DISCUSSION

5.1. Analysis of Variance

5.1.1. Performance of Clones

Analysis of variance revealed highly significant clonal variation for all the characters studied except for girth increment rate under tapping. The results showed that genetic variation exists in the population which would enhance selection programme wherein selection pressure can be profitably exerted on these characters. The result of the present study is supported by the findings of earlier workers like Mydin (1992), Premakumari (1992), Licy (1997), Licy et al., (2002) and John et al., (2003). Eight clones recorded above average annual yield and these clones were identified as high yielding clones. Of these seven clones yielded significantly higher than that of the high yielding clone RRII 105. Among these clones, PB 255 recorded the highest mean yield of 73.52 g t\(^{-1}\) t\(^{-1}\) over the three years of tapping followed by PB 314 (66.88 g t\(^{-1}\) t\(^{-1}\)), PB 280 (66.81 g t\(^{-1}\) t\(^{-1}\)), PB 260 (63.20 g t\(^{-1}\) t\(^{-1}\)), KRS 163 (62.96 g t\(^{-1}\) t\(^{-1}\)), PB 312 (62.13 g t\(^{-1}\) t\(^{-1}\)), PB 311 (60.33 g t\(^{-1}\) t\(^{-1}\)), PB 235 (57.45 g t\(^{-1}\) t\(^{-1}\)), KRS 128 (51.78 g t\(^{-1}\) t\(^{-1}\)), RRII 105 (49.50 g t\(^{-1}\) t\(^{-1}\)). Nga and Subramaniam (1974) and Gilbert et al., (1973) have also reported a high genetic variability for yield, which is in agreement with the result of the present study.

*H. brasiliensis* is a perennial tree crop and shed their leaves annually known as ‘wintering’. In South India ‘wintering’ usually takes place during December to February and by that time all the leaves are shedded. It has been observed that the productivity of the trees dropped down during this period. Dijkman (1951), Wimalaratna and Pathiratna (1974) and Sethuraj (1977) reported the drop in yield soon after wintering. Latex yield is observed
to be low during the dry season of February to May, when the soil water availability is least and the rainfall is about zero. Mass and Bokma (1950), Polhamus (1962), Ninane (1967) and Edgar (1987) reported that summer months are lean in terms of crop production. All the clones have shown reduction in yield during stress period. Highly significant clonal variation was recorded in the yield drop in present study. Yield depression during stress was comparatively less for PB 255 followed by PB 310, PB 314, PB 312, PB 311, PB 217 and KRS 128 and were considered in having stability in yield whereas, PB 235 followed by KRS 163 and PB 280 showed high yield depression during stress. Webster and Paardekooper (1989) reported marked variation among clones in yield depression during the period of refoliation. The result of the present study is in conformity with the reports of the earlier workers.

Ranges of variation was high for yield and all yield components, however panel length, girth increment on tapping, plugging index and bark thickness exhibited relatively low values. Saraswathyamma and Sethuraj (1975) and Licy (1997) reported low values for latex flow characters which is in agreement with the results of present study. Six clones recorded high girth of above 60 cm. The highest girth was recorded for PB 255 (65.99 cm) followed by PB 235 (65.27 cm), PB 280 (64.74 cm), PB 310 (62.36 cm), PB 314 (60.95 cm) and PB 312 (60.61 cm). Highly significant clonal variation was recorded for all the components of yield. It implies that genetic variation exist in the population and there is scope for selection based on these characters. There are four clones viz., PB 255, PB 280, PB 312 and PB 314 showing high vigour in terms of bole girth and high yield and were identified as latex timber clones. All these clones exhibited trunk girth above 60 cm and yield above 60 g t⁻¹ t⁻¹. Latex-timber clones are gaining importance in the changing global scenario where rubber wood is viewed as an alternate source of timber.
5.1.2. Latex and rubber properties

Important properties like pH, total solid content, non rubber substances, ash, gel, acetone extract, nitrogen, Mooney viscosity, plasticity and plasticity retention index, which relate to the qualities of latex and rubber were studied for 13 clones of *Hevea brasiliensis*. The impact of clonal variations on these parameters was observed to be significant. A major source of variability within and between NR grades is probably is dependance of the property on the clones from which the latex is collected (Fuller, 1988). Different clones have different characteristic and give rubber with different properties. The colour and composition of the latex and the plasticity of the rubber tend to be uniform within a clone and different for different clones (Martin, 1961).

The latex pH of the clones showed that the clone KRS 163 recorded highest pH value followed by PB 314, PB 260, PB 280 and PB 311. Clone RRII 105 exhibited neutral latex pH (7.03). Brozozowska *et al.*, (1979) and Coupe and Lambert, (1977) reported rubber production has been shown to be correlated positively with cytosolic pH and transtonoplastic pH gradient (cytosol-lutoids) in the latex. Total solid content is the total fraction of solid particles in natural rubber including dry rubber content. The highest mean value for total solid content recorded for KRS 128 followed by RRII 105, PB 255, PB 280 and PB 235. Viscosity of latex depends on the total solids present. A high total solid content may limit yield by hindering flow (Milford *et al.*, 1969; Buttery and Boatman, 1976 and Brozozowska *et al.*, 1979). On other hand low total solid contents is indication of weak latex regeneration in situ (Eschback *et al.*, 1984; Prevot *et al.*, 1984). The non-rubber constituents in natural rubber have a profound effect on the vulcanization of the hydrocarbon and the physical properties of the resulting vulcanizates. The include proteins, acids, ash and water (Bengtsson and Stenberg, 1996).
These impurities influence the rubber in different ways. The soluble non rubber materials influence mainly the time variation of the relaxation modulus of row NR at longer relaxation time the increases rate of relaxation quite markedly (Campbell and Fuller, 1984). Clone KRS 25 showed highest non rubber substances (3.53 %) followed by PB 255 (3.48 %), PB 311 (3.29 %), KRS 128 (3.29 %) and PB 310 (3.24 %). Clone RRII 105 exhibited 2.95 per cent of NRS.

The ash content represents the amount of mineral matter present in the rubber, such as carbonates and phosphates of potassium, magnesium, calcium, sodium and other trace elements. The highest ash content was noticed for PB 312 (0.26 %) whereas, the lowest for PB 260 and KRS 163 (0.14 %). A high ash content in rubber could also result from contamination during latex collection or processing. Copper and manganese are the two trace elements in ash. These materials are very powerful catalysts for the oxidation of NR by oxygen in the air (Cole, 1958). The presence of inorganic compounds can increase the tendency of vulcanized articles to swell in water (Stagracznski and Kunst, 1993).

Gel is the insoluble fraction of the material when the rubber is dissolved in the solvent. Two types of gel exist in NR, micro gel and macro gel. Micro gel consists of sub micron size particles, which are cross-linked latex particles. Macro gel appears to be a secondary bonded network incorporating micro gel and most of the proteinaceous materials (Allen and Bristow, 1963; Fuller, 1988). Clone PB 255 exhibited highest gel content (22.87 %) followed by RRII 105 (16.66 %) and PB 311 (14.22 %). However, KRS 163 recorded lowest value 4.43 per cent. The gel has a marked influence on the relaxation behaviour of NR. It has predominantly stiffening effect. It produces a comparatively slight decreases in the rate of relaxation. The macrogel phase is an extremely stiff, almost non relaxing material. The
macrogel particles also have a stiffening effect, but they also significantly reduce the rate of relaxation (Campbell and Fuller, 1984).

Acetone extract was highest for PB 260 (4.17 %) followed by PB 217 (4.08 %), KRS 163 (4.07 %) and PB 235 (3.96 %). However, RRIL 105 showed 2.80 per cent of acetone extract. Esah (1990) reported that is property has not be extensively studied. It has been shown to increase after yield stimulation using 2, 4, 5 - trichlorophenoxyacetic acid (2, 4, 5 - T) and to decrease with the age of a tree (Moris and Sekhar, 1959). The acetone extract of NR contains naturally occurring non- rubber constituents such as lipids, fatty acids, quebrachitol, sterols and esters. In addition, acetone will extract the degraded rubber, if the rubber has been exposed to oxidative influences such as strong sun light (Rubber Research Institute of Malaysia, 1992). Lipids are responsible for the stability of the rubber particles (Ho et al., 1976). The sterols and esters are believed to contain the antioxidant which is effective in preserving the raw rubber against oxidation and softening during storage (Bengtsson and Stenberg, 1996). Fatty acids influence strongly the rate of vulcanization with certain accelerator system (Ebi and Kolawole, 1992). Generally acetone extract varies between 2 to 5 per cent in dry rubber (Esah, 1990) and for all the clones, the values are within the limit.

It is known that NR when it leaves the tree contains definite proportion of nitrogen as integral part of macro molecule (Bengtsson and Stenberg, 1996). Clone PB 312 registered highest value for nitrogen content (0.49 %) whereas, RRIL 105 showed 0.42 per cent for nitrogen content. The highest nitrogen for PB 312 was followed by PB 311 (0.48 %), PB 314 (0.48 %) and PB 310 (0.45 %). The nitrogen content of dry rubber is reported to be the proteinaceous material either tenaciously held or chemically bonded to the rubber (Burfield et al., 1976). Tata 1980 reported that about 30 per cent of these materials are present in the rubber
hydrocarbon and about 70 per cent in the non rubber phase. Most of these have been shown to play an important role in the stability of *Hevea* latex. Certain proteinaceous materials had been shown to exert various effects on the technological properties of rubber (Alias and Hasma, 1988).

Mooney viscosity gives an indication of the quantum of mechanical work required on the raw rubber to give mixes with consistent rheological properties after standard mastication, compounding and mixing. This means that a rubber with very high Mooney viscosity may require longer premastication time or need expensive peptisers to obtain a product of a workable and consistent viscosity, whereas the rubbers with comparatively low Mooney viscosity require lesser mastication (Esah, 1990). Mooney viscosity was highest for PB 255 (88.24 unit) followed by PB 217 (83.19 units), KRS 128 (82.63 unit) and RRII 105 (81.68 unit), whereas, KRS 163 exhibited lowest value (63.47 unit) for Mooney viscosity. Besides Mooney viscosity, the important property of bulk viscosity of rubber is also measured by the Wallace plasticity and the plasticity values determined for the clones. Initial Wallace plasticity was recorded highest for PB 255 (60.67) followed by PB 217 (58.11), KRS 128 (57.39) and RRII 105 (54.67).

Plasticity retention index is a measure of the resistance of rubber to molecular breakdown by heat. It is assessed by the percentage change of the original plasticity when the rubber is heated at 140°C for 30 minute. High values correspond to good heat resistance. Clone PB 280 exhibited highest PRI value (88.11 %) followed by KRS 163 (86.89 %), PB 260 (86.44 %) and KRS 25 (85.61 %). RRII 105 exhibited 81.89 per cent for PRI.

In terms of plasticity, most of the clones gave medium to hard rubbers. Clone RRII 105 could be graded to the higher viscosity range. KRS 163 had the lowest P<sub>m</sub>, Mooney
viscosity and gel content, whereas the highest values were observed for clone PB 255. Ash content and plasticity retention index had lesser effect on clone. The data generated could provide a comparative assessment of the latices of clones, though some variations could be expected on changing the soil and environmental conditions.

*Hevea* latex as obtained from the tree consists not only of rubber hydrocarbon particles, but also non-rubber substances, which include lipids, proteins, carbohydrates, acids, amines and some inorganic constituents. It is generally known that some of these non rubbers can affect the properties of latex concentrates and bulk rubber derived from the field latex. As all the rubbers were prepared in the same manner using the same procedure, any variation observed in the properties studied could be considered as mainly due to differences between the clones.

5.1.3. Association of dry rubber yield with latex and rubber properties

Among the various latex and rubber properties viz., pH, total solid content (TSC), non-rubber substances (NRS), acetone extract (AE), nitrogen content (N,), gel content (GC), mooney viscosity (MV), initial plasticity (P,), plasticity retention index (PRI) and ash content (AC) of *Hevea* studied, pH of latex indicated significant correlation with rubber yield (0.583). It shows that pH of latex may have the influence on the rubber yield of *Hevea*. pH, TSC, GC and PRI showed positive association with rubber yield, whereas, NRS, AE, N, MV, P, and AC registered a negative association with yield. The highest correlation of rubber yield with pH of latex is followed by yield × ash content (-0.348), yield × PRI (0.271), yield × TSC (0.266), yield × P, (-0.251) and yield × MV (-0.238) was noticed. One of the most important factors affecting the coagulation of latex is its pH value. Rubber production has been correlated positively with the cytosolic pH of the latex and the transtonoplastic (cytosol/lutoids) pH gradient
The result of the present study is in conformity with the findings of Chrestin and Gidrol (1985) indicated that the positive correlation between rubber production and cytosolic pH of the latex and the transtonoplastic (Cytosol/lutoids) pH gradient is due to the reactivity of Mg dependent ATPase. The pH showed apparent correlation with yield, if it is confirmed to be of general occurrence it will be of importance in explaining the mechanism of yielding rubber in *Hevea*.

5.2. Genetic parameters

Highly significant clonal variation was recorded for all the yield components studied. Wide range of variations was recorded for girth at opening (50.96-61.33 cm.), annual dry rubber yield (38.17 - 73.52 g t⁻¹ t⁻¹), rubber yield in stress season (26.29 - 52.74 g t⁻¹ t⁻¹) and peak season (44.75 - 80.42 g t⁻¹ t⁻¹), yield depression during stress (27.99 % - 49.87 %), latex yield (107.60 ml t⁻¹ t⁻¹ - 176.85 ml t⁻¹ t⁻¹), latex yield during stress (58.31 ml t⁻¹ t⁻¹ - 115.26 ml t⁻¹ t⁻¹) and peak season (117.27 ml t⁻¹ t⁻¹ - 193.17 ml t⁻¹ t⁻¹), latex vessel rows in virgin (16.68 - 28.64) and renewed bark (14.20 - 30.96). However, low range of mean was recorded for girth increment, rubber content, in different seasons and also for bark thickness.

5.2.1. Phenotypic and genotypic coefficient of variation

The present study indicated substantial differences in phenotypic and genotypic coefficient of variation for the characters studied. The highest value of phenotypic coefficient of variation (PCV) was exhibited by mean girth increment (32.56 %) followed by latex yield during stress period (26.95 %), latex vessel rows in renewed bark (26.94 %), rubber yield in stress period (26.26 %) and yield depression under stress (26.01 %), rubber yield in peak period (22.91 %), annual rubber yield (21.60 %), latex yield in peak period (20.96 %), latex vessel rows in virgin bark (20.92 %) and annual latex yield (20.61 %). Girth at opening and
rubber content showed lowest phenotypic coefficient of variation. Moderate PCV was recorded for virgin and renewed bark thickness among the variables studied.

The highest GCV was observed for yield depression under stress (20.84 %) followed by dry rubber yield in stress season (20.27 %), latex vessel in renewed bark (20.19 %), latex yield in stress period (20.09 %), rubber yield in peak period (18.52 %) and annual rubber yield (16.98 %). Low genotypic coefficient of variation was observed for girth at opening, annual rubber content and rubber content in different seasons whereas, virgin and renewed bark thickness, girth increment, latex vessel rows in virgin bark and annual latex yield showed moderate GCV among the characters. Genotypic coefficient of variation (GCV) for yield and yield components showed the existence of substantial genetic variability among the clones studied.

The high value of GCV observed for rubber yield is in agreement with the reports of Whitby (1919), Simmonds (1969), Gilbert et al., (1973), Nga and Subramaniam (1974), Markose and George (1980), and Hamazh and Gomez (1982). Licy (1997) reported a high degree of GCV and PCV for dry rubber yield, latex yield and number of latex vessel rows as observed in the present study. Premakumari (1992) reported a moderate GCV and PCV for rubber yield, latex yield and low values for girth and rubber content, which are in conformity with the present study.

GCV was lower than PCV for all the characters studied. However, the magnitude of difference between GCV and PCV estimate was high for girth increment on tapping, indicating environmental factors influencing the character. It was low for all other characters indicating that genetic factors were predominantly responsible for these characters. Markose (1984) and Mydin (1992) reported genotypic coefficient of variation was lower than the phenotypic
coefficient of variation for all the characters studied which indicates the influence of environment on the genotype in the expression of these characters. Moderate to high GCV and PCV was observed for girth increment on tapping, annual dry rubber yield, dry rubber yield in two seasons, yield depression during stress, annual latex yield and latex yield in two seasons, virgin and renewed bark thickness and latex vessel rows in virgin and renewed bark indicating that selection based on these characters would be advantageous, since there is the predominance of additive gene action in the expression these characters. Low value of genotypic coefficient of variation and phenotypic coefficient of variation for girth and rubber content are in conformity with the findings of Markose (1984). Alika and Onokpise (1982), Mydin (1992), Chandrasekar et al. (1995) and Licy (1997), reported low GCV and PCV for girth.

5.2.2. Heritability

Heritability is the proportion of the total variance of an observable characteristic that may be accounted for by genetic factors. It can also be stated as the fraction of total phenotypic variance that remains after exclusion of the variance due to environmental effects. 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 heritability of the character (Allard, 1960 and 1999). A high heritability expressed by a high value of above 60 per cent was observed for most of the characters. Broad sense heritability was highest for annual rubber content (71.39 %) followed by rubber content during peak period (69.50 %), rubber yield in peak period (65.00 %), rubber content during stress period (64.55 %), yield depression during stress (64.15 %) and annual rubber yield (61.77 %).
indicating that observed variability for these traits are heritable. Breeder can expect additive genetic variance to be available for selection in progeny generation for these characters. Simmonds (1989) explains that in rubber, heritability of economic characters are high. Low heritability was observed for girth at opening and girth increment rate on tapping. Low heritability coupled with low GCV for girth at opening confirms that marked improvement may not be achievable in such characters through selection. The relatively high value of heritability observed for the major yield components explains large proportion of variability observed for these characters is heritable with negligible influence of environment. The low heritability observed for girth may be due to that the observations were conducted during the early years of production phase of the plants. Liang et al., (1980), Alika (1982) reported similar findings. The moderate heritability observed for virgin bark thickness and renewed bark thickness are in agreement with Tan et al., (1975), and Alika and Onokpise (1982). Relatively high heritability for yield and girth was reported by Nga and Subramaniam (1974), Liang et al., (1980), Markose and George (1980) and Markose (1984). However, Mydin (1992) and Licy (1997) reported low heritability for girth which was in agreement with the results of the present study. In general, high heritability for rubber content, latex yield, and annual dry rubber yield indicates that observed variability for the trait is often heritable.

5.2.3. Genetic advance

Genetic advance is the improvement in the mean genotypic value of selected families over the base population. Genetic advance under selection depends up on several factors like 1) the genetic variability among different plants or families in the base population 2) the heritability of character under selection and 3) the intensity of selection i.e., the population of plants or families selected. High genetic advance recorded for yield
depression during stress (34.37 %), dry rubber yield in stress season (32.23 %), latex vessel rows in renewed bark (31.21 %), latex yield in stress period (30.85 %), dry rubber yield in peak period (30.76 %), whereas, annual dry rubber yield (27.49 %), latex yield in peak seasons (25.56 %), annual latex yield (22.09 %), latex vessel rows in renewed bark (19.57 %), virgin bark thickness (18.57 %), registered moderate genetic advance under selection. Renewed bark thickness (14.37 %), rubber content in peak season (13.30 %), rubber content in stress period (10.94 %), girth increment on tapping (9.58 %) and girth at opening (6.41 %) showed genetic advance under selection. In the present study, moderate to high heritability associated with high genetic advance for yield depression during stress, rubber yield in stress period, latex vessel rows in renewed bark, latex yield in stress period and rubber yield during peak season have been observed, which indicated additive gene action in the inheritance of these traits and implies scope for improvement of these traits through selection. Ramanujam and Thirumalachar (1967) opined that broad sense heritability accompanied by high genetic advance is more reliable. Mydin (1992) reported a low to moderate genetic advance for renewed bark thickness, virgin bark thickness, rubber content in peak period, annual rubber content, latex yield during peak period, annual latex yield and rubber yield during peak season which are in conformity with the present study. Licy (1997) reported low genetic advance for rubber content, renewed bark thickness, virgin bark thickness, and number of latex vessel rows in virgin bark. Virgin bark thickness, annual latex yield and latex yield in peak season showed moderate heritability associated with moderate genetic advance indicating comparatively less influence of environment on these parameters. Girth at opening, girth increment, renewed bark thickness observed to have a low heritability estimate associated with low genetic advance under selection is due
to the high influence of the environmental factors in the expression of these traits and presume no improvement through selection. Among yield components rubber content had high heritability and low genetic advance. Since broad sense heritability includes both additive and epistatic effects, it will be reliable only when accompanied by high genetic advance. Panse (1957) indicated that moderate to high estimate of heritability with low genetic advance could be attributed to non-additive gene effects which includes epistasis and dominance.

5.3. Association of characters

Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection can be based for improvement in yield. In Hevea correlation studies provide information about the nature and magnitude of relationship between yield and its components. Correlation coefficients at both genotypic and phenotypic levels depicted that annual dry rubber yield and rubber yield in two seasons exhibited positive correlation with latex yield, flow rate of latex in all seasons, girth, girth increment rate on tapping, length of tapping panel, virgin and renewed bark thickness, number of latex vessel rows in virgin and renewed bark. Stress yield and peak yield also exhibited positive association with annual mean dry yield. The present results are in agreement with the findings of Dijkman and Ostendorf (1929), Narayanan et al., (1973), Tan et al., (1975), Mydin (1992) and Licy (1997). Girth and girth increment rate on tapping recorded a positive correlation with dry rubber yield in all the three seasons. Premakumari et al. (1989) reported high correlation between girth increment on tapping and yield increase on tapping. Dijkman, (1951). Templeton, (1969) and Sethuraj, (1985), reported a sustainable yield on tapping is highly dependant on girth increment on tapping. Narayanan et al., (1974). Tan and
Subramaniam (1976), Liu (1980) reported a positive correlation of yield with girth while Wycherley (1969), Markose (1984), Premakumari (1992) and Abraham (2000) indicated a negative correlation between girth and yield. Ho et al., (1973) and Ho (1976) reported a positive association of yield with girth in early years with gradual decreases in subsequent years of tapping and assumed that girth has a lesser importance in determining yield. Their assumption is that plant assimilates are partitioned in favour of latex formation rather than growth, especially in the case of high yielding clones leading to a negative association of girth and girth increment with rubber yield. The results of the present study indicated a positive association of girth and girth increment on tapping may be due to the early years of yielding of the trees.

Genotypic correlation coefficient were in general, was higher than the phenotypic correlation coefficients for the majority of characters studied. It could be the masking or modifying effect of the environment in genetic associations between characters (Johnson et al., 1955, Oraon et al., 1977) but it is explained that 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. Information on the relationship of yield and the components controlling yield has an immense value in the crop improvement programme. Coefficient of correlation indicates the relationship between two variables however it provides no information regarding the extent of change in one variable resulting from change in another variable. In genetic studies it is common to find a correlation between two or more characters. Genotypic correlation between two or more characters may result from pleiotropic effects of genes or linkage of genes governing inheritance of two or more characters (Falconer, 1981 and 1989).
Sethuraj (1981) reported a relationship between yield and major yield components of rubber. According to him the yield of a rubber tree per tapping is proportional to the initial flow rate of latex, length of tapping cut, rubber content of latex and inversely proportional to the plugging index.

Among yield and yield components annual rubber yield vs. rubber yield in stress and peak period, annual latex yield, latex yield in stress and peak period and latex vessel rows in renewed bark; yield depression during stress vs. latex yield in stress and PI in stress period; annual latex yield vs. latex yield in stress and peak period, annual PI and PI in peak period; annual flow rate of latex vs. flow rate in stress and peak season, annual PI and PI in peak season; annual rubber contents vs. rubber content in stress and peak season, virgin bark thickness; annual plugging index vs. PI in stress and peak period; virgin bark thickness vs. renewed bark thickness; latex vessel rows in virgin bark vs. latex vessel rows in renewed bark; girth vs. annual rubber yield and length of tapping panel, showed high association with each other at genotypic and phenotypic level. Desirable genotypic and phenotypic level would be possible for simultaneous improvement of these characters under selection.

The relationship between pairs of characters i.e., annual rubber yield, vs. volume of latex in stress period, vs. rubber content, vs. rubber content during stress and peak season, vs. flow rate of latex showed a lower value at genotypic level than that of the phenotypic level showed the influence of environment to the expression of these traits.

Generally phenotypic and genotypic correlations varying in magnitude and not the direction. But in the present study it is revealed that rubber yield in stress season vs. rubber content in peak period; yield depression during stress vs. virgin bark thickness; annual latex yield vs. annual rubber content and rubber content during different seasons
and annual initial flow rate of latex; latex yield during stress vs. panel length and virgin bark thickness; latex yield in peak seasons vs. rubber content in peak seasons, annual initial flow rate, and plugging index in peak period; rubber content during stress period vs. initial flow rate of latex in stress seasons; rubber contents in peak seasons vs. girth increment on tapping; annual initial flow rate vs. panel length and girth increment on tapping; initial flow rate of latex during stress vs. girth increment on tapping and latex vessel rows in virgin bark; initial flow rate of latex during peak seasons vs. panel length; annual plugging index vs. panel length; PI during stress period vs. girth; girth vs. virgin bark thickness; girth increment on tapping vs. virgin and renewed bark thickness; panel length vs. latex vessels in virgin bark and renewed bark thickness indicated difference in sign at genotypic and phenotypic level. It may be due to the environmental characters through different physiological mechanism. Licy (1997) reported similar observation in a study of forty clones to estimate the correlation between different yield components.

Phenotypic and genotypic correlation exhibited a negative relationship of dry rubber yield in all three periods with plugging index during three seasons. Milford et al., (1969), Sethuraj et al., (1974), Mydin (1992) and Licy (1997) reported a negative correlation of plugging index with dry rubber yield. It was reported that the flow rate of latex is positively correlated to dry rubber yield (Paardekooper and Samosorn 1969; Sethuraj et al., 1974). The result of the present study indicates that the correlation between dry rubber yield and initial flow rate was positive but not pronounced.

At phenotypic level, the correlation between annual flow rate of latex and latex flow in peak season, girth vs girth increment, virgin bark thickness vs. renewed bark thickness showed highest values of correlation among the major yield components studied.
It is probably due to the fact that the environmental factors have a major role in the gene governing two traits. At phenotypic level, annual plugging index vs. girth increment indicated lowest correlation.

The dry rubber yield showed high positive association with rubber yield in stress and peak period, annual latex yield, latex yield during stress and peak seasons, girth, latex vessel rows. These associations showed that yield is not totally independent and have complex association with other parameters. Among yield components all characters showed positive association with yield except plugging index. It implies that favourable phenotypic and genotypic association among characters would be possible for the simultaneous improvement of these traits.

5.4. D² analysis

Genetic improvement for quantitative traits depends up on the nature and amount of genetic diversity present in the base material as well as the extent to which the desirable traits are heritable. The concept of genetic divergence provides an idea about the genetic diversity among the parents and has a vital utility in determining diversity among the parents.

Heterosis breeding is an added advantage for obtaining quantum jumps in the production and productivity of Hevea clones. The exploitation of heterosis to raise the yield levels has been tried by several workers (Mydin, 1992, Licy, 1997). The level of heterosis as well as selection advance in segregating generations depends up on the genetic diversity among the parents rather than geographic diversity. Therefore, the choice of diverse parents with good combining ability is the prerequisite for efficient hybridization programme.
All the clones were clustered into two major groups. The first group consisted of eight clones and that of the second one included five clones. Clustering of clones was irrespective of their country of origin. Each of the two major clusters were separated into two subgroups. The inter cluster distance between cluster I and II was 78.11. The intra cluster distance in group I was 24.65 and that of groups II was 34.14. The average intra clusters distance was 28.60. The inter cluster distance showed considerable genetic divergence exists among the clones.

In the present study, the highest genetic diversity was estimated between PB 280 and PB 312 (159.55) followed by PB 280 and PB 311 (157.43). It implies that high heterotic progenies could be obtained if these genetically most divergent parents would be used in hybridization.

5.5. Isozyme

As a perennial crop with a long breeding and maturation cycle, conventional practices for evaluation of the genetic variability like raising the F₂ progenies is rather difficult and time consuming. To supplement with, molecular markers linked to a particular trait also offer great scope for improving the efficiency of conventional plant breeding.

Isozymes offer most reliable single gene markers and they are often co-dominant in inheritance Arulsekar and Parfitt, (1986). In Hevea also isozymes were successfully used in estimating the genetic diversity (Chevallier, 1988; Sreelatha et al., 1993; Yeang et al., 1998). In Hevea it is used for the genetic variability studies (Chevallier, 1988) and to identify field plantings or in source bush nurseries (Leconate et al., 1994). Several enzyme gene loci have been identified in Hevea for genetic variability studies in germplasm materials by isozyme analysis (Chevallier, 1988). Out of the nine isozyme systems
analysed, four enzymes showed polymorphism. The number of isozymes bands in different clones was ranged from 11 to 19. Out of the four isozyme systems studied, a combined total of 22 isozyme bands were scorables and a mean of 15 bands per clone could be observed. Yeang et al., 1995 observed that out of the seven isozymes system a combined total of sixteen isozyme bands were consistently scorables and a mean of 11.41 bands could be scored per clone among a total of 60 Hevea genotypes studied. The esterase allele loci in 2nd, 4th, 5th and 6th positions are common to all the 13 clones studied and discrimination among these clones could be possible by esterase polymorphic bands at other loci. In peroxidase one band i.e., at the 7th position, which is common to all the clones studied while the other locus could provide useful information to discriminate from one another. Whereas, in aspartate aminotransferase, 1st, 2nd and 4th isozyme band positions were common to all the varieties studied, while the third locus could be possible to discriminate the cultivars. The number of bands were limited for shikimate dehydrogenase. So based on results of the present study it is clearly demonstrated that, characterization of cultivated clones of Hevea is possible using isozyme zymogram. Isozyme analysis clearly distinguished all the 13 clones from one another.

5.6. RAPD

The RAPD technique can generate polymorphic data more efficiently and less expensively. Most importantly, the application of RAPDs does not need any prior knowledge of genomic nucleotide sequences (Williams et al., 1990). In the present study 59.60 per cent of the RAPD were polymorphic among 13 cultivated clones of Hevea studied. This genetic polymorphism found to be high compared to the reports of other RAPD studies in Hevea (Varghese et al., 1997). The observed DNA polymorphism could be attributed
for the selection of clones with diverse characteristics including geographic origin, as well as specificity of primers used in the RAPD analysis. These genotypes will be useful for developing new hybrid lines as well as mapping population for future breeding programmes.

This study indicated the presence of DNA polymorphism within the cultivated Hevea clones using RAPD analysis. Among the different clones tested, KRS 163 displayed the maximum and highest average genetic distance from the other clones followed by PB 255, KRS 128 and PB 314. This is supported by the view that PB clones and KRS clones are originated from divergent places and their pedigree is entirely different. This result suggests that the specified clones could be used as a potential parent in future breeding programmes.

Genetic distance estimated by RAPD markers revealed that there were three major groups among the thirteen cultivated clones of Hevea studied. The clones belonging to these three major groups originated geographically distinct places, as the places of origin of KRS, PB and RRII series are Thailand, Malaysia and India respectively. Similar reports were also available in Hevea germplasm collected from different geographic areas. The dendrogram based on RAPD data depicts that PB 312 and PB 314 are genetically close and separated by 15.2% of dissimilarity since it may be due to one of its parents common in their ancestry. Among the second group KRS 25, KRS 128 and KRS 163 are grouped together and are separated from the remaining clones with 30.8 per cent dissimilarity. The Indian clone RRII 105 is separated from the rest of the clones as the pedigree of it is different from that of other clones studied. All the Malaysian clones are clustered together as one of its parentage is common for most of these clones and this may be the fact that these clones are clustered into a single major group. The dendrogram based on RAPD analysis indicates that KRS 163 and RRII 105 are the two genetically
most divergent clones that could be utilized for the hybridization programme to raise superior progenies in future.

A comparative analysis of genetic divergence based on Mahalanobis' $D^2$ and RAPD analysis showed that PB 311 and PB 312 were clustered together in one group. It is interesting to observe that these clones originated from same series. Similarly PB 260, PB 217, KRS 25 and KRS 128 were clustered in one group in $D^2$ and RAPD analysis. It may be due to that at least one of its common parents for both clones in their ancestry. However in RAPD clustering pattern was different and all the Malaysian and Thailand clones were grouped independent of each other from RRII 105.

5.7. Performance index

The result of performance index analysis based on the pooled data of yield and major yield components indicate that the Malaysian clone PB 280 ranked first among the clones studied followed by PB 255. The Thailand clone KRS 128 positioned the third rank followed by the outstanding clone RRII 105. (Mydin, 1992) reported similar ranking based on the test tap yield, girth, number of latex vessel rows and number of flushes among 20 progenies of Hevea. Abraham (2000) estimated rank among 80 wild genotypes according to the performance index based on 16 different variables and 38 wild genotypes were ranked as per their performance index higher than the average index value of 247.10. Performance indices were also worked out in young Wickham clones where it was found that in general, high yielders recorded higher values in comparison to medium and low yielders (Varghese et al., 1993). Planting recommendations of the Rubber Research Institute of Malaysia, for 1998 - 2000 included PB 280 and PB 260 in category I. PB 280 was under latex - timber clones. Clone PB 217 was included in category I, PB 255 in category II, PB 310, PB 311, PB 312 and PB 314 in category III

5.8. Progeny analysis

Seedling progeny analysis or estimation of prepotency through seedling progenies is the assessment genetic potentiality of a female parent to produce superior offspring irrespective of the nature of the male parent. The prepotent ability of a clone to produce high quality seedlings could be determined by systematic and planned experiments like seedling progeny analysis (Mydin, 1990). Such multi parent first generation synthetic varieties of rubber (Simmonds, 1986) have been recommended in category I for wide scale planting in Malaysia. The timber yield from such trees is high because of their high vigour and girthing.

Polycross or synthetic seedling populations of polyclonal seed gardens of good clones have been successfully used as planting materials. The seedling population has special agricultural merits in maintaining the genetic variability and adaptability of the population (Mydin et al., 1990; Varghese, 1992). The present investigation was undertaken to evaluate genetically superior mother parents through seedling progeny analysis for the production of quality seeds in the seed gardens. Seedlings, though not comparable with high yielding clones in production potential, have special agricultural merits that there is a need for superior polycross progeny from special polyclonal seed gardens as planting material.

Mydin et al. (2002) reported that in a study of 11 clones, progenies of 5 clones viz., PB 255, RRII 203, RRII 105, PB 260 and GT 1 were identified as likely prepotent with a high performance index and high recovery of superior and elite seedlings in their progeny. This
result of the present study is in conformity with the earlier report, as it is evident from the high performance index value for the progenies of the clones PB 255 and PB 260.

Prepotent parent clones by way of their high GCA are best used as components in polyclonal seed gardens for producing good quality poly cross seeds. The open pollinated progeny of such clones also comprises superior base population for selection and cloning of the best individuals as is the practice in *Hevea* breeding procedures (Simmonds, 1989; Tan, 1998). This could supplement ortet selection programmes as a means of evolving primary clones (Mydin, *et al.*, 2002).

Juvenile characters at the age after one year did not show significant difference among the progenies. However, highly significant variation was noticed for all the characters after two years of growth of progenies. Significant positive correlation was observed for seedling height, girth, number of leaf flushes and juvenile yield at the age of two years was observed. The highest correlation observed between juvenile yield and the vigour of seedlings in terms of height \((r = 0.669)\) followed by girth \((r = 0.578)\) while the lowest relationship was established between yield and number of leaf whorls produced, the correlation was only at 5\% level \((r = 0.314)\) and between girth and the number of leaf whorls \((r = 0.340)\). Correlation between seedling girth, and height was also significantly high at 1\% per cent level \((r = 0.440)\). The relationship between seedlings height and number of whorls were also very high at 1\% per cent level \((r = 0.557)\). 30.23 - 68.00 per cent of progenies of the clones showed above average progeny yield. The progenies of PB 255, PB 260, PB 310, PB 311, PB 312, PB 314 and RRII 105 recorded high percentage of seedlings showing above mean progeny yield and seedling progenies of PB 255 recorded highest (68\%) and KRS 25 (29.58\%) recovered the lowest percentage of superior seedlings in terms of juvenile yield.
In the present study, out of the 13 clones evaluated, 7 clones were identified as likely prepotent with high performance index value and high percentage of the recovery of superior seedlings. Mydin, et al., (2002) evaluated five clones as likely prepotents with a high performance index and high recovery of superior and elite seedlings in the progeny. High performance of progenies of a clone coupled with a high proportion of superior seedlings within the progeny is indicative of the ability of a parent to transmit superior traits to its offspring (Mydin et al., 1996). Seven clones viz., PB 312, PB 314, RRII 105, PB 260, PB 310, PB 255 and PB 311 exhibited high performance indices coupled with a high percentage of recovery of superior seedlings considered as prepotents.