other clones viz. 82/3, 82/7, 82/17, 82/21, 82/22, 82/29 and 82/30 were found to be slightly superior to RRII 105 (Fig. 18).

Table 20. Estimates of heterosis (%) for dry rubber yield over the first three years of tapping

Sl. No.	Clone	Dry rubber yield: Annual mean yield, % heterosis over MP	Annual mean yield, BP (RRII 105)	Summer yield, MP	Summer yield, BP (RRII 105)	Peak yield, MP	Peak yield, BP (RRII 105)
1	82/3	32.37*	9.31	33.01	7.76	33.34*	2.73
2	82/4	17.33	-3.10	15.42	-6.49	22.63	-5.52
3	82/5	-36.13	-47.25	-33.34	-48.42	-43.21	-56.25
4	82/7	36.79*	12.96	-0.38	-19.29	64.62**	26.83
5	82/8	-45.29	-54.82	-49.32	-58.93	-46.13	-58.49
6	82/10	17.08	-3.31	27.95	3.67	11.21	-10.89
7	82/11	-22.71	-36.17	-50.15	-59.61	-2.98	-25.26
8	82/14	82.42**	50.64**	106.25**	67.11**	78.02**	37.15*
9	82/15	-57.61	-64.98	-66.85	-73.13	-53.49	-64.17
10	82/17	26.06	4.09	33.09	7.84	47.01**	13.26
11	82/18	-18.53	-32.72	-8.33	-25.73	21.91	-39.84
12	82/19	-58.20	-65.48	-58.13	-66.07	-54.23	-64.74
13	82/20	-33.32	-44.94	-46.25	-56.45	-37.29	-51.68
14	82/21	27.61	5.38	37.53	11.43	35.59*	4.47
15	82/22	62.89**	34.52*	88.57**	52.79*	61.66**	24.55
16.	82/23	-8.75	-24.64	-17.83	-33.42	-5.68	-27.33
17.	82/24	12.72	-6.92	-6.93	-24.60	17.56	-9.43
18	82/25	10.75	-8.54	9.52	-11.26	10.14	-15.15
19	82/26	-12.53	-27.78	28.13	3.81	-10.39	-30.96
20	82/27	30.22	7.53	36.96	10.44	28.41	-1.06
21	82/28	-8.13	-24.13	-8.75	-26.07	6.89	-28.27
22	82/29	63.04**	34.64*	100.15**	62.16**	59.49**	22.88
23	82/30	48.44**	22.58	42.53*	15.48	50.59**	16.03
	CD (0.05)	15.28	17.64	14.39	16.62	18.63	21.51
	CD (0.01)	20.37	23.53	19.19	22.16	24.84	28.68

*Significant at P < 0.05 ** Significant at P < 0.01
MP - Mid parent
BP - Better parent

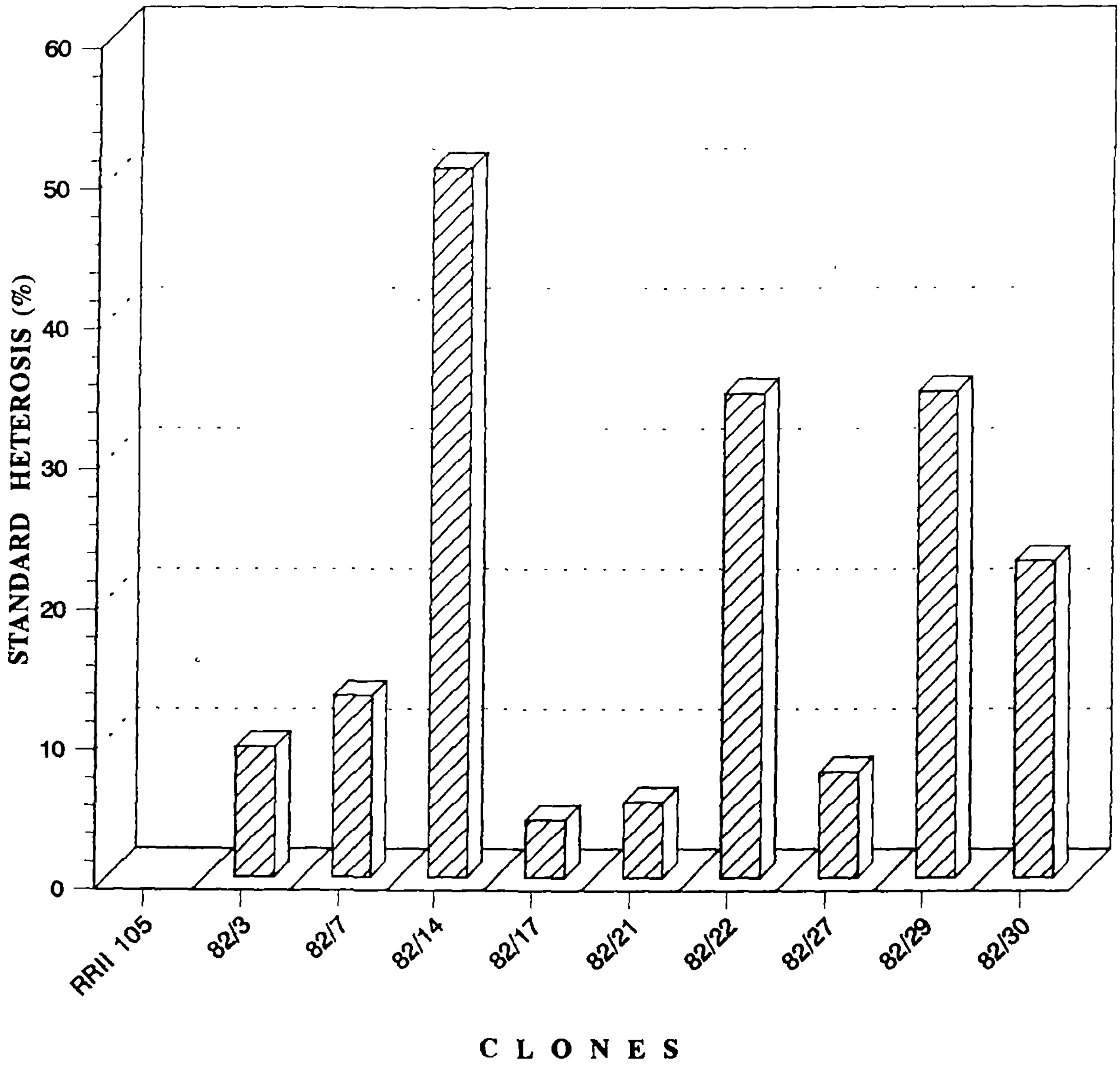


Fig. 16. Standard heterosis for dry rubber yield (annual) in hybrid clones.

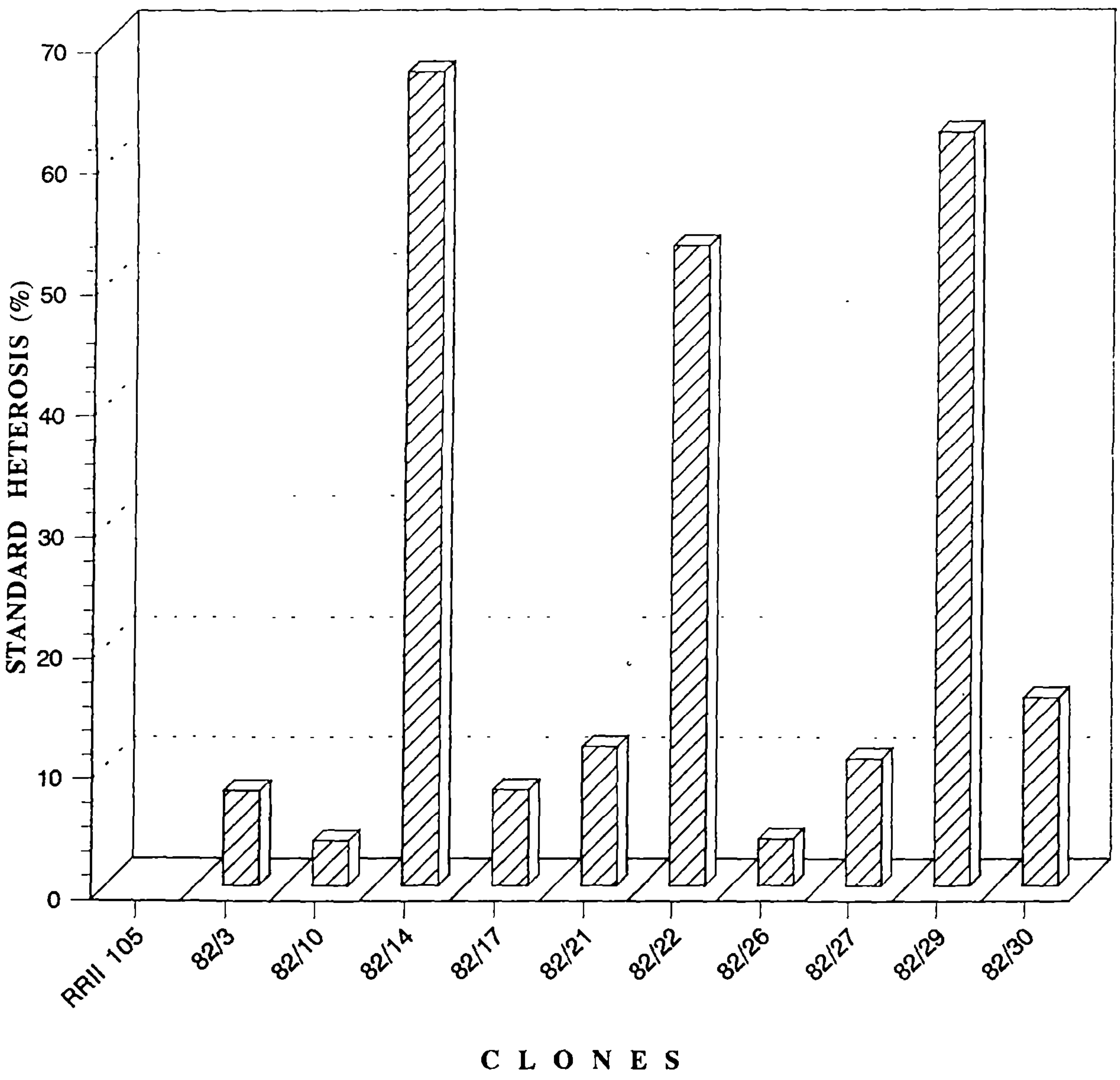


Fig. 17. Standard heterosis for summer yield in hybrid clones.

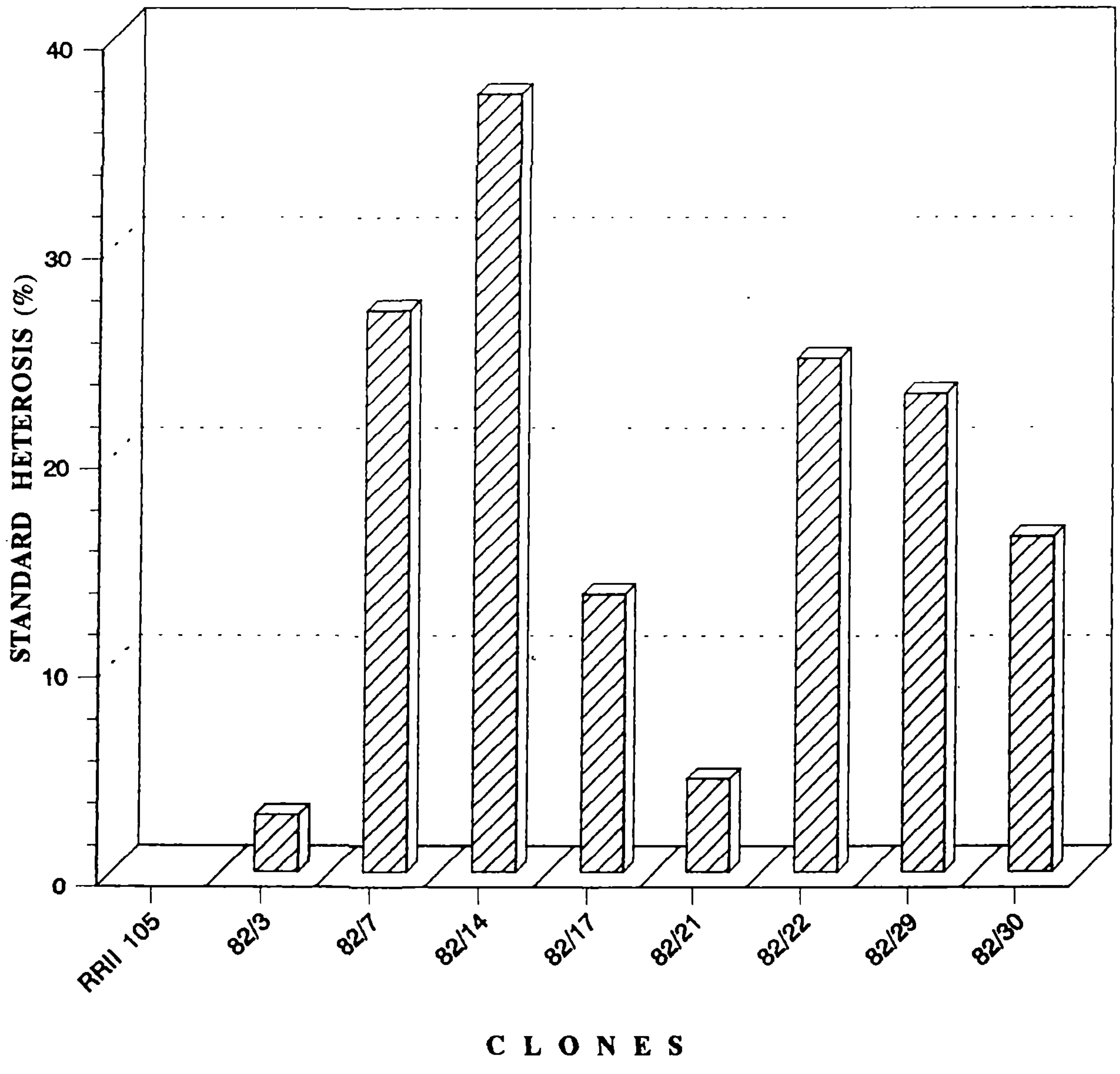


Fig. 18. Standard heterosis for peak yield in hybrid clones.

(iiv) Volume of latex

Heterosis for volume of latex per tap ranged from -38.48 (clone 82/20) to 82.39 (clone 82/14) per cent over the mid parent. Six hybrid clones were found to be significantly superior to the mid parent. Heterosis over the better parent ranged from -65.74 (clone 82/15) to 50.79 (clone 82/14) per cent. Nine clones viz. 82/3, 82/4, 82/10, 82/14, 82/17, 82/22, 82/27, 82/29 and 82/30 exhibited superior performance over the better parent, RRII 105 (Fig. 19) of which the superiority of clone 82/14 was highly significant (Table 21).

(v) Rate of latex flow

The range of variation in heterosis over mid parent for rate of latex flow was from -58.14 (clone 82/19) to 43.13 (clone 82/30) per cent. Three clones were observed to be significantly better than the mid parent. In the case of superiority over better parent RRII 105, only one clone (82/30) was found to be significantly superior, with a heterosis of 16.46 per cent (Table 21).

(vi) Dry rubber content

Heterosis over mid parent ranged from -16.13 (clone 82/19) to 13.71 (clone 82/11) per cent whereas it ranged from -19.01 (clone 82/19) to 9.80 (clone 82/11) per cent over the better parent. Eight clones viz. 82/3, 82/11, 82/15, 82/17, 82/18, 82/21, 82/22 and 82/30 were found to be superior to the better parent RRII 105 (Fig. 20) with respect to the dry rubber content (Table 21).

Table 21. Estimates of heterosis (%) for volume of latex , rate of latex flow and dry rubber content over the first three years of tapping

Sl. No.	Clone	Volume of latex MP	Volume of latex BP (RRII 105)	Rate of flow MP	Rate of flow BP (RRII 105)	Dry rubber content MP	Dry rubber content BP (RRII 105)
		% heterosis over					
1.	82/3	30.11	7.57	-22.23	-36.72	5.23	1.61
2.	82/4	29.88	7.38	-11.53	-28.02	-4.05	-7.35
3.	82/5	-36.95	-47.87	-34.43	-46.65	-0.74	-4.15
4.	82/7	12.85	-6.70	-39.18	-50.51	-12.75	-15.75
5.	82/8	-31.15	-43.08	-41.64	-52.52	-2.19	-5.56
6.	82/10	22 87	1.58	20.87*	-1.65	0.84	-2.63
7.	82/11	-21.54	-35.16	-14.69	-30.59	13.71**	9.80
8.	82/14	82.39**	50.79**	17.61*	-4.31	-5.61	-8.43
9.	82/15	-58.56	-65.74	-39.51	-50.78	7.34	3.65
10.	82/17	36.49*	12.85	8.53	-11.69	7.18	3.49
11.	82/18	-11.86	-28.78	-15.72	-31.42	5.88	2.24
12.	82/19	-40.29	-50.63	-58.14	-65.94	-16.13	-19.01
13.	82/20	-38.48	-49.13	-56.28	-64.43	-5.19	-8.46
14.	82/21	13.10	-6.49	-11.29	-27.82	13.43**	9.53
15.	82/22	54.64**	27.85	6.59	-13.27	6.06	2.42
16.	82/23	-9.90	-25.51	-13.79	-29.86	3.78	0.21
17.	82/24	13.88	-5.85	-17.42	-32.81	-3.86	-6.24
18.	82/25	19.57	-1.14	-13.56	-29.66	-11.76	-14.79
19.	82/26	0.77	-16.68	-19.09	-34.17	-7.09	-10.28
20.	82/27	44.86**	19.77	-4.32	-22.15	-7.52	-10.69
21.	82/28	-13.42	-28.42	1.92	-17.07	0.89	-2.57
22.	82/29	54.42**	27.67	-15.20	-31.00	-10.83	-13.89
23.	82/30	45.75**	20.49	43.33**	16.46*	9.13	5.38
	CD (0.05)	47.83	55.23	6.31	7.29	3.22	3.72
	CD (0.01)	63.77	73.63	8.42	9.72	4.29	4.96

* Significant at P < 0.05 ** Significant at P < 0.01

MP - Mid parent

BP - Better parent

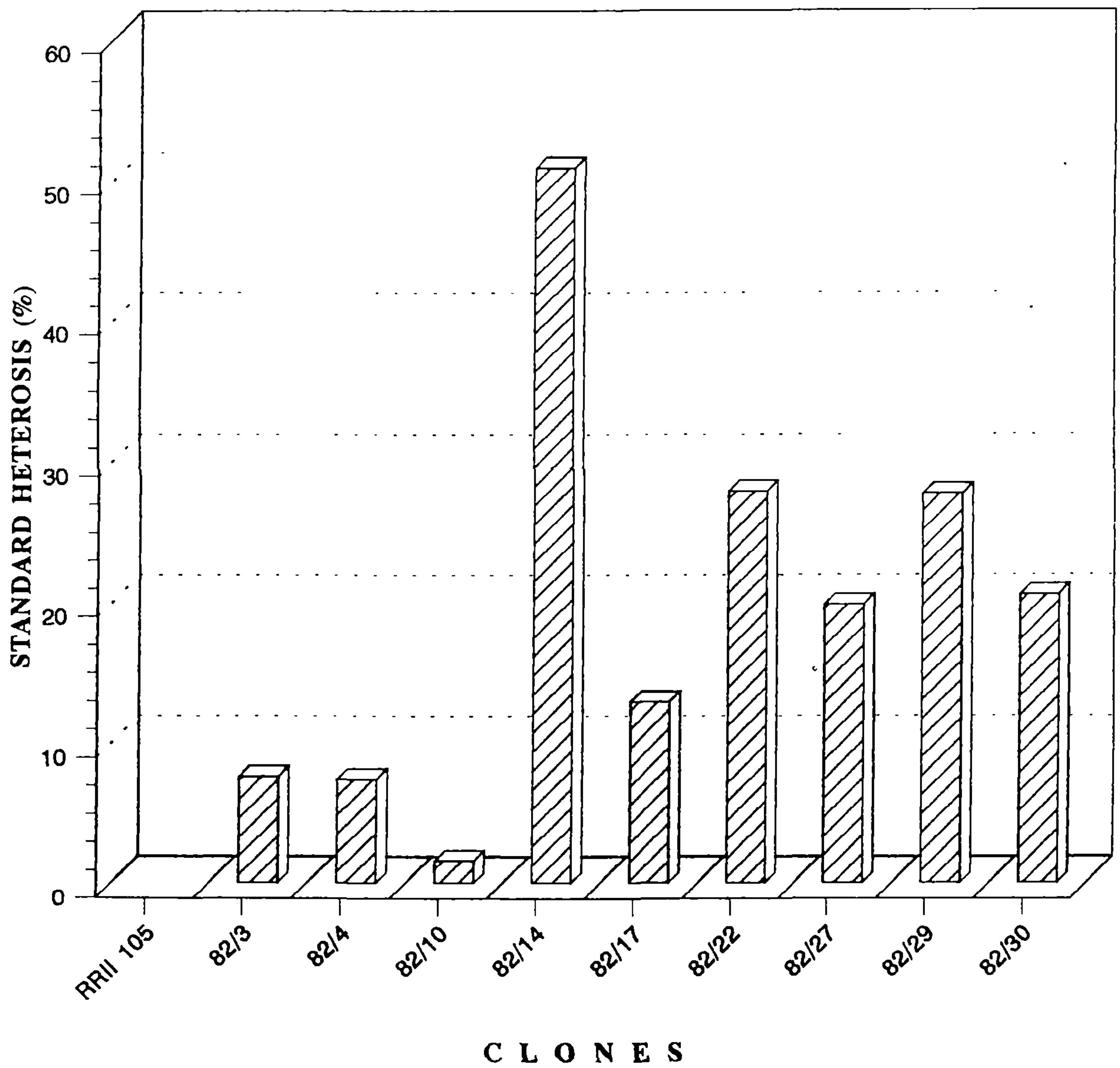


Fig.19. Standard heterosis for volume of latex in hybrid clones.

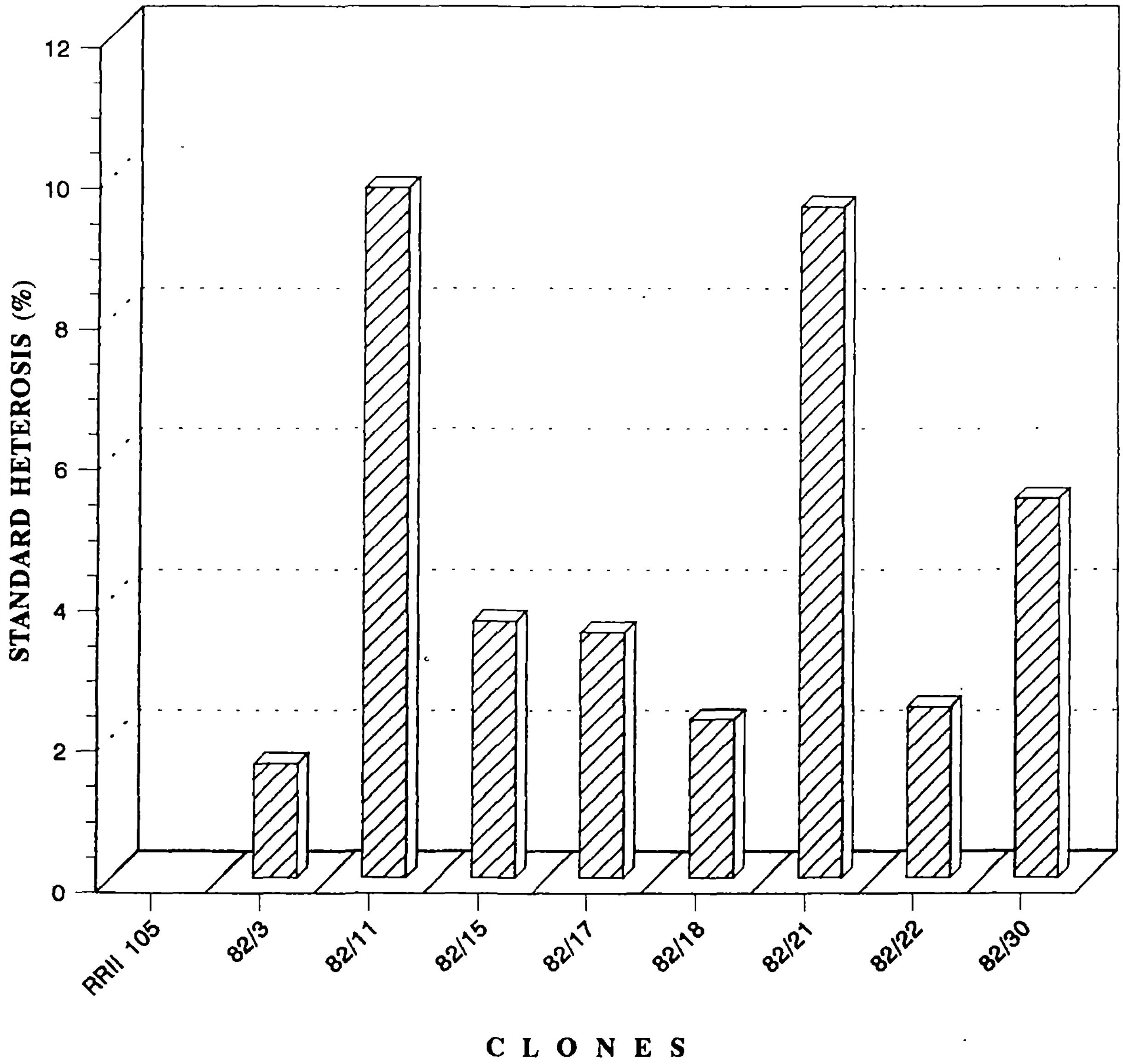


Fig.20. Standard heterosis for dry rubber content in hybrid clones.

(vii) Plugging index

The heterotic increase over mid parent ranged from -35.28 (clone 82/29) to 39.72 (clone 82/15) per cent with eight clones significantly superior to the mid parent. The range of heterosis over the better parent was from -35.28 (clone 82/29) to 39.72 (clone 82/15) per cent. Fourteen clones viz. 82/3, 82/4, 82/7, 82/14, 82/17, 82/19, 82/20, 82/21, 82/22, 82/24, 82/25, 82/26, 82/27 and 82/29 exhibited superior performance over RRII 105 of which the superiority of six clones were significant (Table 22).

(viii) Girth at opening

The estimates of heterosis over mid parent ranged from 0.46 (clone 82/26) to 25.77 (clone 82/29) per cent over the mid parent. The range of variation over better parent, RRIC 100, was from -2.34 (clone 82/24) to 23.61 (clone 82/29) per cent. Standard heterosis ranged from 1.12 (clone 82/24) to 27.99 (clone 82/29) per cent. All the hybrid clones were found to be superior in performance to RRII 105 (Fig. 21) of which seven clones exhibited significant superiority (Table 22).

(ix) Girth increment rate

The heterosis values over mid parent ranged from -54.39 (clone 82/18) to 100.42 (clone 82/8) per cent. Fourteen clones were found to be superior to the mid parent. Four clones viz. 82/7, 82/8, 82/19 and 82/20 were found to excel RRII 105, the better parent, heterosis ranging from 3.15 (clone 82/19) to 37.25 (clone 82/8) per cent (Table 22).

Table 22. **Estimates of heterosis (%) for plugging index, girth at opening and girth increment rate in clones**

		Plugging index		Girth at opening			Girth increment rate	
		% heterosis over						
Sl. No.	Clone	MP	BP (RRII 105)	MP	BP (RRIC 100)	Standard clone (RRII 105)	MP	BP (RRII 105)
1.	82/3	-26.74**	-26.94**	9.28	7.40	11.22	-3.35	-33.81
2.	82/4	-20.26*	-20.27*	17.59**	15.58*	19.68**	8.37	-25.79
3.	82/5	30.08	29.72	15.29**	13.31*	17.33**	20.08	-17.77
4.	82/7	-26.74**	-26.94**	12.88*	10.95	14.89*	75.31**	20.06
5.	82/8	24.23	23.88	13.88**	11.93	15.91*	100.42**	37.25
6.	82/10	6.13	5.83	7.23	5.40	9.14	23.85	-15.19
7.	82/11	37.05	36.67	2.95	1.18	4.77	46.44	0.29
8.	82/14	-27.86**	-28.05**	15.19**	13.21*	17.23*	27.62	-12.619.
9.	82/15	40.11	39.72	0.96	-0.76	2.75	43.51	-1.72
10.	82/17	-4.74	-5.00	9.65	7.78	11.60	-22.18	-46.70
11.	82/18	3.06	2.78	2.79	1.02	4.61	-54.39	-68.76
12.	82/19	-7.52	-7.78	2.26	0.51	4.08	50.63	3.15
13.	82/20	-9.19	-9.44	14.69*	12.72*	16.72*	65.27*	13.18
14.	82/21	-17.29	-17.50	1.46	-0.28	3.26	-48.12	-64.47
15.	82/22	-21.45*	-21.67*	4.99	3.19	6.85	-1.67	-32.66
16.	82/23	4.46	4.17	1.36	-0.37	3.16	29.29	-11.46
17.	82/24	-19.78	-20.00	0.64	-2.34	1.12	35.98	-6.88
18.	82/25	-22.84*	-23.06*	4.35	2.56	6.19	-15.42	-42.12
19.	82/26	-18.66	-18.89	0.46	-2.17	1.31	14.64	-21.49
20.	82/27	-31.19**	-31.39**	5.77	3.96	7.65	-41.84	-60.17
21.	82/28	11.98	11.67	4.99	3.19	2.18	-34.31	-55.01
22.	82/29	-35.09**	-35.28**	25.77**	23.61**	27.99**	37.24	-6.02
23.	82/30	8.64	8.33	7.03	5.19	8.93	-36.82	-56.73
	CD (0.05)	0.72	0.83	5.63	6.50	6.50	1.27	1.46
	CD (0.01)	0.96	1.11	7.51	8.67	8.67	1.69	1.95

* Significant at P < 0.05 ** Significant at P < 0.01

MP - Mid parent

BP - Better parent

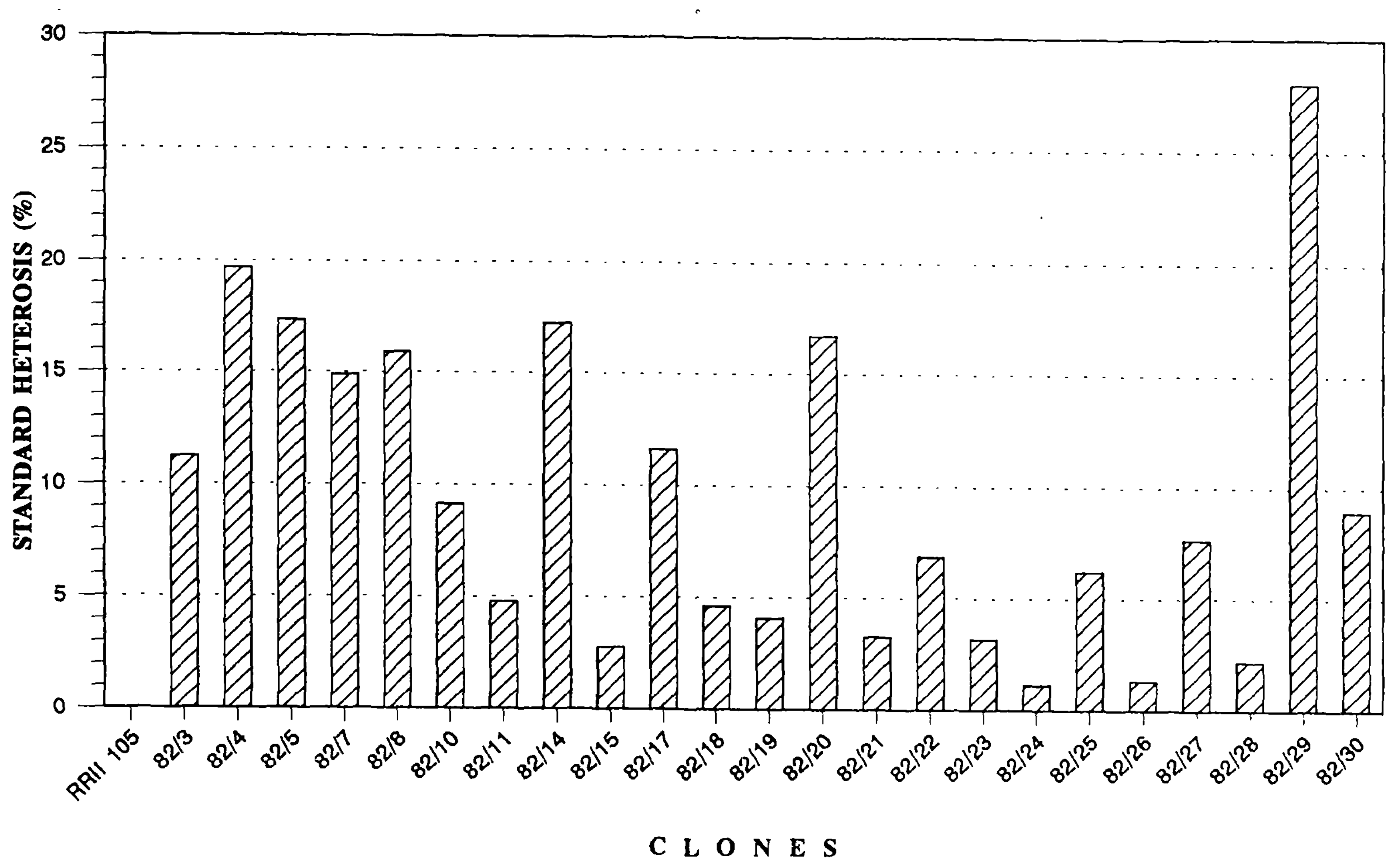


Fig.21. Standard heterosis for girth at opening in hybrid clones.

(x) Virgin bark thickness

Virgin bark thickness at the third year of tapping recorded a range of variation of -6.02 (clone 82/15) to 13.48 (clone 82/8) per cent over mid parent value. Fifteen clones exhibited their superiority over the mid parent. The estimates over better parent, RRII 105, ranged from -12.12 (clone 82/15) to 6.12 (clone 82/8) per cent. Five clones viz. 82/8, 82/14, 82/21, 82/25 and 82/27 excelled RRII 105 with heterosis ranging from 2.69 (clone 82/21) to 6.12 (clone 82/8) per cent (Table 23).

(xi) Number of latex vessel rows in virgin bark

The range of variation of heterosis over mid parent values was from -39.34 (clone 82/19) to 43.04 (clone 82/29) per cent. The estimates over better parent ranged from -40.00 (clone 82/19) to 41.48 (clone 82/29) per cent. Eighteen hybrid clones exhibited superior performance over RRII 105 (Fig. 22), the superiority being significant in the case of five clones (Table 23).

(xii) Renewed bark thickness

Thickness of bark at the sixth year of renewal revealed a heterosis over mid parent to range from -7.79 (clone 82/15) to 22.02 (clone 82/8) per cent. Thirteen clones excelled the mid parent of which it was significant in three clones. The estimates of heterosis over the better parent, RRII 105 ranged from -15.75 (clone 82/15) to 11.50 (clone 82/8) per cent. Four clones viz. 82/7, 82/8, 82/10 and 82/17 were found to be superior to RRII 105, heterosis ranging from 3.13 (clone 82/7) to 11.50 (clone 82/8) per cent (Table 24).

(xiii) Number of latex vessel rows in renewed bark

In the case of number of latex vessel rows in the renewed bark at the sixth year of renewal, heterosis estimates over mid parent ranged from -44.58 (clone 82/19) to 60.32 (clone 82/22) per cent. Eleven clones exhibited superior performance over the better parent of which it was significant in three clones. The range of variation for heterosis over the better parent, RRII 105, was from -53.86 (clone 82/19) to 33.44 (clone 82/22) per cent. Three clones viz. 82/14, 82/22 and 82/29 excelled the better parent, RRII 105 (Table 24).

Table 23. Estimates of heterosis (%) for structural components during the third year of tapping

Sl.No.	Clone	Virgin bark: Bark thickness MP	Bark thickness BP (RRI 105)	No. of latex vessel rows MP	No. of latex vessel rows BP (RRIC 100)	Standard clone RRII 105
		% Heterosis over				
1.	82/3	-1.83	-8.20	18.66	17.36	19.98
2.	82/4	3.14	-3.55	-4.29	-5.34	-3.22
3.	82/5	1.96	-4.65	-10.08	-11.06	-9.07
4.	82/7	5.24	-1.59	0.07	-1.03	1.18
5.	82/8	13.48*	6.12	17.36	16.08	18.67
6.	82/10	2.62	-4.04	27.31*	25.92	28.73*
7.	82/11	-4.71	-10.89	10.86	9.65	12.09
8.	82/14	12.69*	5.39	41.48**	39.94**	43.06**
9.	82/15	-6.02	-12.12	-21.65	-22.51	-20.78
10.	82/17	5.89	-0.98	33.22**	31.77*	34.71*
11.	82/18	4.71	-2.08	4.03	2.89	5.19
12.	82/19	-5.62	-11.75	-39.34	-40.00	-38.66
13.	82/20	-4.58	-10.77	-7.93	-8.94	-6.90
14.	82/21	9.81	2.69	32.89**	31.45*	34.39*
15.	82/22	7.06	0.12	40.83**	39.29**	42.41**
16.	82/23	-1.57	-7.96	0.39	-0.71	1.51
17.	82/24	1.44	-5.14	7.61	6.43	8.81
18.	82/25	7.46	4.89	13.39	12.15	14.66
19.	82/26	-0.79	-7.22	11.96	10.74	13.21
20.	82/27	7.06	1.22	8.71	7.52	9.93
21.	82/28	-3.14	-9.42	2.54	1.41	3.68
22.	82/29	3.27	-3.43	43.04**	41.48**	44.64**
23.	82/30	3.66	-3.06	19.12	17.81	20.45
	CD (0.05)	0.80	0.93	3.70	4.27	4.27
	CD (0.01)	1.07	1.24	4.94	5.70	5.70

* Significant at $P < 0.05$ ** Significant at $P < 0.01$

MP - Mid parent

BP - Better parent

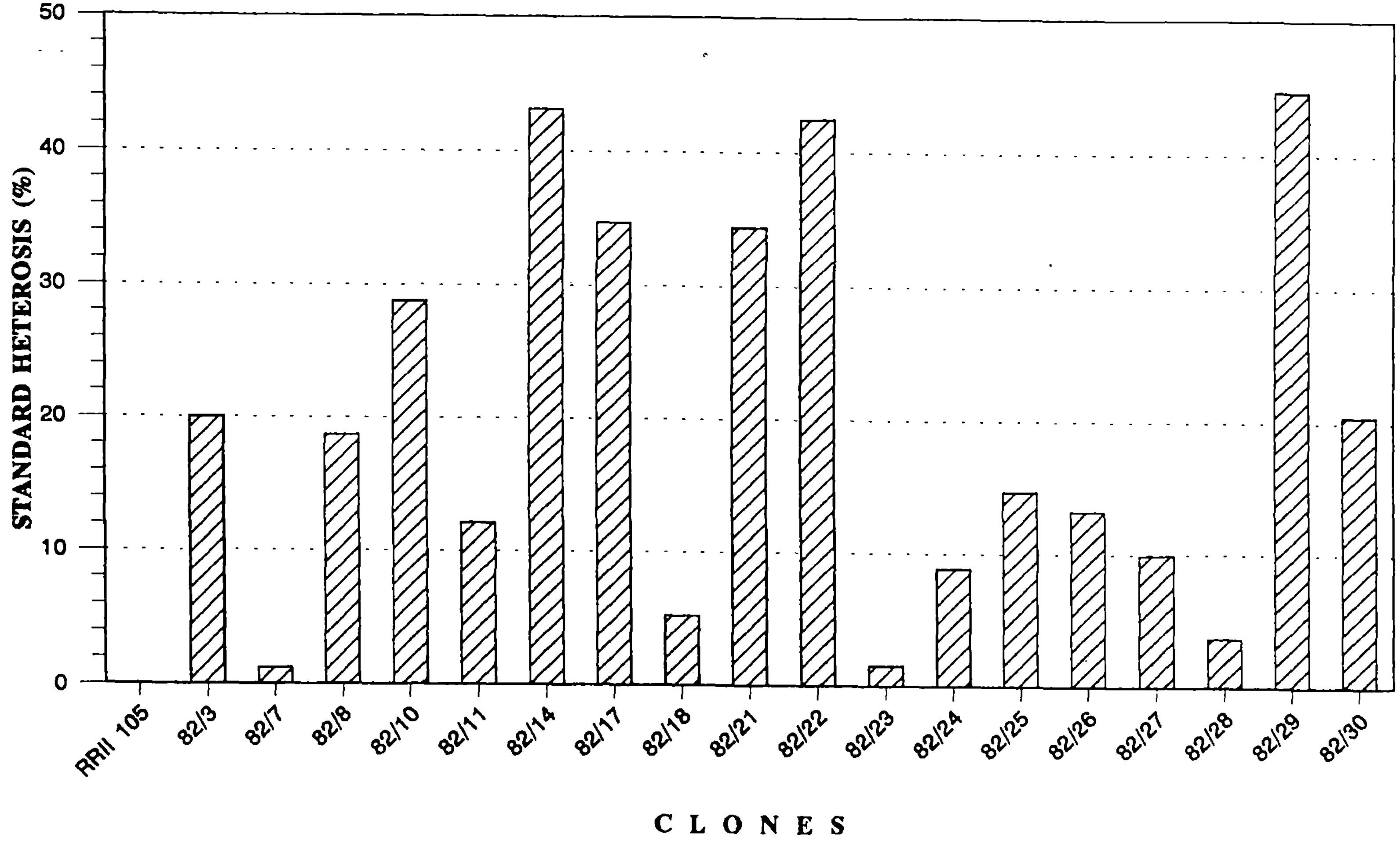


Fig.22. Standard heterosis for latex vessel rows in virgin bark in hybrid clones in the third year of tapping.

Table 24. Estimates of heterosis (%) for renewed bark thickness and number of latex vessel rows in renewed bark

Sl.No.	Clone	Renewed bark thickness			
		Bark thickness		No. of latex vessel rows	
		% heterosis over			
		MP	BP (RRII 105)	MP	BP (RRII 105)
1.	82/3	-0.27	-8.87	-16.31	-30.34
2.	82/4	-4.92	-13.13	8.80	-9.44
3.	82/5	-0.27	-8.88	-15.99	-30.08
4.	82/7	12.86*	3.13	3.71	-13.67
5.	82/8	22.02**	11.50	6.45	-11.40
6.	82/10	16.83**	6.75	7.75	-10.32
7.	82/11	0.27	-8.38	2.97	-14.29
8.	82/14	7.39	-1.88	22.94*	2.32
9.	82/15	-7.79	-15.75	-41.17	-51.03
10.	82/17	14.09*	4.25	17.36	-2.32
11.	82/18	1.50	-7.25	-18.59	-32.25
12.	82/19	5.34	-13.50	-44.58	-53.86
13.	82/20	-0.27	-8.88	-1.18	-17.75
14.	82/21	3.28	-5.63	-1.36	-17.19
15.	82/22	4.92	-4.13	60.32**	33.44**
16.	82/23	5.34	-3.75	-13.02	-27.61
17.	82/24	3.69	-5.25	3.35	-13.98
18.	82/25	4.38	-4.63	-4.96	-20.89
19.	82/26	0.27	-8.38	1.61	-15.43
20.	82/27	0.41	-8.28	-13.14	-27.71
21.	82/28	-1.78	-10.25	-8.74	-24.05
22.	82/29	5.06	-4.00	34.16**	11.66
23.	82/30	0.96	-7.75	-26.66	-38.96
	CD (0.05)	0.90	1.04	3.45	3.99
	CD (0.01)	1.20	1.39	4.60	5.32

* Significant at $P < 0.05$ ** Significant at $P < 0.01$

MP - Mid parent

BP - Better parent

CHAPTER 4

Discussion

An understanding of the genetics of quantitative characters is most essential for systematic handling of the breeding material in any scientific crop improvement programme. This is especially true in the case of economic characters affecting yield, on which the breeder is most concerned. Many of these characters are quantitatively inherited and are greatly influenced by the environment. Therefore, total reliance to the conventional Mendalian analysis will not be practicable, leading to a situation which calls for sophisticated biometrical methods.

Improvement of perennial crop in general and rubber, in particular, by breeding is very complicated and time consuming due to long juvenile period, the long intervel between generations, heterozygous cross fertilized nature of the tree, the long period of experimentation required to obtain results and the large area required for statistical layout of the experiment. Inspite of these limitations substantial amount of work has been done in India on breeding of perennial crops especially of plantation crops with considerable progress. To cite a few examples; successful attempts have been made in *Cocos nucifera* (coconut) to select palms at the nursery stage by correlating seedling characters with adult palm y;ield. The discovery of hybrid vigour in coconut was a significant land mark in the history of coconut improvement (Ratnambal, 1996). Evolution of improved varieties in *Areca catechu* (arecanut), has been achieved through the introduction of indegenous and exotic types and refinement of selection procedures in mother-palms, seed nuts and seedlings (Nair, 1996). A modified version of reciprocal recurrent selection is adopted in *Elaeis guineensis* (oil palm) breeding aimed at yield improvement (Nampoothiri, 1996). In *Anacardium occidentale* (cashew), parents with prolific bearing and good nut size combined with good nutritive value are crossed to obtain hybrid vigour (Bhaskara Rao and Bhat, 1996). In *Piper nigrum* (black pepper), the perennial vine, besides open pollinated progeny selection, hybridization and clonal selection have been used for evolving new varieties (Sasikumar *et al.*, 1996). The same holds good for rubber breeding also. Systematic breeding in this industrial plantation crop species was started only during the late twenties after the discovery of the technique of hybridization.

H. brasiliensis has a highly heterozygous genetic system. The heterotic gain and the nature and magnitude of quantitative traits transmitted to the progenies even in a single parental combination have not been subjected to detailed investigations. In the present study, analysis of a biparental cross combination of *H. brasiliensis*, RRII 105 X RRIC 100, has been attempted with a view to bring out information on the extent of variability, the nature and magnitude of association of characters and the magnitude and nature of heterosis for yield and yield components, in the hybrid clonal progenies.

4.1 Genetic Variability

High degree of variability present in a population enhances the efficiency of selection programme. While variability among seedling population of *H. brasiliensis* was given importance in earlier periods (Whitby, 1919; Mass, 1937; Gilbert, *et al.*, 1973; Nga and Subramaniam, 1974; Tan and Subramaniam, 1976), attention was later diverted to studies on clonal variation with the onset of hybridization and clonal selection (Ross and Brookson, 1966; Simmonds, 1969; Markose and George, 1980; Liu, 1980; Nazeer, *et al.*, 1986; Mydin, *et al.* 1992a). The nature and magnitude of different yield components controlling rubber yield of *Hevea* clones differ at different growth phases (Ho, 1976) and at different environments (Jayasekera, *et al.*, 1977; Meenattoor, *et al.*, 1991).

4.1.1 Analysis of variance

The results obtained in the present investigations in the first three years of normal tapping revealed highly significant clonal variation for all the characters studied (Table 2 and Table 3). Analysis of variance revealed highly significant clonal variation for all the characters studied viz. dry rubber yield, volume of latex, rate of latex flow, dry rubber content, plugging index, girth at opening, girth increment rate, thickness of virgin and renewed bark, number of latex vessel rows in both virgin and renewed bark, total solid content, thiols, inorganic phosphorus, sucrose and magnesium except virgin bark thickness for which the clonal variation was significant only at 5% level of probability. The results are in agreement with the findings of Mydin (1992) and Premakumari (1992). The above observations suggest the presence of inherent genetic variability in the population which would enhance selection programme wherein selection pressure can be profitably exerted on these characters. Ranges of variation in the volume of latex and dry rubber yield during the three periods were among the highest. (Table 8 and Figs. 1-4). This observation is in confirmity with the high genetic variability for rubber yield obtained by Nga and Subramaniam (1974), Gilbert *et al.* (1973), Tan *et al.*(1975), Mydin *et al.* (1992) and Licy *et al.* (1992). The rubber tree is deciduous. Wintering takes place during the period, December to February, in South India. Soon after wintering the tree refoliates which is accompanied by flowering. It had been generally recognized in the past that the productivity of the trees dropped during this period. In the present study also a decrease in yield was noticed in all the clones. Maas and Bokma (1950), Edgar (1987), Polhamus (1962) and Ninane (1967) reported that summer months are lean in terms of crop production. Yield decrease during or soon after wintering had been reported by Dijkman (1951), Wimalaratna and Pathiratna (1974) and Sethuraj (1977). The drop in yield observed in the present hybrid population under study during the summer period is in confirmity with the low production reported by the authors cited above. During the peak yielding period also, dry rubber yield revealed significant clonal variation and all the clones yielded high during this period. Prakash (1984) had reported that around 60% of the total yield was realised during July to December (which includes the peak yielding period) under commercial practice. Twelve clones viz. 82/3, 82/4, 82/7, 82/10, 82/14, 82/17, 82/21, 82/22, 82/25, 82/27, 82/29 and 82/30 exhibited high yields in all the three seasons and could be considered to possess stability for yield. Saraswathyamma and Sethuraj (1975) have reported clonal variations for latex flow characters and yield which are in agreement with the present findings. Ranges of variation observed for bark thickness, plugging index, girth increment rate and dry rubber content were low (Table 8).

In the case of biochemical parameters, among the eleven clones studied, ranges of magnesium and inorganic phosphorus were high followed by thiols and ranges for sucrose and total solid content were low (Table 9). Licy *et al.* (1993) observed supporting evidence of significant clonal variation for biochemical parameters with highest and lowest ranges of variations as observed in the present investigation. The high ranges of variation observed for most of the characters viz. dry rubber yield (during the three periods), volume of latex, rate of latex flow, number of latex vessel rows in both virgin and in renewed bark suggest that considerable improvement could be achieved in these characters by selection. On the contrary, the low ranges of variability exhibited in the case of bark thickness, drc, plugging index, girth increment rate, total solid content and sucrose lead to the conclusion that not much significant improvement by selection could be achievable for reasonable improvement in these traits. It is suggested that parents with more genetic diversity for each of the traits should be taken up to provide enough variability for achieving good genetic advance through selection.

Results of the present study confirmed the existence of tremendous variability for yield and yield attributes and enabled the identification of clones with superiority for the various components and yield *per se.*

4.2 Genetic parameters

Genetic parameters like genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (H^2) and genetic advance

(GA) help in partitioning the genetic variability into heritable and non heritable components (Johansen, 1909; Henderson, 1953 and King and Henderson, 1954). While GCV provides a valid basis for comparing and assessing range of variability for quantitative characters, PCV measures only the extent of total variability. Suitable methods for estimation of genetic parameters in perennial crops have been discussed by several forest geneticists. (Sakai and Halakeyama, 1963, Sakai and Mukhaide, 1967, Huhn, 1975, Kedharnath *et al.*, 1969). Though rubber has a narrow genetic base, it shows wide range of variability (Fyfe and Gilbert, 1963; Gilbert *et al.*, 1973; Comstock and Robinson, 1948) due to its high heterozygous nature.

4.2.1 Genotypic and phenotypic coefficients of variation

A perusal of tables 8 and 9 and figures. 11 to 13, reveals that phenotypic coefficient of variation is higher than genotypic coefficient of variation for all the characters studied. This is quite natural as variability at phenotypic level includes both genotypic and environmental variabilities besides interaction (GxE). It may also be true that a large part of phenotypic coefficient of variation may be due to the influence of environmental factors and if it is so, selection would be ineffective. Variability at the genotypic level, particularly additive genetic variability is the one which decides the response to selection.

Among the eighteen characters studied, dry rubber yield, volume of latex, girth increment rate of tapping, magnesium, inorganic phosphorus and sucrose exhibited large GCV whereas number of latex vessel rows, rate of latex flow, plugging index and thiols revealed moderate estimates indicating more involvement of genetic factors in the expression of these characters. The lowest level of variation was shown by bark thickness (both virgin and renewed bark), girth at opening, total solid content and dry rubber content (Tables 8 and 9 and Figs. 11 to 13). Licy *et al.* (1992) recorded high GCV and PCV for annual mean dry rubber yield (34.56 and 41.92), summer yield (34.20 and 44.47), peak yield (37.42 and 45.61), volume of latex (42.71 and 74.63), plugging index (36.82 and 49.20), initial flow rate(37.8 and 49.49) and number of latex vessel rows (17.03 and 29.04) in the material under study in the early phase of evaluation. Premakumari (1992) also reported moderate to high GCV and PCV for rubber yield (22.32 and 24.67), volume of latex (18.61 and 26.60), initial rate of flow (57.98 and 74.53) and plugging index (31.10 and 48.85) and low values for girth (8.29 and 9.67) and drc (5.79 and 7.40). Licy *et al.* (1993) reported medium to high estimates of GCV and PCV for dry rubber yield (63.82 and 78.74), inorganic phosphorus (74.13 and 85.16), magnesium (63.08 and 69.84), thiols (48.55 and 60.85) and sucrose (21.53 and 28.17) in contrast to low estimates for total solid content (7.05 and 10.91) which are in agreement with the present findings. Licy *et al.* (1993) reported high estimates of coefficient of variation in another set of hybrid clones for most of the characters under study. The moderate to high estimates of GCV and PCV observed for dry rubber yield (33.73 and 39.54), volume of latex (30.91 and 36.98) and low GCV and PCV for girth (4.81 and 10.19), drc (7.02 and 9.96), bark thickness (3.79 and 8.15) and renewed bark thickness (5.35 and 9.97) observed in the present study are in confirmity with the findings of Markose (1984) and Mydin (1992). Very little estimate of GCV for girth was reported by Alika and Onokpise (1982). On evaluation of hundred genotypes of Brazilian germplasm in the early growth phase, Abraham *et al.*(1992) observed high GCV and PCV for number of latex vessel rows in contrast to low values for girth. Low values of GCV and PCV for girth and bark thickness in the present study are in confirmity with the results of

Chandrashekar *et al.*(1995). The strong parallelism observed between genotypic and phenotypic coefficients of variation signifies that these characters are comparatively stable with negligible environmental influences.

The present observations again confirmed that medium to high estimates of GCV and PCV obtained in the case of dry rubber yield, volume of latex, rate of latex flow, plugging index, number of latex vessel rows, magnesium, inorganic phosphorus, thiols and sucrose indicating that selection based on these characters would be advantageous since there is the predominance of additive gene action in the expression of these characters (Tables 8 and 9).

4.2.2 Heritability (broad sense)

Heritability is the fraction of the observed or phenotypic variance which is caused by differences between the genes or genotypes of individuals in a population. The degree to which the variability for a quantitative character is transmitted to the progeny is referred to as heritability and it measures the heritable portion of variability. In the broad sense, it refers to the functioning of the whole genotype as a unit and is used in contrast with environmental sources of variation (Lerner and Michael, 1950). It is estimated as the ratio of genotypic variance to phenotypic variance. The estimation of heritable variation is not possible with the help of genotypic coefficient of variation alone. Burton (1952) suggested that genotypic coefficient of variation together with heritability estimates would give a better idea of selection advance to be expected. Selection acts on genetic differences and gains from selection for a specific character depends largely on the heritability of the character (Allard, 1960).

For most of the characters studied, the heritability estimates were high or very high, indicating good response to selection of these traits. The heritability values exhibited by dry rubber yield [annual (72.21), summer (68.16) and peak yield (73.89)], volume of latex (69.85), rate of latex flow (79.46), plugging index (66.23), number of latex vessel rows in virgin bark (51.12), number of latex vessel rows in renewed bark (65.86), magnesium (73.73), inorganic phosphorus (60.59), thiols (54.51) and sucrose (56.81) were high. Dry rubber content, girth increment rate and total solid content revealed moderate heritability estimates (49.71, 50.64 and 48.39 respectively). Similar results were observed by Licy *et al.* (1992) in the present material under study, during the early phase of evaluation. Moderate to high estimates of heritability for most of the characters in the present experiment are in agreement with the view of Simmonds (1989) that heritability of economic characters in rubber are generally high. Tan (1979) estimated a heritability of 56 per cent for mature yield. Samsuddin *et al.* (1985) could obtain moderate heritability values for nursery yield (38.00), girth at opening (39.00) and girth increment on tapping (21.00). Mydin (1992) reported moderate to high heritability estimates for yield and most of the traits considered under the present investigation. High heritability for yield obtained by Nga and Subramaniam (1974), Liang *et al.* (1980), Markose and George (1980) and Markose (1984) is in agreement with the present observation while their observation of high heritability for girth was in contrast to the present finding of low heritability for girth. The moderate to high heritability estimates coupled with moderate to high GCV values for dry rubber yield during the three periods, volume of latex, rate of latex flow, plugging index, number of latex vessel rows, girth increment rate, inorganic phosphorus, magnesium, thiols and sucrose indicate that the observed variability for the traits is heritable. But traits such as dry rubber content and total solid content recorded moderate to high heritability (49.71 and 50.64 respectively) in spite of low GCV (7.02 and 6.16 respectively). This indicates that large proportion of the variability observed for these characters is heritable with negligible influence of environment. Low heritability coupled with low GCV values recorded in the case of girth and bark thickness confirms that marked improvement may not be achievable in these characters through selection.

4.2.3 Genetic advance

A measure of heritablity alone does not give an idea about the expected gain in the next generation but has to be considered in conjunction with genetic advance. Johnson *et al.* (1955) suggested that heritability estimates along with genetic advance (expressed in percentage of mean) furnishes a better picture than heritability alone. Ramanujam and Thirumalachar (1967) also suggested that broad sense heritability accompanied by high genetic advance is more reliable. In the present study moderate to high heritability coupled with moderate to high genetic advance was observed for dry rubber yield during the three periods, volume of latex, rate of latex flow, girth increment rate, plugging index, number of latex vessel rows, magnesium, inorganic phosphorus, thiols and sucrose. The above findings suggest the preponderance of additive gene action and hence considerable genetic gain could be achieved by including these characters in selection programme. Mydin (1992) also reported moderate estimates of genetic advance for dry rubber yield (37.2), volume of latex (25.9), rate of latex flow (32.7) and plugging index (23.8) which are in agreement with the present results. High heritability with low genetic advance obtained in the case of drc and total solid content reveal that the expression of these characters are controlled to a certain extent by non-heritable factors as suggested by Panse (1957) and hence response to selection would be limited. Exploitation of heterosis for these traits could be possible if dominance is involved in the non-additive gene effects (Singh and Chaudhary, 1985).

4.3 Association of characters

A knowledge of association of quantitative characters, especially of yield and its attributes would be of immense practical value in crop breeding programmes. Selection pressure can be profitably exerted in any of these easily discernible characters having close association with yield. Thus, how selection pressure on one character brings about changes in other traits is worth studying. Correlation studies provide information on the nature and magnitude of relationship between yield and its components. This forms an essential prerequisite for formulating breeding programmes (Gilbert, 1961) aimed at achieving desirable combination of various components of rubber yield. The estimates of genotypic and phenotypic correlation coefficient between various characters revealed the direction and magnitude of correlation and facilitated the interpretation of results already obtained.

4.3.1 Intercharacter correlations

While phenotypic correlations mainly serve the purpose of orientation, the genotypic correlations serve as reliable means for predicting the resultant effect of selection. The genotypic correlations provide a reliable measure of genetic association between characters and help to differentiate the vital associations useful in breeding from the non-vital ones (Falconer, 1981). Therefore, estimation of genotypic and phenotypic correlations among rubber yield and its components would be of advantage in understanding the relative importance of characters that could be used in selection programmes.

In the present study, genotypic and phenotypic correlations have been estimated and presented in (Tables 10 to 13 and Fig 14). In general genotypic correlations were higher than the phenotypic correlations in most cases. This could occur when genes governing two traits are similar but the environmental factors pertaining to the expression of the trait have a small effect.

However, the correlations for character pairs dry rubber yield (annual, summer and peak) versus drc, versus girth increment rate, volume of latex vs. drc, rate of flow vs girth increment rate, drc vs. girth rate increment rate, number of latex vessel rows vs, plugging index, vs. virgin bark thickness, bark thickness vs. drc, vs. plugging index, vs. girth at opening, vs. girth increment rate, renewed bark thickness vs. dry rubber yield, vs. drc and vs. plugging index at genotypic level were lower than those at the phenotypic level.

In general, the genotypic and phenotypic correlations were varying in magnitude but not in direction. While in the case of character pairs drc vs. annual mean dry rubber yield, vs. summer yield, vs. volume of latex, girth at opening vs. rate of flow, girth increment rate vs. peak yield, vs. drc, vs. girth at opening, number of latex vessel rows vs. drc, plugging index vs. girth increment rate, virgin bark thickness vs. drc, vs. plugging index, number of latex vessel rows vs. drc, vs. girth at opening and renewed bark thickness vs. drc, the genotypic and phenotypic correlation coefficients were different in sign. It appears that environmental factors might have influenced these characters through different physiological mechanisms.

At both genotypic and phenotypic levels total volume of latex, initial rate of latex flow, girth at opening, number of latex vessel rows in virgin as well as in renewed bark and virgin and renewed bark thickness exhibited positive correlations with dry rubber yield in all the three seasons. Summer yield and peak yield also exhibited significant positive associations with annual mean dry rubber yield and between each other. Mydin (1992) also reported similar findings in a study of forty clones of Wickham origin. The present results are in agreement with the findings of Dijkman and Ostendorf (1929), Narayanan *et al.* (1973) and Tan *et al.* (1975). Dry rubber yield has been reported to be positively correlated to the initial rate of latex flow (Paardekooper and Samosorn, 1969) and negatively correlated to plugging index (Milford *et al.*, 1969; Sethuraj *et al.*, 1974). Sethuraj (1981) has elucidated that yield of rubber from a tree per tapping is proportional to the initial rate of latex flow, length of the tapping cut, the dry rubber content of latex and inversely proportional to the plugging index. Narayanan *et al.* (1974), Tan and Subramaniam (1976) and Liu (1980) reported a positive correlation of yield with tree girth while Wycherley (1969) and Markose (1984) reported a negative correlation between girth and yield. Ho *et al.* (1973) and Ho (1976) observed a positive association of yield with girth in the initial years of tapping with a gradual decrease in the later years. In the present study, while girth exhibited positive genotypic association with yield, girth increment rate revealed negative genotypic association with yield. This may be attributed to the fact that once the tree is under the stress of tapping, more of the assimilates are partitioned towards latex formation and less towards girthing rate as suggested by Ho *et al.* (1973), Wycherley (1975, 1976) and

Sethuraj (1985). Hence the negative association of yield with girth increment rate. Dijkman (1951), Markose (1984) and Sethuraj (1977) also reported that growth rate of rubber tree is affected by tapping. Girth is a very important trait governing juvenile yield (Narayanan and Ho, 1973; Ho, 1976; Licy *et al.*, 1988; Varghese *et al.*, 1993 and Premakumari *et al.*, 1989).

In the case of biochemical parameters genotypic correlations were higher than the phenotypic correlations with respect to character pairs latex volume vs. total solid content, vs. thiols, vs. inorganic phosphorus, vs. sucrose and also with regard to character pairs total solid content vs. thiols, vs. inorganic phosphorus, vs. magnesium, vs. sucrose and inorganic phosphorus vs. Sucrose (Tables 12 and 13). In rest of the cases the association was higher at the phenotypic level than was the case at genotypic level which indicates high environmental influence. Licy *et al.* (1992) observed positive association of all the above parameters with latex yield in a set of nine clones in the early phase of evaluation. Licy *et al.* (1993) reported positive genotypic and phenotypic correlations of rubber yield with thiols, inorganic phosphorus, sucrose and magnesium in contrast to a negative association with total solid content. Lynen (1969) reported that a high value of inorganic phosphorus indicates an active laticiferous system and hence a high positive association between inorganic phosphorus and production. The positive association of latex volume and thiols indicates the influence of thiols via the activating key enzymes involved in production as suggested by Jacob *et al.* (1986). So also the high positive association of sucrose with the latex volume leads to the conclusion that there is a high metabolic production of sucrose leading to increased photosynthetic efficiency which in turn leads to increased latex production (Tupy and Prevot, 1976; Prevot *et al.*, 1984a) A high total solid content by increasing viscosity of latex may limit latex flow and hence the negative association with latex yield as opined by Brozosowska *et al.* (1979) and Milford *et al.* (1969).

The correlation estimates in the present study reinforced the fact that dry rubber yield during summer and peak seasons, volume of latex, rate of latex flow, plugging index, number of latex vessel rows, bark thickness along with biochemical parameters like thiols, inorgnic phosphorus and sucrose have a preponderant effect on rubber yield. It is imperative that considerable improvement in rubber yield could be achieved by selecting a genotype with a good and favourable combination of all the above traits.

4.4 Forecasting future performance and early selection

The major problem in perennial crop breeding is the long time needed to draw conclusions due to the long prebearing period. Some reports about the relationship between seedling characters and the future performance of trees are available (Annamma *et al.*, 1990;Ramachander, 1990). However, the relationship established is not very strong. Complicated mathematical models, especially the system analysis procedures by splitting the range of a character in to small intervals and trying to find out the most appropriate relation within these intervals needs to be done on priority basis (Ramachander 1990). Establishment of such relation also would help in identification of high yielding planting materials at an early stage.

4.4.1 Early versus mature character correlations

Early versus mature character correlations for yield and the major yield components under study are presented in Tables 17 and 18. The correlations revealed that dry rubber yield in the early phase (immature phase of four and a half years after field planting) had strong and significance favourable association with most of the characters in the mature phase. Similar trend was observed in the case of association of mature yield with most of the early characters. Association of all the characters in the early phase with the same characters in all the three consecutive years of mature phase were highly significant and promising (Table 18) indicating a more or less reliable possibility of selection of potential clones in the early phase ie. six to seven years earlier than the conventional period. This also suggests that performance of early potential clones could be confirmed in the first year of tapping itself. Studies on correlation between nursery yield and mature yield revealed only low to moderate associations between the two parameters (Ong *et al.*, 1986). Premakumari *et al.* (1989) obtained a correlation coefficient of r=0.55 between immature yield and yield of trees under first year of tapping, in a seedling population and found that the mean yield recorded in different seasons was more reliable than one recording at a particular season alone. Highly significant association of nursery yield and plugging index with mature yield have also been reported (Ho, 1976). Tan (1983) opined that nursery yield should be viewed only as an early guide in selection which has to be confirmed by mature yield. Hence evaluation of clones in the immature phase assumes importance. Licy *et al.* (1990) reported that, based on yield and girth in the immature phase in the small scale trial, a fair degree of selection for further testing may be possible. According to a study in Nigeria (Alika, 1980), correlation between yearwise yield over an eight year period of tapping in the early mature phase, revealed that the correlation of first year yield with that in the second year was very high (r=0.92) which dropped gradually with third, fourth and fifth years of tapping. Tan (1978) suggested that selection based on early mature yield would be more effective than nursery yield.

In the present investigation the highly significant correlation between yield and yield attributes in the immature phase of four and a half years' of growth with those of first and subsequent years of tapping emphasizes the importance of characters in the early phase in predicting mature performance (Table 18).

In the case of biochemical parameters all the characters in the early phase revealed positive association with the same characters in the mature phase (Table 19). The early versus mature associations with regard to total solid content, thiols, inorganic phosphorus and magnesium were highly significant (Table 19). This also points towards the fact that with greater degree of reliability we would be able to include these parameters in early selection of potential clones. Ditinger *et al.* (1981) and Henon *et al.* (1984) have suggested that latex diagnosis techniques could be tried on young trees which would enable early selection of promising clones. Bricard and Nicolas (1989) carried out studies to determine the reliability of the above biochemical parameters and observed that all the above parameters exhibited high reliability. They also found total solid content to be least reliable among the above five parameters as was observed in the present study.

4.4.2 Early selection and reduction in yield testing period

The well established conventional breeding and selection cycle in rubber is elaborate and requires about 30-32 years from seedling nursery till final release of a clone. The sort of three phased selection through small scale, large scale and block trials impedes quick release of cultivars, though necessary for systematic exploration of large number of progenies. Alika (1980), Gilbert *et al.* (1973) and Tan (1979) opined that reduction in the period of evaluation is a necessity. Ways to reduce this long testing period have been tried by several workers with some amount of success. The promotion plot trials introduced by the RRIM in 1972 is a good step forward in this line. In this method a few high yielding progenies, selected based on nursery evaluation, are tested straight from the nursery in a kind of large scale trial in two replications with a plot size of 0.2 hectare per clone. The main drawback in this method is that only a very small proportion is selected based on nursery yield prediction, which by itself, is not fully reliable. Subramaniam (1980) reported on bye-passing one of the testing stages for shortening the testing period. Markose and Panikkar (1984) suggested establishment of replicated field trials during the third year after pollination and take task wise trials, if possible, in different locations during the twelfth year, which would enable a planting recommendation in 24-25 years.

Studies on the correlation between nursery and mature yield revealed only low to moderate association between the two parameters (Ong *et al.*,1986). Thus with the available early prediction methods, nursery yield can be considered only as a fair indicator of mature yield. Tan (1978) suggested that selection based on early mature yield would be more effective than nursery yield. Licy *et al.* (1990) reported the importance of evaluation of hybrid clones in the immature phase of four and a half years after field planting to identify promising selections. The results of the intercharacter as well as early versus mature character correlations have proved the reliability of yield and yield components in the early clonal phase as parameters in early selection. The regression of mature yield on early yield (Fig. 15) proved to a great extent that the method of evaluation in the early clonal phase of four and a half years after field planting could be relied upon with still more confidence than any of the methods available so far.

With the exception in a very few cases, all the clones which exhibited heterotic improvement for yield and yield components in the mature phase over the first three years of tapping (Tables 20 - 24) did exhibit their superiority in the early phase too (Licy *et al.*, 1992). Based on the early clonal performance of 63 hybrid clones which also included the hybrid clones under the present study, Licy *et al.* (1990) predicted the possible chance of gaining potential hybrid clones from among them (which were to be confirmed in the mature phase) that would result in shortening the yield testing period by about 6 -7 years. In the present investigation the highly significant positive association of early yield and yield attributes with those of first and subsequent years of tapping suggests more possibilities of reliable selection based on early clonal performance, thus confirming the earlier predictions. Scrutiny of the regression of mature yield on early yield further confirmed that early clonal yield could be considered as a good predictor of mature yield (Fig. 15). Early evaluation of the materials under the present study resulted in the identification of fifteen clones having heterotic improvement for yield over the standard clone RRII 105 (Licy *et al.*, 1992). Based on a critical evaluation of yield and yield components in the early clonal phase of four and a half years, from among the fifteen, nine clones viz. 82/3, 82/7, 82/10, 82/14, 82/17, 82/22, 82/27, 82/29 and 82/30 (Fig. 23) were identified as having better potential for yield, with a minimum of about 35% yield improvement over RRII 105 (Licy *et al.*, 1992). These clones were put for testing in the further stage of evaluation ie. large scale clone trial, during 1993 itself for further large scale testing. Eight out of these nine clones continued to exhibit their superiority over RRII 105 in the mature phase too though with a decrease in the magnitude of heterotic increase and were confirmed to be promising (Fig. 23). This holds good especially in the case of the top ranking three clones viz. 82/14, 82/22 and 82/29 which were confirmed to be top rankers and significantly superior to RRII 105 in the mature phase also.

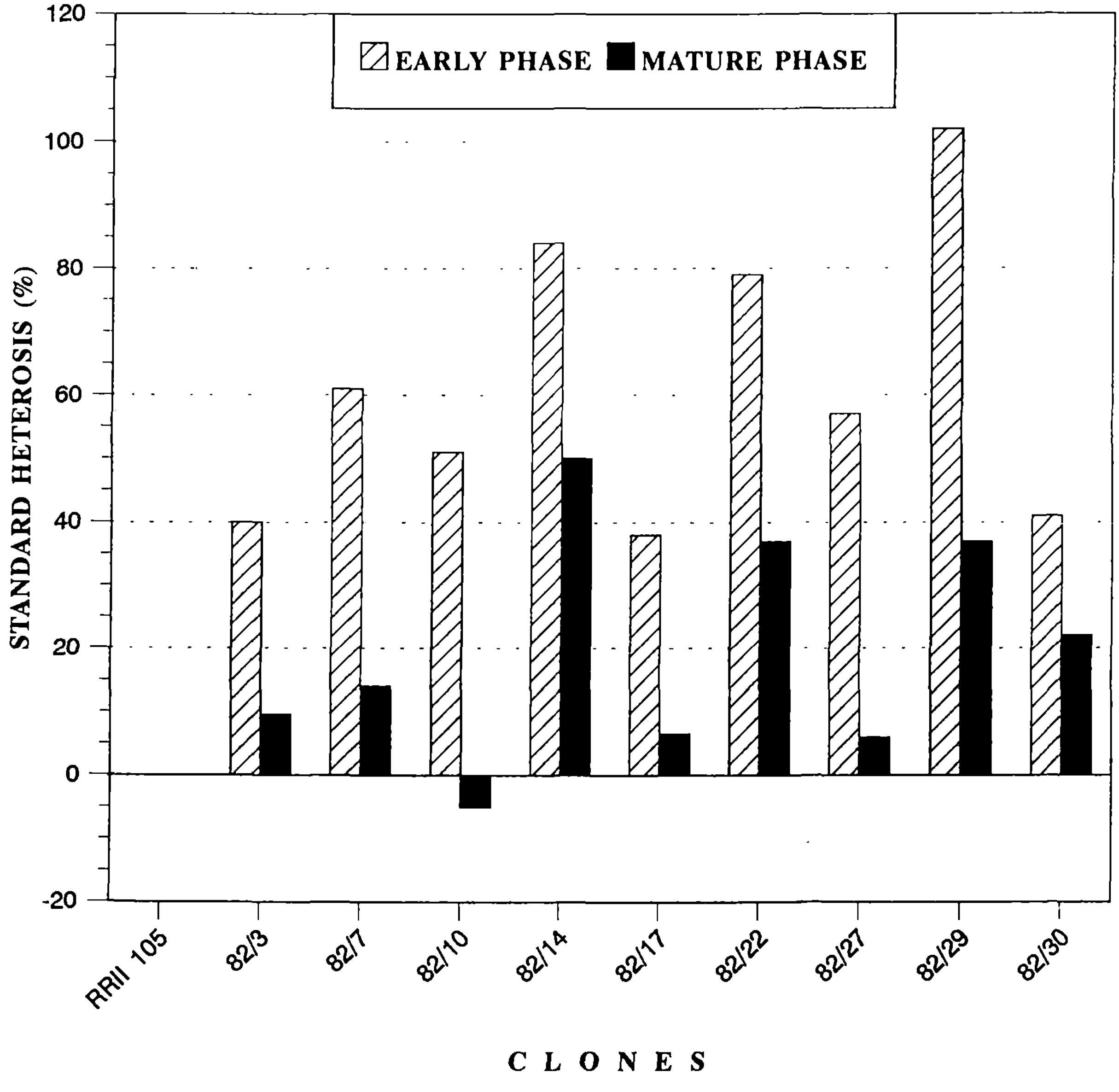


Fig. 23. Standard heterosis for yield in the early and mature phases

The clone 82/10 though yielded slightly lower than RRII 105, was found to be statistically on par with RRII 105. The above observations lead to the inference that a fair degree of early selection of superior heterotic hybrids in the immature phase will definitely hold the most promising ones to be gained after the mature phase of evaluation.

Inclusion of all the above nine clones (based on early performance) in the further stage of evaluation during 1993 itself without prolonging it for a further period of five years to get a confirmatory performance over the first five years of tapping (as is the case with the conventional practice), has helped in saving around 6 to 7 seven years' yield testing period, in the small scale clone trial. Since the results in the early clonal phase were found to be indicative of mature performance, the method of accelerated evaluation adopted in the early phase is of advantage in shortening the period of yield testing by about 6 to 7 years.

4.5 Heterosis

The primary goal of a plant breeding programme is essentially to improve the genetic potentiality of the crop, particularly the yielding ability and productivity of a genotype. This is being achieved in several ways, the most attractive and achievable one being heterosis breeding. Heterosis has been exploited for quite long, in cross pollinated crops. The development of quantitative genetic theory relating to hybrid vigour centered around 'dominant gene hypothesis'. According to this hypothesis, the masking of the deleterious recessives by their dominant counterparts in the heterozygous F_1 hybrids was supposed to account for greater vigour. The mutual complementation of two genotypes was thought to be further contributing to this phenomenon. There appears to be some relationship between the degree of heterosis in a hybrid and the extent of differences between parents with respect to number of alleles, gene action, the genetic background or a combination of these factors. Cross pollination is the rule rather than an exception in rubber. Due to the heterozygous nature of the crop segregation of characters take place in the F_1 generation itself and vegetative propagation enables to fix heterosis obtained in the F_1 generation.

In rubber the conventional method of direct selection was based on the first five years' yield. It is however, now viewed that the first three years' yield data is reliable and adequate for selecting superior clones (Ong, 1980 and Swaminathan, 1975), which naturally will shorten the testing time. Comparison of hybrids with the best and most accepted ones among the released varieties is more important from practical point of view than their performances above their parents. Hence estimation of standard heterosis is given importance in the present study and are discussed below.

4.5.1 Heterosis for yield and physiological yield attributes over the first three years of tapping

In the case of dry rubber yield (annual mean), nine hybrid clones viz. 82/3, 82/7, 82/14, 82/17, 82/21, 82/22, 82/27, 82/29 and 82/30 exhibited positive standard heterosis over the most popular high yielding variety, RRII 105 (which is also the female parent) which ranged from 4.09 to 50.64 per cent indicating that these hybrids have got higher potential for yield than the commercially popular variety, RRII 105 (Fig.16). Clones 82/14, 82/22 and 82/29 exhibited significant superiority over RRII 105 (with heterosis percentages 50.64, 34.52 and 34.64

respectively) indicating future promise. Usually with respect to yield, heterosis more than 20% is considered to be adequate for commercial exploitation (Rai, 1979). Hence in the present study standard heterosis observed in clones, 82/14, 82/22, 82/29 and 82/30 offers a fertile field for further improvement in *H. brasiliensis.*

In the case of yield during summer (stress) period, ten clones viz. 82/3, 82/10, 82/14, 82/17, 82/21, 82/22, 82/26, 82/27, 82/29 and 82/30 out yielded RRII 105 (Fig.17) the heterosis percentage ranging from 3.67 to 67.11 whereas in the case of the yield during peak yielding period eight clones viz. 82/3, 82/7, 82/14, 82/17, 82/21, 82/22, 82/29 and 82/30, with percentage heterosis ranging from 2.73 to 37.15 were found to be superior to RRII 105. (Fig.18). Most of the hybrid clones were common for heterotic expression for dry rubber yield in all the three seasons which suggests better scope for further exploitation of heterosis for yield (Table 20).

Nine clones viz. 82/3, 82/4, 82/10, 82/14, 82/17, 82/22, 82/27, 82/29 and 82/30 were found to exhibit standard heterosis for volume of latex (Fig. 19) ranging from 2 to 51%(Table 21). Only one clone, 82/14, having a heterosis of 50.79% was found to be significantly superior to the standard clone RRII 105, indicating substantial superiority of this clone over RRII 105. Very high estimates of heterosis of latex yield of *Hevea* was observed by Olapade (1988) which is supportive of the results obtained in the present study.

Only one clone ie. clone 82/30 exhibited significant superiority over RRII 105 (with a heterosis of 16.46 %), for initial rate of latex flow while two other clones ie. 82/14 and 82/10 were on par (with heterosis percentages -4.3 and -1.65) with RRII 105 (Table 21). With respect to dry rubber content clones 82/3, 82/11, 82/15, 82/17, 82/18, 82/21, 82/22 and 82/30 were found to excel RRII 105, with heterosis values ranging from 1.61 to 9.80 % (Fig. 20). Both the parental clones were found to be on par with each other for this trait.

Fourteen clones viz. 82/3, 82/4, 82/7, 82/14, 82/17, 82/19 82/20, 82/21, 82/22, 82/24, 82/25, 82/26, 82/27 and 82/29 (Table 22) which recorded their superiority over RRII 105 for plugging index offer vast potential towards improving yield via using them as parents in breeding for component level improvement of characters. Both the parents were equally good in plugging index and hence might have contributed to hybrid vigour for the character.

4.5.2 Heterosis for growth and structural attributes

With regard to girth at opening all the hybrid clones were superior to RRII 105 (Table 22), standard heterosis ranging from 1.1 to 27.99% (Fig. 21). As both the parental clones are equally vigorous, the resultant hybrid clones were found to be excelling their parents. This could be attributed to the complementary gene action of both the parents. Early vigour facilitates early tapping. Hence the encouraging results obtained for the hybrid clones render scope for early exploitation, thereby resulting in reduction in the immaturity period to a considerable extent. So also in the context of timber being gaining more and more importance, a clone having good timber combined with high latex yield is worth evolving. The present results throw light in this direction. Mydin *et al.* (1990) also recorded high estimates of heterosis for juvenile girth in certain hybrid *Hevea* clones.

Four clones viz. 82/7, 82/8, 82/19 and 82/20 excelled RRII 105 for girth increment rate on tapping (Table 22), the standard heterosis ranging from 3.15 to 37.25%. This suggests better scope for utilizing these clones in crosses aimed at girth improvement. The female parent RRII 105 (which is the better parent) exhibited good girth increment rate on tapping (3.49 cm $year^{-1}$) compared to the male parent RRIC 100 (1.28 cm $year^{-1}$) and it could be inferred that the heterotic increase for girth increment rate in the above four clones could be due to major contribution by RRII 105.

While eighteen clones viz. 82/3, 82/7, 82/8, 82/10, 82/11, 82/14, 82/17, 82/18, 82/21, 82/22, 82/23, 82/24, 82/25, 82/26, 82/27, 82/28, 82/29 and 82/30 exhibited standard heterosis ranging from 1.18 to 44.64% for number of latex vessel rows in virgin bark (Fig. 22) at the third year of tapping, only the top ranking three clones viz. 82/14, 82/22 and 82/29 excelled RRII 105 for number of latex vessel rows in renewed bark, the standard heterosis ranging from 2.32 to 33.44%. Number of latex vessel rows is a clonal character (Bobilioff, 1923; Sanderson and Sutcliffe, 1929 and Vischer, 1921, 1922) and frequency of laticifer differentiation is genetically controlled. The above results suggest the immense potentiality of these clones in crop improvement of rubber, especially for using as parents in breeding programmes aimed at component level improvement of characters.

Clones, 82/8, 82/14, 82/21, 82/25 and 82/27 were found to be slightly superior to RRII 105 for virgin bark thickness whereas clones, 82/7, 82/8, 82/10 and 82/17 were found to be superior to RRII 105 with regard to renewed bark thickness with standard heterosis ranging from 3.13 to 11.50%.

Examination of the heterotic response for yield and its components in general revealed that majority of the hybrids displaying significant hybrid vigour for yield also possessed marked heterotic advantages in one or the other components. According to Graffius (1959) there cannot be any gene system for yield *per se* and yield is an end product of multiple interactions between the yield components. This would mean that heterosis for yield is the reflection of heterosis for one or more of the individual yield components as observed in the present investigation. It was interesting to note that none of the hybrid clones was found to be inferior to RRII 105 for all the characters studied. Even the very low yielders ie. clones 82/19 and 82/15 excelled RRII 105 with respect to girth at opening and girth increment rate. Clone 82/15 exhibited superiority over RRII 105 for dry rubber content also. This further indicates that all the 23 hybrid clones possess greater potentiality either in terms of yield or in terms of yield components. It provides scope for using these clones as parents in satisfying componentwise breeding objectives besides rendering scope for direct commercial exploitation.

The realization of good estimates of heterosis for yield and yield attributes in the clonal materials under the present study shows that the cross, RRII 105 x RRIC 100 could be better exploited for improving yield in rubber. The parents have been identified as genetically distant, the genetic distance being 0.614 as evidenced by studies using random amplified polymorphic DNA markers

(Varghese *et al.*, 1996) and might have facilitated marked heterosis for yield and yield attributes.

Judging from the results discussed, a good number of the hybrid clones especially clones, 82/3, 82/7, 82/10, 82/14, 82/17, 82/21, 82/22, 82/27, 82/29 and 82/30 which were identified as, either on par with or superior to RRII 105 in performance, seem to offer better potential towards improving productivity in rubber.

4.6 Multiclone concept and clonal composites

Monoculture of a limited number of high yielding varieties of any agricultural crop in a geographical area has the potential danger of narrowing down the genetic variability which in due course may lead to disease and pest epidemics. Specific examples include (i) Irish famine of the 1940's due to damage to the potatoe crop by *Phytophthora infestans*, (ii) Bengal famine in India in 1943 associated with brown spot disease of rice, (iii) breakdown of rust resistance of Kalyanosona wheat variety in South East Asia during 1973-'74 and (iv) Coffee rust in Ceylon, which caused a shift to tea production (Varghese, 1990).

In *Hevea*, recent reports indicate instances of less serious diseases becoming more severe. A serious problem reported is serve incidences of *Corynospora* leaf disease affecting clones RRIC 103, KRS 21 and RRIM 725 in Sri Lanka. Thus RRIC 103, one of the most popular high yielding clone planted extensively in Sri Lanka, had to be withdrawn from the planting recommendation and extensive areas under this clone were replanted. Similarly, a new anthracnose diseasae caused by *Fusicoccum* reported during 1987 in

Malaysia, a minor disease of *Guignardia* observed intermittently in Malaysian estates since 1982 (IRRDB 1988) affecting clones like PB 235, PB 260 and PB 217, etc. are some other examples. This points towards the fact that if monoculture of a high yielding variety is adopted, in the eventuality of emergence of a virulent strain of any particular pathogen, the disease will spread and cause serious damage.

The development of RRII 105 by the Rubber Research Institute of India and its popularity among the farming community have been a land mark in increasing productivity and total production of natural rubber in India. The clone is such an outstanding high yielder that now it has come to a stage that more than 90% of the growers plant only this clone. This practice has lead to a situation of monoclonal development during the last decade. If this trend is continued, within a few years, most of the rubber growing areas will be covered by this single clone. This situation can lead to serious consequences like disease and pest epidemics likely to affect rubber production adversely. Hence, it is highly essential to prevent such a possible catastrophe.

Realising the importance of the situation a strategy for multiclone planting was proposed by the Rubber Research Institute of India, during 1991. Considering the potentially dreadful consequences, the recommendations taken was to restrict the planting of RRII 105 to not more than 50% of the total area and to fill the remaining area with promising clones in category II a (upto 35%) and categogry II b (upto 15%) of the planting recommendations of tbe Board. It was even suggested that the Board may consider possibility of making this clonal blending as a condtion for giving subsidy to growers.

In this context promising alternative clones either comparable with or superior to, of RRII 105 are worth considering as possible clonal components. The potential high yielding clones like 82/3, 82/7, 82/10, 82/14, 82/17, 82/21, 82/22, 82/27, 82/29 and 82/30, identified in the present investigation offer scope in this direction. A comparative performance of yield of the above clones reveal that clones 82/14, 82/22 and 82/29 have yielded 35 to 50% above RRII 105 and are significantly superior. Except clone 82/10 all the other clones also exceeded RRII 105 in yield, the yield increase in these clones ranging from 4 to 23%. Clone 82/10 though slightly lower than RRII 105 in yield performance was found to be comparable to it. In terms of girth, all the above clones are vigorous than RRII 105, the percentage increase ranging from 3 to 28%. These clones blended with other diverse genetic materials forming a clonal composite population offer better protection to the plantation industry from possible future disasters.

4.7 Future prospects

Rubber becoming more and more a small holders' crop, breeding objectives should take care of their specific needs like early high yields, resistance to high intensity tapping, availability of stable high yields etc. (Annamma, *et al.*, 1990). With a view to exploiting the genetic variability at yield component level emphasis is being given for selection of parent clones with complementary yield components which would result in higher yielding hybrid clones.

Shortening the breeding cycle in *Hevea* is an essential pre-requisite in evolving planting materials and making them available to the planting community in shorter spells. The method of early evaluation which has been successful in the present study renders better scope in this direction. However, the rubber breeder has to ensure the quality and reliability of the newer materials resultant of early selection which largely depend on several heritable and environmental factors as well as agromanagement practices. This demands future inter-disciplinary approaches for development of stable, high yielding clones.

At present extensive areas are cultivated with a handful of high yielding clones which are more or less closely related. The rubber breeder has to be cautious about the possible danger of monoculture-vulnurability to diseases and pests. Hence it calls for evolving high yielding diverse planting materials to constitute components of a clonal composite population.

Pressure on land and socio-economic constraints necessitates the expansion of rubber cultivation to marginal lands. In India, rubber cultivation has already been extended to non-traditional areas exposed to different stress situations. Clones capable of withstanding such situations need to be bred and evaluated for maximising productivity in these areas. Action has already been initialed to evaluate some of the high yielding clones (the top ranking five clones) identified in the present study, in traditional as well as non-traditional areas with the objective of evolving location specific clones.

Among the major rubber producing countries of the world, India stands first in productivity of natural rubber and fourth in production. The productivity has increased from 284 kg ha^{-1} $year^{-1}$ in 1950-51 to 1422 kg ha^{-1} $year^{-1}$ in

'95-'96 (Rubber Board, 1997). The present production of natural rubber in India does not meet the consumption demand fully. It is sufficient to meet only 96% of the demand in the country. The outlook for the future is one of widening demand supply gap. The demand is projected to exceed 7 lakh tonnes by the year 2000 and reach 12 lakh tonnes by 2010 while the production is estimated at 6.77 lakh tonnes and 9 lakh tonnes respectively (Mathew, 1995).

Therefore the development objective for the rubber plantation industry should be one of increasing production with a view to minimising import of natural rubber. Development of a number of high yielding varieties in the present study assumes special significance in this context. In spite of creditable improvement in productivity within a short span of time, theoretical conclusions indicate more potential in terms of yield (Sethuraj, 1981). The encouraging results of the present investigation suggests further scope for exploitation of heterosis for crop improvement in rubber.

CHAPTER 5

Summary

The main objectives of the investigations were (1) to ascertain the extent of variability, (2) to estimate genetic parameters like heritability and genetic advance, (3) to estimate the nature and magnitude of inter character associations for yield and yield attributes, (4) to assess the extent of heterosis for yield and its components and (5) to apprise character associations governing yield and yield attributes between early and mature phases in the plantation crop species, *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell. Arg., the principal source of natural rubber. The study was also aimed at finding out methods for early detection of potential clones and identifying a set of clones, comparable with or superior to RRII 105, the most popular high yielding clone in India, as probable components for clonal composites.

Genetic analysis were carried out in the biparental cross involving RRII 105 and RRIC 100, the former evolved by the Rubber Research Institute of India and the latter by the Rubber Research Institute of Sri Lanka. The yield components subjected to detailed study were volume of latex, rate of latex flow, dry rubber content, plugging index, girth at opening, girth increment rate, thickness of virgin and renewed bark , number of latex vessel rows in both virgin and renewed bark and total solids, thiols, inorganic phosphorus, sucrose and magnesium content in latex.

High ranges of means were observed for characters, volume of latex (63.65-280.12 ml tapping $^{-1}$), peak yield(26.82-104.32 g tree^{-1} tapping^{-1}), annual mean dry rubber yield(20.21-88.20 g tree^{-1} tapping^{-1}), summer yield (11.14-69.30 g tree^{-1} tapping^{-1}), initial rate of latex flow (15.50 -53.0 ml min $^{-5}$ cm $^{-1}$ x 50), number of latex vessel rows in both virgin (9.33-22.00) as well as in renewed bark (8.94-25.86), inorganic phosphorus (717.43 - 2043.77 μg g$^{-1)}$, magnesium (425.54 - 2106.22 μg g$^{-1)}$) and thiols (102.00 - 220.50 μg g$^{-1)}$) and the ranges of means were lower for girth at opening, girth increment rate, plugging index, dry rubber content, bark thickness and total solid content.

The phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the characters studied. However, it was closer for most of the characters suggesting lesser environmental influence. Moderate to high GCV was observed for the characters annual mean dry rubber yield (33.73) summer yield (40.68), peak yield (34.36%), volume of latex (30.91), girth increment rate (32.09), number of latex vessel rows in both virgin (22.01) as well as in renewed bark (26.14), rate of latex flow (27.17), plugging index (20.94), magnesium (40.10), inorganic phosphorus (31.12), sucrose (28.60) and thiols (22.65). High heritability coupled with high genetic advance was also observed for some of the economic traits like dry rubber yield in all the three periods, volume of latex, rate of latex flow and biochemical characters like inorganic phosphorus, magnesium and sucrose.

Genotypic correlations in general were higher than phenotypic correlations in most of the cases. Among the 18 chracters studied, most of the correlations were found to be in the positive direction. At both phenotypic and gentoypic levels, summer yield, peak yield, volume of latex, number of latex vessel rows in both virgin as well as in renewed bark and virgin bark thickness exhibited high positive associations and plugging index high negative association with annual mean dry rubber yield. Inorganic phosphorus and thiols also revealed positive association with latex volume. The above characters in turn showed high positive associations among themselves too. This suggests the scope for simultaneous improvement of these traits by selection which in turn will improve yield as well.

The early versus mature character associations revealed highly significant association of early yield with all the characters in the mature phase. So also a highly significant association of mature yield with all the characters in the early phase was observed. All the characters in the early phase exhibited highly significant positive association with the same characters in the mature phase. The findings stress the significance of characters in the immature phase as parameters of early detection of potential clones.

In rubber, the long duration of the breeding and selection cycle poses a strong hindrance towards rapid development of clones. Analysis of regression of mature yield on early yield suggests the posssibility of early prediction of potential clones that would result in shortening the yield testing period by about 6 -7 years enabling comparatively rapid developement and release of clones. In this context the method of evaluation in the early phase, at four and a half years of age after field planting, was found to be of immense practical utility.

The range of heterosis of the hybrid clones over the standard clone RRII 105, which is also the better parent, in most cases was more for dry rubber yield in all the three periods (-65.48-50.64, -73.13-67.11 and -64.74-37.15% respectively), volume of latex (-65.74-50.79%), rate of latex flow (-65.94-16.46%), girth increment rate (-68.76-37.25%) and number of latex vessel rows in both virgin (-38.66-44.64%) and renewed bark (-53.86-33.44%). The ranges of heterosis estimates were narrow for the characters, thickness of both virgin and renewed bark and dry rubber content. For plugging index and girth at opening, the range of heterosis was intermediate. The cross RRII 105 x RRIC 100 in general gave high positive standard heterosis for most of the characters studied viz. dry rubber yield(in all the three periods) volume of latex, rate of latex flow, plugging index, number of latex vessel rows (in both virgin as well as in renewed bark) girth at opening and girth increment rate. Based on the heterotic response for yield and yield components, ten clones viz. 82/3, 82/7, 82/10, 82/14, 82/17, 82/21, 82/22, 82/27, 82/29 and 82/30 were identified as having better potential towards improving yield in rubber. Besides being geographically divergent the parental clones are proved to be genetically distant also, which might have mainly contributed to manifestation of high heterosis for yield and yield components.

In the context of the changing scenario from *monoclonal to multiclonal* planting recommendation in rubber, scrutiny of yield and yield components of the 23 hybrid clones under study revealed the above ten clones to be having better potential for high yield which could be used along with other promising clones to constitute components of a clonal composite population.

The study also indicates that parental combinations possessing high genetic distance offer immense scope for exploitation of heterosis for crop improvement in *H. brasiliensis.*

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