REVIEW OF LITERATURE
2. REVIEW OF LITERATURE

Propagation

Management of perennial crops involves judicious selection of most suitable planting materials based on scientific evidence. Low yield and high variability necessitate crop improvement programmes in any crop. There are two basic types of plant propagations - generative and vegetative. Preserving the genetic identity during mass multiplication was achieved through vegetative propagation. Propagation of some species may be easier, more rapid and more economical by vegetative than by generative methods. The concept of clone does not mean that all individual members are necessarily identical in all characteristics. The actual phenotype results from the interaction of its genes with the environment in which it was growing.

Bud grafting

Grafting is uniting two or more pieces of living plant tissues by means of regeneration so that they grow as a single plant, and is a horticultural technique that dates to antiquity (Andrews and Marquez, 1993). Many horticultural applications had been derived from grafting, including exploitation of desired characteristics of rootstock and/or scion into a single plant, increasing precocity of bearing by eliminating the juvenile period, hastening the growth of seedlings in breeding programmes, obtaining special growth forms, rapid cultivar change on existing root systems, repairing trees with bark or root damage, and virus indexing and the study of
viral diseases (Hartmann et al., 1990). Budding is often termed as “bud grafting” since the physiological processes involved are the same as in grafting.

**Technique**

Budding is a process that involves choice of stock and scion species, creation of a graft union by physical manipulation, healing of the union and acclimatization of the compound plant. It is limited to plants, which developed the secondary plant body; the principal tissue concerned is cambium, which have the ability to make new cells. The sequence of structural events in grafts of herbaceous plants had been reviewed by Andrews and Marquez (1993). During grafting the two structures, stock and scion were prepared in such a way that the vascular cambium of each was placed close to or in contact with each other and held together until the two structures grew together. By grafting, new combinations unite and grow together. Tissues which form the union is called callus, a bridge of living tissues between the scion and the stock and thus facilitate the passage of water, hormones and essential raw materials from stock to scion, manufactured food and hormones in the scion which pass from the scion to stock. The sequence of structural events occurred in compatible grafts, in various plant species had been studied by researchers (Stoddard and McCully, 1979, 1980; Moore and Walker, 1981a; McCully 1983; Moore, 1984; Gebhardt and Goldbach; 1988). First the ruptured cells at the graft interface collapse and form a necrotic layer, which disappears during subsequent events. Then living cells from both stock and scion extend into the necrotic zone. A callus bridge of interdigitating parenchyma cells forms by cell division, rupturing and invading the necrotic layer. During these events the strength of the graft increases due to physical cohesion between the partners. This strengthening occurred as
dictyosome-mediated secretion of cell wall precursors aided in cohesion. Now new vascular cambium is differentiated from parenchyma cells. Secondary xylem and phloem are produced by this cambium, providing vascular connection between stock and scion. The bridge between the graft partners differentiates primarily from cortex and pith tissues. Pericycle and cambium are involved to a lesser extent (Stoddard and McCully, 1979).

Most of the fruit and nut species are propagated by budding or grafting on root stock seedlings. Rootstock breeding research of avocado received high priority at the University of California (Reutli, 1961) and large-scale rootstock experimental system was established (Halma, 1954). Blueberry cultivars were propagated by budding (Hartmann and Kester, 1972). Cherry nursery trees were generally propagated by T-budding the desired cultivars on seedling rootstock. The T-bud method of vegetative propagation was very successful with citrus (Hartmann and Kester, 1972). The mere presence of graft or bud-union tends to stimulate earlier heavier bearing. Good quality fruits of excellent size were produced on grape fruit stock. Tree vigor, height and yield were influenced by rootstock in mango cultivars (Reddy et al., 1989; Kurian et al., 1996). In an imperfect graft union, there was probably a partial blocking effect on the movement of nutrients, which resulted in increased fruitfulness (Hartmann and Kester, 1972).

A satisfactory method of establishing grape varieties on resistant rootstocks is by field budding. Mangoes were commonly propagated by veneer grafting or by chip budding (Hartmann and Kester, 1972). Olives were propagated in a number of ways such as by budding or grafting on seedling or clonal rootstocks, by hard or semi-hard wood cuttings or suckers from old trees. Plums are always propagated by T-budding.
Advantages of Vegetative Propagation

Vegetative propagation is used for cultivar change, repair or invigoration of older established trees. Small trees were created by the use of dwarfing root stock (Brrientos-Priego et al., 1992). The use of graftage overcomes the difficulty in root formation in many fruit trees, in which propagation through cuttings was impractical.

Grafting was an important research tool in the study of secondary metabolites (Heuser-1983), plant growth regulators (Sachs, 1981; Jones, 1986), translocation (Beeson, 1986) water relations (Schmid et al., 1988), anatomical development (Gebhart and Goldbach, 1988), cell relations (Basic and Clark, 1988), senescence, stress physiology (Feucht, 1988) and molecular genetics (Ochatt, 1989). Grafting had also been used as means to study the transmission of signals affecting vernalization and photo period (Suge, 1992), as well as transmission of virus into indicator plants and to eliminate viruses. Grafting was restricted to dicots since their vascular bundle arrangement and presence of continuous cambium offered greater degree of potential grafting success (Hartmann and Kester, 1972).

The interactions of stock and scion affected growth and productivity (Beak and Roger, 1956, Rom and Carlson, 1987). Studies on different species had yielded enormous amount of information on the anatomical and physiological events that occurred during the formation of compatible graft union.
Considerable variability existed in the tolerance of various rootstocks to adverse soil conditions and hence choice of rootstock is very important. Avocado orchards were not uniform either in tree vigor or in productivity; the explanation for such a phenomenon was the rootstock variability resulted from seed heterozygosity. Certain American grape varieties obtained great yield when they were grafted on vigorous rootstocks in comparison with own rooted plant (Valle, 1938). Grape varieties were definitely influenced by the type of rootstock in which they were grafted (Harmon, 1949). Cases in which rootstocks impart disease resistance to the scion variety were common. One example in this case was the infection of stone fruit in California by bacterial canker. In a number of instances apricots and plums when grafted on myrobalan plum roots, became much more seriously infected than when they were worked on the peach roots. Pear decline disease, which occurred in America and California, killed hundreds of pear trees. In early studies it was believed that trouble was related to the rootstock used (Batjer and Schneider, 1960).

According to Hartmann and Kester (1972), clonal rootstocks were desirable not only to produce uniformity but, also to preserve special characteristics and specific influence on scion cultivars such as disease resistance, growth, soil stress factors etc. Stronger rootstocks can more easily withstand complex stresses. Vigorous, strongly growing rootstocks in some cases resulted in larger and more vigorous plant, which produced greater crops over a long period of time. Dwarfing rootstocks may be more fruitful if closely planted.
The salinity problem of Avocado is partly due to sodium translocation and could be solved by using resistant rootstock (Ayers et al; 1951). Kadman and Ben-Ya'acov, (1976) observed that sodium was accumulated in the root system and little accumulates in the leaves. In Avocado dwarfness could be achieved by growing dwarf cultivars. For large-sized cultivars, dwarfing rootstock would be the best means of size-control (Bergh, 1976; Brokaw, 1982). Rootstock effect on tree size and vigour is strongly related to tree productivity. The “tree efficiency” in many horticultural races was influenced by rootstocks (Gregoriou, 1992).

Inter-specific hybrids possessing excellent tolerance to diseases had been developed for rootstock use in many crops, like Pepper, Capsicum and other Solanaceous vegetables. In egg plants, the rootstocks played an important role in disease resistance (Katao and Lou, 1989; Kim, 1999). Rootstock selection in Solanum species was usually done based on the population of soil borne pathogens in the relevant production area. The influence of rootstock as a source of drought tolerance in tomato had been reported by Bhatt et al., (2002). The study indicated the existence of considerable interaction of scion and stock in cultivation strategies of tomato under water stress condition.

**Biochemical studies**

Plant improvement programme in any perennial crop needs reliable biochemical studies. Isozymes provide useful evidence in the study of variation within crop cultivars in terms of intensity as well as presence or absence of bands (William and Mujeeb Kazi, 1992). A study in which growth rate of scion and rootstock were measured close to the graft union, in incompatible pear quince combinations, failed to
show that the incompatibility was due to difference in growth rates or time of cambial activity. Incompatibility may be attributed to physiological and biochemical differences between stock and scion (Gur, 1957). Various laboratory methods had been developed for evaluating stock–scion compatibility in nursery trees without growing trees to maturity (Evans and Hilton, 1957). One bio-chemical method was based upon pear quince incompatibility due to the presence of glucoside (Samish, 1962).

Enzyme polymorphism was used as genetic markers in Avocado (Torres et al., 1978), datepalm (Torres and Tisserat, 1980), *Camellia Japonica* (Wendel and parks, 1983), sugarbeet (Vangeyt and Smed, 1984); apple cultivars (Weeden and Lamb, 1985). Bower and Nel (1982) found that rootstock played a role in the final expression of bio-chemical activity in the scion. The affinity between the scion and different rootstocks could be predicted by the relative electrophoretic mobilities of the total proteins in *Vitis vinifera* (Masa, 1989). Increased peroxidase activity and accumulation of lignin were considered as symptoms of incompatibility. Peroxidases appeared as large numbers of isozymes and participated in numerous physiological activities. Peroxidase activity also was observed in compatible grafts only for a short duration (Deloire and Hebant, 1982). High lignification had been observed in incompatible host pathogen combinations and absent in compatible combinations, Santamour (1988b) reported potential application of electrophoresis as a means of predicting incompatibility before grafting. Santamour (1988a) in studies of intraspecific grafts of red oak, found abundant variation in cambial isoperoxidase
banding patterns. Isoelectric focusing of peroxidase and acid phosphate isozymes were used for characterizing *Diascoria* food yams by Twyford et al., (1990).

**Incompatibility**

The inability of the parts of two different plants, when grafted together to produce a successful union, and of the resulting single plant to develop satisfactorily was termed as incompatibility. It appeared as genetically controlled by multiple genes with additive effects (Copes 1970, 1978), Moore and Walker (1981a; b; 1983) and Moore (1983) described and compared the anatomical and physiological events occurred in compatible autografts and incompatible heterografts. Salesses and Al kai (1985) reported that incompatibility acted as a genetic dominant, which needed at least two genes for expression. Lee (1989, 1994) and Ko (1999) studied graft incompatibility in cucurbits and concluded that it could be changed depending on the grafting methods and growing environments.

Propagation of many ornamental conifers were affected by stock-scion incompatibility. Since more than 50% of grafted trees showed incompatibility responses, tree growers in New Zealand were forced to change (Sweet and Thulin, 1973) from grafting to seedling orchards of Monterey pine. Researchers considered graft incompatibility as the most serious limitation to grafting success (Garner, 1979).

Incompatibility symptoms were diverse, depending upon species, internal symptoms usually preceded the external ones. The observations disproved the concept that the vascular cambium was the only source of callus for bridging. While using the standard grafting or budding methods, there were numerous possible variables, which may affect
the success of the operation (Roberts, 1927). If the union was healed properly, growth
will proceed in normal manner. Attention to proper polarity is very important to make the
graft union permanently successful. Sometimes the grafting technique is so poor that only
very little portion of the cambium of stock and scion is brought together. It was still
recommended that the cambium of stock and scion be well aligned, so that new vascular
elements were formed longitudinally providing greater mechanical strength (Crafts, 1934;
Esau, 1965, Kollmann et al., 1985). A comprehensive review had been written by
Lachaud (1975). Grafting errors like uneven cuts, delayed waxing, use of desiccated scion
etc resulted in grafting failure, which caused incompatibility.

Phloem tissues were more severely affected than xylem tissues in incompatible
combinations. Symptoms included phloem and cortex degeneration (Breen, 1974),
atypical axillary xylem parenchyma (Copes, 1980); lack of axillary parenchyma in the
phloem and necrosis of cortex cells, increased peroxidase activity in both partners and
deposition of lignin and polyphenols at the graft union, impeding formation of vascular
connections and translocations (Deloire and Hebant, 1982). Due to these problems in
vascular conductivity higher concentrations of starch, free sugars and sugar alcohols had
been found in the scion and higher concentrations of inorganic nutrients (N, P, K, Ca,
Mg), were found in the root stock (Breen, 1975; Salesses and Al Kai, 1985). Changes in
nutrient levels accompanied or followed changes in carbohydrate levels, but never
preceded them (Breen and Muraoka, 1975). Findings by Breen and Muroaka (1975)
explained the starch distribution as a consequence of vascular discontinuity, refuted the
early and long accepted hypothesis that considered differential starch distribution as a
cause of graft incompatibility (Rogers and Beakbane, 1957; Garner, 1979).
Incompatibility symptoms included excessive suberization and bark thickening due to over production of sieve cells, and under production of tracheids, excessive tannin accumulation, indicated by abnormally dark stained bark, and a wavy pattern of annual growth rings (Copes, 1980). Late bud break (Nelson, 1968), abnormal leaf morphology and premature leaf abscission (Copes, 1980), reduced vegetative growth, shoot dieback, ill health, and premature death (Hartmann and Kester, 1972), and discolouration in scion leaves were the external symptoms observed. Due to vascular discontinuity the scion leaves showed discoloration (Breen, 1975).

Swelling often develops above the union with vascular discontinuities. Over growth at the graft union was considered as a symptom of incompatibility (Bhattacharya and Dutta, 1952; Garner, 1979; Westwood, 1988). In trees, a clean breakage at the graft union was considered as the most reliable diagnosis of incompatibility (Garner, 1979; Eleftheriou, 1985). It implied that very few or no functional vascular connections and interlocking fibres between scion and rootstock confer significant mechanical strength and lead to full graft development.

Types of incompatibility

Herrero (1956) classified graft incompatibility into four categories: failed bud growth, virus caused graft failures, mechanical obstruction at the union, and abnormal union structure usually associated with disproportional starch accumulation. Mossè (1962) divided incompatibility into translocated and localized type. Localized incompatibility occurred at the graft interface and required actual tissue contact between the two components, both incompatibilities can occur in the same graft combination as in
pear and quince graft union. Translocated incompatibility is due to the phloem degeneration of which a brown line or necrotic area in the bark was developed, which resulted in the blocking of movements of carbohydrates at the graft union. Virus induced incompatibility cases were included in translocated incompatibility. One component of the combination may carry a virus and may be symptomless, but the other component may be susceptible to it.

Delayed incompatibility had been used to describe graft combinations that failed after a period of successful growth (Argles, 1937; Randhawa and Bajwa, 1958). Delayed incompatibility had been identified as disease such as pear decline, which occurred in Italy, California and North America and killed hundreds of pear trees (Shalla Chiarappa, 1961; Hibino et al., 1971). It was found that trouble was related to the rootstock used. Further researches showed that this was associated with a virus, the scion variety were tolerant to the virus, but the rootstock was susceptible showing a phloem degeneration just below the union, for the decline condition to appear, the concurrent presence of virus and a susceptible rootstock was necessary (Jensen et al.; 1964).

Physiologically based “delayed” incompatibility was possible if the production of incompatibility toxin took place as graft partners age, such as the developmental transition from juvenile to mature tissues (Andrews and Marquez, 1993). More recent studies revealed the fact that stress and senescence were considered as triggers of delayed incompatibility response (Feucht, 1988; Treutter and Feucht, 1988). Prominent differences in the development of interspecific plasmodesmata between stock and scion suggested that cell recognition and functional co-ordination might be involved in graft formation (Kollmann and Glockmann, 1985; Kollmann et al., 1985).
Prediction of incompatibility

Prediction of incompatible graft combination is a very important area of study for preventing economic loss due to graft incompatibility. The incompatibility could be partially controlled in cases where the mechanism depends on the presence of toxins, by selecting rootstocks or scions that produced lower levels of these metabolites.

Isozymes separated by electrophoresis was one of the earliest methods used for the prediction of graft incompatibility (Copes, 1978). Electrophoretic techniques for detection of incompatibility have advantages over anatomical observations, since testing could be done before actual grafting and graft union need not be destroyed. The differences occurred in the isozymes patterns predict the anatomical or external symptoms of delayed incompatibility. Seedlings, with similar peroxidase composition, were compatible and vascular continuity was restored. However, if composition differed, incompatibility was observed following grafting.

Rubber

*Hevea brasiliensis* (wild, ex Adr. de Juss.) Muell. Arg. (Family Euphorbiaceae) is a quick growing perennial tree. Pollination is entomophilous and fruits, a regma, mature within five months. Seeds weigh 4 to 6 grams and, possess characteristic mottling (Polhamus, 1962), which is helpful for clone identification. Each seed has a dorsal and ventral side and had frontal and lateral depressions.
Commercial rubber is recovered from the latex extracted from the bark of the trunk. A comprehensive description of the structure of mature bark was made by Bryce and Campbell (1917). In the bark, below the protective tissue or cork, there were two distinguishable zones: an inner zone consisting of soft tissues, termed soft bast and an outer zone made up of hard and thick walled cells, the major component being sclerified cells or stone cells. Most of the functional latex vessels are present in the soft bast region. Towards the outer portion of the hard bast, the latex vessels, sieve tubes, etc become discontinuous and non-functional due to age and senescence.

The latex vessels are oriented in an anti-clockwise direction at an angle of inclination of two to seven degrees, they are produced in discrete rows and the vessels belonging to the same row are interconnected tangentially. The laticifers appear as straight tubes in radial, longitudinal sections where as the structure resembles an expanded meshwork in tangential longitudinal sections while in cross section it is circular shape.

**Tapping and bark renewal**

Rubber tree is commercially exploited for latex by a systematic regular excision of bark of the trunk. The economic period of *Hevea* tree is 20–23 years from the commencement of tapping by which both virgin and renewed bark are exploited.

During every tapping, a thin slice of bark 1.0-1.5 mm in thickness is shaved off to cut open the latex vessels, the cambium is not injured in this process. Moreover,
a layer of soft bast is also left uncut during tapping which gives protection to the cambium. The protective tissue removed on tapping is replaced by the formation and activity of a new phellogen below the cut surface (Bobilioff, 1923; Panikkar, 1974), and the vascular cambium continues its activity.

Importance of the extension of drainage area mediated through dilution reaction after tapping was well elucidated (Sethuraj, 1977). Physiological parameters such as initial flow rate (Volume of latex obtained per minute for the first five minutes after tapping) and plugging index received much attention.

The occurrence of intraxylary phloem in Hevea was identified by Premakumari et al, (1985 b). Clones vary significantly for the quantity of intraxylary phloem and occurrence of high quantity of internal phloem was found to be beneficial to reduce girth retardation on tapping (Premakumari and Panikkar, 1988).

**Propagation**

**Seedlings:**

*Hevea* is propagated both generatively and vegetatively. Vegetative method is by budding. Rubber seeds are collected during the rainfall season. Due to considerable tree-to-tree variations recorded in yield among the seedling populations, raised during early periods of rubber cultivation attempts were made to propagate *Hevea* vegetatively (Dijkstra, 1951). These seeds retain viability only for a short period (Edgar, 1958). Fresh and heavy seeds show early germination (Saraswathyamma and Nair, 1976). Seedlings raised from assorted seeds were being used as the main source of stock seedlings for bud grafting.
Budding

Vegetative propagation in *Hevea* to produce clonal materials began with introduction of brown budding (Dijkman, 1951). Young seedlings were raised in seedling nurseries to be used as rootstocks for budding and desired clones were budded on them. Patch budding was adopted in *Hevea* (Marattukalam and Saraswathiamma, 1992). According to the age and colour of scion shoot used for bud collection, budding is termed as green budding or brown budding.

Green budding

Green budding was an advanced method of vegetative propagation developed in Indonesia in 1960 by H.R Hurov. Both stock plant and bud wood used for green budding are comparatively young compared to brown budding. Seedlings, which were two to eight months old, were used as stock. Buds are collected from six to eight weeks old budwood plants. These buds are green in colour and hence the name green budding. Green budwood is obtained from budwood plants grown in nurseries. Budding can be carried out at anytime of the year. However, too dry or very wet weather is unsuitable (Desilva, 1957). Green budding gives good success during the first half of summer months. Days with heavy rainfall are not suitable for budding (Marattukalam and Premakumari, 1982).
Polybag plants

Green budded stumps are planted in the polybags of appropriate size and are transplanted in the field without disturbing the shoot and root systems. These plants are transplanted to the field at two to three whorl stage or at four to six whorl stage according to the size of the bag used. Polybag plants are advanced planting material now under use for rubber cultivation. The maintenance of these plants in the early stages will be easier in the nursery than in the field. The immaturity period in the field can be reduced by planting these advanced planting materials (Sivanadyan et al., 1976). Uniform growth, less casualty, early establishment, less weed growth and cost reduction were also the advantages of polybag plants.

Stock-Scion Interaction

The stock-scion interaction is an area in rubber research, now gaining much attention due to the fact that rootstock influence varies with the variety of scion used and stock can influence the growth and yield of scion at varying degrees (Singh, 1980). Stocks raised from monoclonal seeds of PB5/5 are found to influence favourably the growth and yield of several scion clones, while some other stocks like RRIM 600 affect the growth performance of the scion negatively. The high yield potential of a clone could be exploited to the maximum by using the most compatible stock material. Early attempts to study the influence of stock on scion and vice versa were employed using twin plants raised from split clonal seedlings (Dijkman, 1951). The results showed a high correlation indicating the influence of stock on the productivity of the scion. Growth of Hevea budding was observed with particular
reference to the vigour of various clones by Templeton (1960): Seneviratne *et al.* (1966) observed that the growth vigour of the stock influenced the scion growth in rubber. They observed a positive correlation between girth and height of the plants. Ng *et al.*, (1981) reported the influence of six rootstocks on growth and yield of six clones of *Hevea*. The study indicated that rootstock influenced the growth and yield of scion significantly. Dijkman, (1951) and Buttery (1961) reported that rootstock influence on yield was independent of its influence on growth. Sagy and Omokhafe (1996) evaluated the variation in clonal combinations of rootstocks and scion among five clones of *Hevea*. They observed significant variation in rootstock effects and general combining ability. In none of these works any incompatible symptoms have been identified to be utilized for nursery selection of compatible grafts.

Yeet *et al.*, (1977) studied protein and enzyme variation in some cultivars of *Hevea*. The polyclonal rootstocks used for the evaluation of stock influence on *Hevea* by Yeang *et al.*, (1996) showed a clear evidence of rootstock effect both in the stock as well as in the scion portions.

Krishnakumar *et al.*, (1992) observed polymorphic isozyme expressions caused by stock – scion interaction among the plants of the same clone raised on seedlings of assorted seeds. Variability in isozyme expressions in different *Hevea* clones, raised using assorted seedlings as rootstock was observed by Sobhana *et al.*, (2000). Though the work mentioned above had established the effect of stock on scion, there was no work to quantify the variability occurring among the available assorted seeds and monoclonal seeds or within the groups of rootstock seed sources. The nature of variability and the type of incompatibility occurring to influence the
growth and yield or other agronomic characters of the grafted plants are yet to be studied.

**Constraints in Rubber Cultivation:**

Jayasekare *et al.*, (1977) used regression analysis to study the genotype environment interactions in some *Hevea clones* and reported that the clones can be categorized into different adaptability groups based on their significant linear components. The summer drop pattern of various clones and some biochemical and physiological factors influencing the seasonal effect of yield variations have been reported. Diseases are also constraints, which affect yield of *Hevea*. In India two major leaf diseases are the abnormal leaf fall disease (during monsoon) caused by *Phytophthora* sps and powdery mildew (during January – March) caused by *Oidium Heveae* had received much attention (John *et al.*, 2001). Disease susceptibility is clone specific and effective selection parameters for disease resistance are lacking.

**Tapping Panel Dryness (TPD)**

The productivity of a plantation was seriously affected due to panel dryness of trees and this constraint is more affected in the case of high yielding clones (Premakumari *et al.*, 1991) and in association with increased tapping intensity (Sethuraj, 1988; Vijayakumar *et al.*, 1991). In advance or in association with the dryness, various external and internal symptoms occurred. The external symptoms were expressed differently. It could be partial or complete drying of the tapping cut leading to cessation of latex flow (Sanderson and Sutcliffe, 1921); in some cases the dryness reached up to the cambium (de Fay, 1981). Cracking and flaking of the bark
(Rands, 1921) are external symptoms. In some cases prolonged flow of latex before the expression of other external symptoms were common. It was also reported that the trees which were initially slow growing were more readily suffering from the problem and after the onset of the disease vegetative growth accelerates and the trunk becomes larger than usual (Jobbe-Duval, 1986).

There were different arguments on the causal factors as tapping intensity, especially frequency of tapping (Bealing and Chua; 1972; Beauchamp and Fridovich, 1971; Chua, 1965; 1967). It is now widely known that stress due to mechanical causes, tapping, chemicals, or pathological infections cause internal ethylene formation (Yang and Prat, 1978) and it was accepted that endogenous and exogenous ethylene were involved in natural stimulation of Hevea (Abeles, 1973; Lieberman, 1979). One theory postulate nutritional stress (Chua, 1966) but this theory had been contradicted on the ground that carbohydrate reserve remains plentiful in the trunk of dry trees (Chua, 1967; Krishnakumar et al., 2001). Premakumari (1991) reported that the number of latex vessel rows and the number of intraxylary phloem groups along with the total volume of latex governed 49 % variation in the occurrence of tapping panel dryness.

Krishnakumar et al., (1998) observed higher peroxidative activity in TPD affected plants. Higher activity of peroxidase was negatively correlated with cytokinin in the tissue of TPD affected trees (Krishnakumar et al., 1998). While ethylene tilted the metabolic equilibrium from anabolic to catabolic (Wang et al., 1990) leading to senescence, cytokinins have antisenescence effects in plants through prevention of free radical production as well as their scavenging activities (Leshem, 1984).
Increased activity of peroxidase in the TPD affected bark may be an indication of increased production of active oxygen species such as superoxide radicals (O$_2^-$). Crestin (1985) reported an abnormal rise in the production of toxic oxygen species in TPD affected plants. Production of free radicals and active oxygen species damaging membrane systems, including lutoids and consequent disturbance in lutoid stability and premature \textit{in situ} coagulation of latex on the panel of TPD affected trees was suggested by Crestin (1985). The chances of accumulating such toxic oxygen species in the tissue would lead to oxidative stress to the cellular constituents including mitochondria. Inhibition of the mitochondrial activity could lead to a possible accumulation of carbohydrates as observed by Krishnakumar et al., (1999) and a decreased availability of ATP for the conversion of sucrose into rubber, a process where high energy was consumed (Jacob and Prevot, 1992). However the production of toxic substances in trees confronting stress situation and the possible accumulation of such substances in the panel of some trees leading to TPD is a possible theory.

Genetic control of TPD was suggested by various researchers. Mydin et al., (1999) reported that tapping panel dryness was confirmed to be a distinct clonal characteristic with high heritability and low genetic advance. Non-additive gene action in the inheritance of TPD had also been suggested. Sobhana et al., (1999) had reported that the greater the genetic distance between rootstock and scion, the greater the possibility of the scion showing symptoms of TPD, which was randomly distributed in the field.
Genetic parameters and associations

Co-efficient of variation

In any comparative study, estimation of variations of quantitative characters is an essential part. The comparison is meaningful when the standard variations represented by different units are converted into a unit less measurement. Co-efficient of variation which is the standard deviation from the mean expressed as percentage of the mean value, thus provides such a measurement for comparing the extent of variation between different characters measured in different scales. Genotypic coefficient of variation is the relative magnitude of variability contributed by genetic factors and helps in the comparison of genetic variability present in a population for different characters. In the case of quantitative characters, which are involved by a large number of minor genes with cumulative but small individual effects, it becomes impossible to measure the contribution of each and every gene to the total variance directly. The external expression of genetic values as modified by the environment is measurable as phenotypic values. The available variability in a population could be partitioned into heritable and non-heritable components. The heritable component is genotypic co-efficient of variation (GCV) and the non-heritable component is phenotype co-efficient of variation or PCV. In the case of grafted plants, the genetic make up of the scion part of all-individuals of a clone is the same. Hence any amount of genotypic co-efficient of variation pertaining to a character is contributed by the stock part.
Heritability

The term ‘heritability’ was first introduced and defined by Fisher (1918) as the ratio of the fixable genetic variance to the total genetic variance. Lush (1937) defined heritability in the ‘broad sense’ as the proportion of total genotypic variance to the total phenotypic variance and in the narrow sense as the ratio of additive genetic variance to the total variance. Robinson et al., (1949) defined it as “the additive genetic variance in percent of the total variance.

Clonal variability for yield and associated traits in rubber

Development of improved varieties depends on the available variability in the existing population. Unidirectional selection for yield, adoption of cylindrical generation wise assortative breeding and wider adoption of clonal population by bud grafting led to further narrowing down of the genetic base (Wycherley, 1969). Still considerable variability has been recorded for both source and sink components in Hevea. High genotypic and phenotypic variability of dry rubber yield was observed among Hevea clones in various studies (Markose, 1984, Premakumari, 1992a). Vigorous growth of the tree in the juvenile phase will reduce the unyielding time. Thus breeders task is to maximize latex yield in a tree on a sustainable basis. There were various reports on clonal variability for girth and girth increment on tapping (Templeton, 1969; Napithapulu, 1973; Premakumari, et al; 1987, Premakumari, 1992; Wycherley, 1975, 1976; Licy, 1997; Mydin, 1992) of mature tree and also on the girthing rate at immature phase (Licy, et al., 1992; Varghese et al., 1993, 1996).
Latex production and storage is in the laticiferous tissue in the bark. Clonal variability for bark thickness, number of latex vessel rows, density and diameter of latex vessels, laticifer area and phloem ray characters had been extensively studied (Ho et al., 1973; Gomez 1982, Markose 1984; Premakumari et al., 1985b; Premakumari 1992a). Production of an internal core of phloem tissue in Hevea was reported by Premakumari et al., (1985b). Significant clonal variations for such phloem points were also noticed. The clonal variability of latex flow characters such as plugging index, initial rate of flow and duration of flow (Sethurag, et al 1974; Saraswathyamma and Sethuraj, 1975,) as well as the total volume of latex and dry rubber content had been well established.

**Correlation**

Correlation explains the degree of relationship between characters and it is measured as correlation coefficient, which defines to what degree two variants are related when they vary together. Correlation was first defined by Galton (1889) and was later elaborated by Fisher (1918) and Wright (1921). Such information on the magnitude and direction of correlation existing between different characters are very usefully applied in selection work in biological sciences. It is also an advantage that selection for some of the corrected characters will results in the improvement of the other characters also.

**Associations among yield and yield component traits**

In Hevea juvenile yield is an indication of mature yield showing significant association (Samsuddin et al., 1982). Hence information on correlation between the yield at juvenile and adult stage was useful to strengthen the feasibility of early prediction.
Intra-clonal variations in rubber

Intraclonal variation and association in rubber have been reviewed by Henon et al (1984). In a nursery study yield displayed the greatest variability with a coefficient of variation of 60% and anatomical characters displayed lesser coefficient of variation ranging from 5% to 20%. Intra-clonal variations in yield and certain component traits had been reported (Dijkman 1951; Buttery, 1961; Chandrasekhar et al., 1997; Thomas et al., 2000a; Premakumari et al., 2002). Sobhana (1998) also observed enzyme polymorphism among young plants in a given clone, produced using heterogenous type of rootstocks. Intraclonal variations in isozyme profiles of three-enzyme system such as peroxidase, catalase and esterase were reported by Sobhana, (1998) and Sobhana et al., (2000). RAPD analysis of the bark tissues of both root-stocks and scion tissues of a clone by Sobhana et al., (1999). Thomas, et al., (2004 b) revealed genetic homogeneity among the scion tissues while appreciable variation was expressed among the root stocks confirming the heterogeneity of the root stock. Thomas et al., (2000a) observed intra-clonal variation for yield and certain biochemical components of yield in a popular Hevea clone. In most of the above studies regarding quantitative traits, the nature of variability as genotypic or phenotypic has not been examined and hence any major role of rootstock in such variability cannot be assured. Premakumari et al, (2002) made a new approach to assess the nature of intraclonal variability of yield and girth in 13 Hevea clones by estimating the ‘b’ values along with the coefficient of variations since a high value of ‘b’ indicates high genetic influence in the expression of the respective character. Stock sensitivity of the clones with respect to the two traits have also been advocated. Premakumari et al; (2002) also reported higher coefficient of variation for yield
between trees within clone, in 13 *Hevea* clones compared to the CV value of girth of the respective clones. In this case the ‘b’ values were higher for girth indicating high genetic influence for the intraclonal variations of girth than that for yield.

**Intra-clonal associations in rubber**

Henon *et al.*, (1984) has reviewed the work on intra-clonal associations among yield and bark structural characters. Girth and latex vessel rings were suggested as important determinant traits for yield. The scope of identification and utilization of stock sensitivity of clones for the improvement of growth and productivity is also discussed. Chandrashekar *et al.*, (1997) estimated intra-class correlation coefficients to measure the relative magnitude of the variations existing between trees as well as between different tappings of a tree for yield in *Hevea* clones to assess the seasonal consistency of yield. They observed poor consistency of yield for RRII 105 during summer. According to Premakumari *et al.*, (2002), intraclonal association between yield and girth was significant in certain clones only.

The present review is to estimate the intra-clonal variability of important agronomic traits of rubber to study the nature of variability to trace out stock effect for collecting information useful to promote stock selection. Finally, it helps to identify incompatibility symptoms as parameters to cull out undesirable graft combinations. The purpose of this review is to elucidate the recently proposed mechanisms of graft incompatibility in various species and to suggest potential techniques for predicting incompatible combinations.