EVALUATION OF COCOA TYPES FOR RESISTANCE TO CAPSIDS

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DEDICATION

To my wife Cynthia and my two children, Nenneh Addy Boadu and Adiki Boadu for their patience and love when I had to spend long hours away from home for my studies.

DECLARATION

I do, hereby, declare that except for references to works of other scholars which have been duly acknowledged, this thesis is my own original research which has neither beeen presented in whole or in part to any other university for the award of a degree.

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ABSTRACT

Ten clones and 10 hybrids each of four cocoa populations; Nanays (Na), IMCs, Trinidad introduction (Ts) and Parinaris (Pa), were screened for attractiveness and resistance/tolerance to the capsid, *Sahlbergella singularis (Hagl.)*. Two screening methods; a laboratory 'microtest' and an insectary test were used to determine the attractiveness of the genotypes to capsids. In addition, seedlings exposed to capsids in the insectary were observed under 'semi-field' conditions to assess their tolerance and ability to outgrow capsid damage.

The laboratory microtest on the clonal materials established the Parinaris (2.27 lesions/chupon) as the most preferred population followed by the Ts (2.20 lesions/ chupon), the IMCs (1.97 lesions/chupon) and the Nanays (1.55 lesions/chupons) in that order. Pa 7/808 (3.25 lesions/chupon) was the most susceptible clone. The Nanays, Na 744 (1.15 lesions/chupon), Na 225 (1.19 lesions/chupon), Na 427 (1.29 lesions/ chupon) and Na 260 (1.38 lesions/chupon) were the least susceptible clones. Results from the insectary preference tests followed the same order with the Parinari clones emerging as the most preferred and the Nanays as the least preferred.

Preference test on hybrids in the insectary showed that the IMC crosses (4.99 lesions/seedling) were the most preferred, followed by the Parinari crosses (4.78 lesions/seedling), the T crosses (4.71 lesions/seedling) and Nanays (4.18 lesions/ seedling) in that order.

In the semi-field tests, some level of tolerance was observed in both the clonal and hybrid materials but growth measurements showed that the latter were more vigorous. The Parinari clones recorded the highest mean increase in height (25.8cm in 8 weeks) whilst the remaining three populations, IMCs (9.5cm in 8 weeks), Ts (8.7cm in 8 weeks) and Na (5.9cm in 8 weeks) showed no significant differences

(P>0.05) in growth.

For the hybrids, the Nanays (32.0cm in 8 weeks), Ts (28.9cm in 8 weeks) and the Parinaris (27.65cm in 8 weeks) showed no significant differences in increments in height (P>0.05) but growth in all three populations were significantly higher than in the IMC population (19.24cm in 8 weeks). T17/524 x IMC 76 (13.60cm in 8 weeks) recorded the lowest height increment among all hybrids.

The Nanays (2.87cm in 8 weeks), Parinaris (2.8cm in 8 weeks) and IMCs (2.59cm in 8 weeks) showed no significant differences in girth increments (P>0.05) but increase in girth for the Nanays and Parinaris differed significantly from increases in girth of Ts (2.36cm in 8 weeks).

With a few exceptions among the Parinari clones some hybrid varieties, height and girth increments in seedlings exposed to capsids were significantly much lower than increments in seedlings that were not exposed to capsids (controls).

Results from all the experiments conducted in the present study indicate that some of the Nanay hybrids (Na 744 x Pa 7/808, Na 440 x Pa 7/808, Na 279 x IMC 76, Na 260 x IMC 76), some Parinari hybrids (Pa 16 x Na 33, Pa 150 x IMC 76, Pa 107 x IMC 76, Pa 7/808 x T16/613, Pa 184 x T16/613), and some T hybrids (T85/ 799 x Pa 7/808, T79/501 x IMC 76, T63/971 x IMC 76, T65/238 x Na 33, T79/467 x Pa7/808) and some Parinari clones (Pa 107, Pa 118 Pa 121 and Pa 7/808) are potential materials for the development of cocoa genotypes that are resistant/tolerant to capsid attack. Other clonal and hybrid materials such as T79/501, T79/467, T85/ 799, IMC 76, IMC 68 x IMC 49, IMC 11 x IMC 22, IMC 36 x IMC 47 and IMC 49 x IMC 68 which did not differ significantly in height and girth increments from the controls should be further investigated in future experiments to confirm their potential as breeding materials for capsid control.

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CHAPTER ONE

INTRODUCTION

Cocoa (*Theobroma cacao*) is a lower storey rainforest tree. There are over 1500 species of insects associated with cocoa but only a few species are of economic importance (Entwistle, 1972). The insect pest complex that cause economic damage to cocoa in Ghana are the mirids, also called capsids (Heteroptera: Miridae), and quiet recently, termites, the shieldbug, *Bathycoelia thalassina* (H.S) (Heteroptera: Pentatomidae) and the stem borers, *Eulophonotus myrmeleon* Fldr.(Lepidoptera:Cossidae). In addition, mealybugs (Homoptera: Pseudococcidae) are vectors of the swollen shoot virus disease which, together with capsid damage, cause annual yield losses of about 25-30%.

Cocoa capsids are the most important pests of cocoa in Ghana and other West African producer countries (Dungeon, 1910; Entwistle, 1972). Four species have been identified: *Distantiella theobroma* Distant, which is black in colour, *Sahlbergella singularis* Haglund, which is brown, *Bryocoropsis laticollis* Schmacher, which is glossy and *Helopeltis* spp (cocoa mosquito). Of these *D. theobroma* and *S. singularis* are the most important species (Entwistle, 1972). *D. theobroma* was previously the most important species in Ghana whilst *S. singularis* was and still remains the important species in Nigeria. In recent times, however, there is some indication that *S. singularis* is becoming more important in Ghana (Padi and Adu-Acheampong, 2001). For both *D. theobroma* and *S. singularis,* there are five nymphal stages all of which, like the adults, feed on shoots and pods by sucking plant sap.

Damage to pods can cause young cocoa pods to wilt but is of little importance. Feeding on shoots, when complicated by invasion of the parasitic fungus *Calonectria*

rigidiuscula Berk through the feeding lesions, causes dieback and eventual death of the tree. Crowdy (1947) reported that the fungus infected 80% of capsid lesions in the Gold Coast.

Mirid infestation and the ensuing diseases are estimated to reduce crop yield to about 25-30 % annually (Wills, 1962). If left unattended capsid damage alone can reduce yield by as much as 75% within three years after which the farm becomes moribund (Padi, 1997). Young cocoa is particularly vulnerable to capsid damage. Thus mirid infestation can delay the establishment of young cocoa over long periods particularly on denuded lands.

Since 1957, the main method for capsid control has been the use of insecticides (Donald, 1957; Padi, 1997). The current recommended insecticides are Gammalin 20 (Lindane) applied at 280 g.a.i. in 56 litres of water/ha and Unden 20 (Propoxur) at 210 g.a.i in 56 litres of water/ha applied at 4-weekly intervals from August to December, omitting November (Collingwood and Marchant, 1971). The two chemicals are alternated every two years between the northern and southern sectors of the cocoa growing areas of the country as a measure to prevent early development of resistance by capsids.

Justification

The success of chemical control of cocoa capsids is plagued by several problems including the resurgence of resistant strains such as occurred with Lindane in the early 1960s. Other problems include, the destruction of beneficial insects such as pollinators and natural enemies resulting in the upsurge of hitherto minor pests as occured with the pod borer *B. thalassina* (Owusu-Manu, 1974), and the high cost of inputs such as spraying machines, chemicals and labour (Donkor *et al.*, 1991; Handerson *et. al.*, 1994; Padi *et al.*, 2000a). Moreover, with the tedious spraying

procedure (Adomako 1990), the cocoa farmer finds it difficult to support 25 kg of insecticide solution on his back during spraying. Also the prevailing warm and humid tropical weather makes the use of protective clothing uncomfortable and most sprayers refuse to wear them, thus risking insecticide contamination (Padi, 1997).

Because of these constraints, the adoption rate of the current recommendation has been very low as evidenced by recent surveys (Donkor *et al.*, 1991; Handerson *et. al.*, 1994; Padi *et. al.*, 2000a) with the result that the mirid menace in Ghana still prevails. This, coupled with the consumer and universal outcry against environmental pollution and food contamination in the form of taint and toxic residues by insecticides, has made it necessary to look for alternative control methods that are environmentally friendly and devoid of the risks and problems associated with the current practice. Thus, quiet recently, Confidor (Imidacloprid), a nitroguanidine insecticide known to have low mammalian toxicity has been screened and recommended to cocoa farmers in Ghana (Padi, personal communication). It has also become necessary to direct research attention to other areas that are less dependent on the use of conventional insecticides. Thus Cocoa Research Institute of Ghana (CRIG) is currently developing and selecting high-yielding and vigorous cocoa varieties that are also resistant to cocoa swollen shoot virus disease (Adu-Ampomah, 1994) and it has become necessary to incorporate into the breeding programme the development of hybrids that are tolerant/resistant to black pod disease and capsid attack.

The objective of the present study was, therefore, to screen various cocoa clones and hybrids for capsid resistance/tolerance as part of the overall cocoa breeding programme. The cultivation of capsid resistant/tolerant cocoa will obviously be cheaper than other capsid control methods since the major input that farmers will require for capsid control will be their planting material (Padi, 1997).

LITERATURE REVIEW

2.1 THE CACAO PLANT AND ITS ORIGIN

Cocoa, *Theobroma cacao* L. (Tilliales:Sterculiacea) originates from the foot of the Andes in the Upper reaches of the Amazon river in South America (Mossu, 1992).

The Genus *Theobroma* contains 22 species, all originating in the tropical rainforests of equatorial America where some of the species are grown locally for making cooked dishes, jellies or refreshing beverages. The only species grown commercially is *T. cacao* which is cultivated for the production of seeds for making chocolate and for the extraction of cocoa butter.

The Maya Indians were the first to cultivate *T. cacao* and the Aztec Indians of the high Mexican plateau extended their empire to the cocoa growing regions where they levied taxes in the form of seeds which they called 'cacahoatl', hence the word 'cocoa' (Mossu, 1992). The Aztec Indians thought the tree was brought to the earth by the god Quetzacoatl (the plumed serpent). It was probably based on this legend that Linnaeus gave the cultivated cocoa plant the name *Theobroma cacao* which literally means "food of the gods".

2.2 BREEDING WORK IN WEST AFRICA

The first introduction of cocoa to Ghana was made by the Basle Missionaries in 1857 (Wanner, 1962), but the introduction from Fernando Po in 1879 by Tetteh Quashie was of greater importance since it led to the commercial cultivation of cocoa in Ghana. Although there is historical evidence that a few trees were grown in Ghana at the end of the eighteenth century, large-scale cultivation did not begin until late in the nineteenth century.

In 1944, Posnette made a large introduction of new planting material from Trinidad. These included 100 pods from various sources but the most significant were pods of Upper Amazon selections which had reached Trinidad after Pound's expedition in 1938 (Mossu, 1992).

After quality assessment at Tafo for bean size and flavour, certain pods were released for planting (Appendix 1). Following that, a large scale breeding programme was initiated in the 1970s, and as a result, progenies having higher resistance to the cocoa swollen shoot virus disease (CSSVD) compared with the standard Amelonado variety, became available. Since then breeding programmes at CRIG have been focused on the selection of CSSVD-resistant cocoa types but it has now become necessary to incorporate into the breeding programme the development of hybrids that are tolerant/ resistant to black pod disease and capsid attack.

2.3 CLASSIFICATION OF COCOA

Chessman (1944) classified cocoa into two major populations as follows:

i. Criollo (native): This includes Central American Criollo and South American Criollo.

ii. Forastero (foreign): This includes Amazonian Forastero and Trinitarios.

2.3.1 The Criollo Group

The Criollo populations are found cultivated in Mexico, Guatemala, Columbia, Venezuela, Madagascar, the Comoro Island, Sri Lanka, Indonesia and the Samoa Islands (Mossu, 1992). They have pale pink staminodes and pods that are green or red before ripening, varying in shape, generally with very warty and thin pericarp and a mesocarp that is only slightly woody and thin. The plum beans are round in cross-

section with white or very pigmented cotyledons.

Criollo beans have strong aroma and are less bitter. They are, however, not very vigorous and are very vulnerable to the witches broom disease which occurs in Brazil (Mossu, 1992).

2.3.2 The Forastero Group

The general name given to this type of cocoa is *forastero* (of the forest). The fruits are hardier than the Criollo type, grow stronger and yield more but have not so fine flavour.

2.3.2.1 The Amazon Forastero

The fruit wall is hard and smooth on the surface. The beans are flat, deep violet in colour, and very bitter in taste and the resulting product is medium in quality. It is grown commonly in the Amazon basin (Brazil), in the Guyanas and along the Orinoco river in Venezuela, West Africa and South East Asia.

The Upper Amazonian cocoa include the Forasteros collected during several expeditions from the Upper part of the Amazon basin by many researchers. They bear the name of the place or the river in the region in which they have been traditionally harvested. These include Iquitos, Nanay, Paranari, Scavina, Morona, Moquique.

2.3.2.2 Amelonado

This is the main and first cocoa type introduced into West Africa from Fernando Po by Tetteh Quashie (Are and Gwynne-Jones, 1974). It is a lower Amazonian Forastero cocoa. Most cocoa in West Africa is of the Forastero type. The Amelonado cocoa of West Africa is a very homogenous population which can be distinguished from the newer Amazonian Forasteros that originated from the collecting expeditions since

the later are heterogenous.

2.3.2.3 Trinidad Introductions

These are seedlings within pod progenies introduced to West Africa in 1944 from Trinidad by Posnette. They were selected from the Upper Amazon regions. Thus T79/501 is a seedling of pod number 79.

2.3.2.4 The Trinitario Group

The Trinitario group consists of very different and very heterogeneous types probably resulting from Forastero and Criollo crosses. They are grown in countries where Criollos were formally grown ie. Mexico and Central America, Trinidad, Columbia and Venezuela as well as in African and South East Asian countries.

Trinitario cocoa is the third most important type after Amelonado (Lower Amazon) and F_3 Amazon (Upper Amazon) in West Africa. The botanical characteristics have all intermediate features of Criollo and Forastero groups. They were originally selected from Trinidad. Trinitario cultivars generally bear the name of the bodies or research centres which originally selected them: ICS (Selection of Imperial College of Trinidad), UF (United Fruit Selection of Costa Rica), SNC (Selection of the Nkoemvone Station in Cameroon).

2.4 COCOA PESTS

Over 1,500 different species of insect pests have been recorded on cocoa but most of these have negligible effect on the plant (Mossu, 1992).

The insect pest complex that cause economic damage to cocoa in Ghana are the mirids or capsids (Heteroptera:Miridae), the mealybugs (Homoptera:Pseudococcidae) and, more recently the shieldbug, *Bathycoelia thalassina* (Heteroptera:

Pentatomidae), termites (Isoptera: Termitidae) and the stem borer, *E. mymerleon* (Hill, 1993).

Important pests, world wide, include defoliators such as *Adoretus lineola* (Coleoptera: Scarabidae); *Zonocerus variegatus* (L) (Orthoptera: Acrididae); *Earias sp* (Lepidoptera: Noctuidae); stem borers such as *Tragocephala* sp. (Coleoptera: Cerambycidae); *Zeuzera coffeae* Nietn. (Lepidoptera: Cossidae), *E. myrmeleon*, *Xyleborus* sp. (Coleoptera: Scolytidae). Others are the pod borers *Characoma stictograpta* Hmps (Lepidoptera: Noctuidae); *Ceratitis capitata* (Wied) (Diptera: Tephritidae); the virus vectors *Pseudococcus citri* (Risso) (Homoptera: Pseudococcidae). Foliage feeders include *Toxoptera aurantii* (B de F.) (Homoptera: Aphididae) and *Tyora tessmani* (Homoptera: Psyllidae) (Hill, 1993).

The pest status of insect species does not remain constant. For example, it is only recently that the shieldbug, *B. thalassina,* which had for a long time been of minor importance to cocoa in Ghana, has risen to a major pest status (Owusu-Manu, 1974). Thus, many insects normally regarded as minor pests can assume a major pest status, but the reverse can also occur. For example, *Bryocoropsis laticollis* Schumacher (Heteroptera: Miridae) which used to be one of the important capsid pests of cocoa in Ghana in the 1950s is, at present, rarely encountered (Owusu-Manu, *pers comm.*).

2.4.1 The Mirids (Capsid Species)

The nine genera of cocoa mirids (Hemiptera:Heteroptera) that infest cocoa world-wide are all of the subfamily Bryocorinae. In West Africa, six species, all belonging to the tribe Bryocorini, are known to attack cocoa (Entwistle, 1964).

The most widespread species in West Africa is *S. singularis* which is present from Sierra Leone to the Congo and in Fernando Po (known today as Bioko). *D.*

theobroma attacks cocoa in Côte d'Ivore, Ghana, Nigeria, but is rare in the Cameroon. Lavabre (1957) found it at Yaounde in the ratio of 1:140 *S. singularis* in 1957. Results of recent capsid population studies at CRIG indicate that *S. singularis* is now the dominant species in Ghana (Padi and Adu-Acheampong, 2001). *B. laticollis*, perhaps synonymous with *Brycoropsis cotterelli* China in Bioko seems restricted to Ghana, Côte d'Ivore and the Congo (Entwistle and Youdeowei, 1964).

Taxonomic confusion has complicated a distributional discussion of *Helopeltis species. Helopeltis bergrothi* (Rent) is believed to extend from Ghana to Nigeria. *Helopeltis schontedeni* (Rent) occurs in Cameroon and Sao Thomé and *H. bergevini* Pop., *H. lemosi* Ghesq., and *H. West Woodii* (White) (= *allaudii* Rent) in Bioko, Sao Thomé and the Congo respectively. *Odoniella reuteri* (Hagl.) is known only from the Congo (Entwistle and Youdeowei, 1964).

New world cocoa appears to be attacked exclusively by the genus *Monalonian* Herrick-Schaeter, which, according to Morales and Matarita (1961), occurs on all Latin American cocoa. Eleven species occur from Mexico to Brazil and the genus also occurs in Columbia, Equador, Peru, Panama, Costa Rica and Venezuela.

To date, Caribbean cocoa-producing islands are free from mirid attack. On the other hand, more genera (*Sahlbergella, Distantiella, Bryocoropsis, Odoneilla, Helopeltis* and *Boxiopsis)* attack cocoa in the Aethiopian and Madagascarene regions than elsewhere (Entwistle and Youdeowei, 1964).

2.4.2 *S. singularis* and *D. theobroma*

Cotterell (1926) observed that *S. singularis* is more active than *D. theobroma,* and Dunn (1963) postulated that this would make the species more likely to escape from insecticide application than *D. theobroma.* Other differences known to occur between the two species include the information that parasitism of *S. singularis* varies

from 6.8–15.7% in June–October to 22.4–32.1% in February and March (Anon, 1946) while *D. theobroma* very seldom contains parasites. Williams (1953) showed that in Ghana *D. theobroma* has a slightly shorter life cycle and a higher rate of egg production. He also suggested that since the few chupons present at a time in an area as food are rapidly destroyed by the mirids, interspecific competition must be important.

2.4.3 The Biology of Mirids

Cotterell (1943) stated that *B. laticollis* laid an average of 64 eggs per female of which only 50% hatched. Cotterell (1926) also recorded 91 eggs from an adult *D. theobroma* which lived for 27 days. Normally the eggs are buried completely in the plant tissue, except for two barely visible filaments arising near the operculum which presumably aid in respiration(Cotterel 1926). Eggs of *B. laticollis* were found only half buried (Cotterel 1926).

Williams (1953) believed that in the Gold Coast (Ghana), mirids limited egg laying to pods and chupons and Entwistle (1964) found more eggs per unit length of chupon than on fan tissue, but greater total numbers were recorded on the latter.

Observations in the Gold Coast on *D. theobroma* by Cotterell (1926) showed that caged females, but not caged mixed sexes, attracted males. Mating of both species takes place readily *in vitro* and a two hour copulation period has been observed for *S. singularis* (Cotterell, 1926).

West African mirids tend to be negatively phototropic for feeding and oviposition. Youdeowei (1975) observed more feeding in the dark with *S. singularis* in Nigeria and Prins (1964) found *D. theobroma* increased egg laying as the photoperiod decreased in Ghana. Ironically, however, the mirids are usually attracted to parts of the cocoa farm penetrated by light since they tend to be areas where their favourite food, soft chupons and fan tissue, occur. In day time, both species remain inactive in

protected places on the plant. Adults are observed to fly readily in the day time, but for short distances only, when disturbed.

Feeding occurs on unhardened stems, woody tissue, pods and pod stalks but *S. singularis* feeds on hardened braches as well. Stem lesions are elongated and parallel with the stem long axis. Conway (1964) in Sabah reported that the lesions of *H. clavifer* appear triangular and black on new terminal shoots. Lesions on pods are round and their pattern of distribution is often a guide to the mirid species involved. Typical mirid lesions are dark, water-soaked and slightly sunken. Goldchild (1952) suggested that high pressure saliva injections result in the production of an acid toxic to plant cells and that death results in the contents being leached out and the collapse of the cells. The brown colouration is a postmortem effect. Miller (1941) noted that the lesions of *Helopeltis theobromae* (Miller) were covered with a white powder and that gummosis often occurred.

Helopeltis ceylonensis (De Silva) may produce 10–50 lesions a day according to the developmental stage of the insect and condition of the pod (De Silva, 1961). Petioles are often attacked in West Africa but attack on the leaf itself has never been observed, though Green (1901) noted *Helopeltis antonii* (Sign.) probing leaves in Ceylon.

2.4.4 Effects of capsid attack on the host plant and crop losses

The first recorded instance of mirid attack on cocoa was in Sri Lanka in 1863 (Mbakogu, 1964). *D. theobroma* was first noted in Ghana in 1909 and in Nigeria in 1913 (Entwistle and Youdeowei, 1964). Crop losses may result from feeding on pods and pod stalks but the extent of this is unknown for West Africa. Young pods may wilt or become severely distorted, cracked and with beans decayed but effects of feeding on mature pods are insignificant although attack by pathogenic fungi follow-

ing attack on pods has often been reported for West Africa.

Miller (1941) detected significant damage by *H. theobromae* in Malaysia to small pods only. Seventy to 80% losses were caused by *Pseudodoniella leansis* (Miller) in North Papua in 1955. Losses of 60 to 70% were noted for *Pseudodoniella typicus* (Ch. and car.) in New Britain where attack was largely on pods; a lot of this loss was attributed to invasion by the pathogenic fungus *Gleosporium* sp. (Dun, 1954).

Fernando and Manickvasger (1956) noted in Sri Lanka that pod attack by *H. ceylonensis* preceed invasion by the fungus, *Phytophthora palmivora* and attack, on old pods, by the caterpillar of *Dichocrosis punctiferalis*. Conway (1964) observed that attack by *Pseudodoniella apiformis* in Sabah exceeds that of *H. clavifer* due to the intensity of subsequent fungal attack.

Attack on shoots and stems cause the greatest loss in West Africa, where a few lesions on green stems may result in apical death of a shoot. On stems of all ages the lesions allow entry of the fungus *Calonectria rigidiuscula* Berk. and Br. (Sacc.), a weak pathogen. This is a wound parasite which may attack trees wounded by causes other than capsid damage.

Crowdy (1947) stated that in the Gold Coast, fungus infected 80% of mirid lesions in the field. In Nigeria, 95% were infected (Anon, 1957). Among all fungal lesions *C. rigidiuscula* was found to be the most frequent with *Botryodiplodia theobroma* (Pat.) slightly less (Owen, 1956). Crowdy (1947) concluded that the true position with regard to capsid attack is that neither the insect [mirid] nor the fungus alone normally does serious damage to the tree but, in combination, their damage is one of the major problems facing the cacao industry in West Africa.

According to Dun (1954), mirid damage is not associated with fungal attack in New Britain and New Guinea. In Sabah, die-back does not follow the feeding of *H. clavifer* (Conway, 1964) .

Capsid feeding may result in **capsid blast** where concentration of attack on branches leads to their death. The dead leaves turn brown, having withered, but remain on the branches for sometime and this gives a characteristic scorched appearance. In Ghana blasting, occurs during the dry season i.e. January–February. Feeding may also lead to the formation of **capsid pockets** which occur when the canopy of more or less discrete groups of trees is strongly degraded by intensive feeding on the branches. Two main phases of tree deterioration generally recognized are stag-headed trees and bare-poles.

Confusing factors make estimates of West African crop losses caused by mirids difficult, but in Ghana Owusu-Manu reported in 1984 that about 25% of acreage under cocoa was badly affected by capsids causing annual losses of about 100,000 tonnes of dry cocoa per annum (Asante, 1997).

2.4.5 Alternative host plants

Cocoa, indigenous to the Amazon basin, is elsewhere an adopted mirid host. *D. theobroma* and *B. laticollis* occur in Sierra Leone and Nigeria, respectively, on wild hosts only suggesting non-cocoa feeding races. The only known host plants of *S. singularis* in Nigeria are *Cola nitida* and *Veronia* sp. and for *D. theobroma* citrus and *Ceiba pentandra* (Golding, 1941 and Anon, 1947a). *Helopeltis* has been recorded on a large number of plant species but due to taxonomic confusion within the genus it is impossible to give an accurate host list. *B. laticollis* has been found on *Uvaria* spp, *Uvariodendron* spp., *Anona squomosa* and *A. muricate* (Squire, 1947; Entwistle and Youdeowei, 1964).

In Ghana, three alternative host plants, *citrus* sp., *Adansonia digitata* and *Ceiba pentandra* have been recorded for *D. theobroma* and 17 hosts including several

Cola species and *Desplatsia dewevrei* (De Wild and Th. Dur) have been recorded for *S. singularis* (Hutchinson and Dalziel, 1958; Entwistle, 1972; Hawthrone, 1990; Padi, *et. al.*, 1996).

2.4.6 Ecology of Cocoa Mirids

Factors which determine the distribution, occurance and abundance of mirids include the presence or absence of alternative hosts, parasitoids and predators, the level of overhead shade, palatability of cocoa types and climatic conditions (Entwistle and Youdeowei, 1964). Entwistle (1972) observed that a moderate rainy season was beneficial to mirids.

In Ghana mirid attack usually begins under breaks in the tree canopy. *S. singulars* is usually the first coloniser due, according to Williams (1953), to its ability to feed better on fan branches than *D. theobroma*. The latter increases in numbers with regenerative chupon development. In Nigeria cocoa is seldom shaded and mirid attack tends to be more diffuse, though pocket formation may result from breaks in the cocoa canopy itself. Mirid numbers fluctuate greatly during the year. Peak populations of *S. singularis* and *D. theobroma* in Ghana and Nigeria occur from September to February with low populations from April to June.

The factors affecting population change are little understood. In Ghana and Nigeria peaks of *S. singularis* and *D. theobroma* extend from the late rains into the dry season. Cotterell (1943) observed that numbers of *S. singularis* decrease rapidly in severe dry periods and that 60% humidity is critical. In Côte d'Ivoire, Lavabre *et al.* (1963) recorded greater fluctuations in the western section than in the eastern and coastal areas. Parasitism by *Euphorus sahlbergellae* (Wilk) may reach 40% on *S. singularis,* in Nigeria (Decker, unpublished), but is apparently less in Ghana (Cotterell,

1943). *Distantiela theobroma* is parasitized very rarely. The highest level of parasitism (20.0-59.5%) has been recorded in fourth instar nymphs of *S. singularis* (King, 1971; Kumah, 1976).

The quantitative effect of predators are not known. As most mirid species can feed on woody tissue the shortage of soft shoots and pods during the dry season is unlikely to be a controlling factor except for *D. theobroma* which feeds mainly on soft tisseue. Mirid predators have been noted in West Africa and elsewhere and are mostly spiders, Reduviidae (Hemiptera: Heteroptera) and ants.

There seem to be a strong antagonism between some ants and mirids. Thus, the ant *Dolichoderos bituberculatus* (Meyr) was used extensively in Java as a check on *Helopeltis* spp. Dun lists *Oecophylla smargdina* (F) as one of the main predators of mirids in the Territory of Papua and New Guinea and Fernando observed that this species is a deterent to attack on pods by *Helopeltis* in Sri Lanka.

In West Africa, *Oecophylla longinoda* and *Macromischoides aculeatus* have both been noted to be antagonistic to mirids. However, it is not generally felt that they offer possibilities of practical mirid control since they are facultative predators.

Mirid parasites are largely *Braconidae* (Hymenoptera). *E. sahlbergellae,* which also attacks *B. laticollis,* occurs at least from Ghana to 5° south in the Congo (Squire, 1947). It is hyperparasitized by *Musochorus melanothorax* (Wilk). *D. theobroma* is occasionally parasitized by *Encyrtus cotterelli* (Hymenoptera: Chalcidae) in Ghana (Waterston 1922). *Helopeltis* spp. in Ghana is attacked by *Euphorus anatus* (Nix), (Nixon 1946) and *H. antonii* in Java by *Euphorus helopeltides* (Ferr) which is hyperparasitized by *Stictophistus javensis* Ferr (Miller, 1941). No mirid parasites have been recorded from Sabah or the Territory of Papua and New Guinea. Ectoparasitic mites (*Leptus* sp?) attack *S. singularis* in Ghana and Nigeria and

Helopeltis sp. in the Congo. The nematode *Mermis* sp has been noted on *S. singularis* in Ghana, Nigeria and the Congo.

2.5 CONTROL OF COCOA CAPSIDS

2.5.1 Chemical Control

Mirid control relies heavily on the use of chemicals. Prior to the discovery of synthetic inorganic insecticides, kerosine/soap emulsions were used to control mirids. Dichlodiphenyltrichloroethane (DDT) was used in the 1940's after the second world war.

The current recommendation for capsid control involves spraying four times, in August, September, October and in December at the rate of 1 and 1.4 litres/ha for Unden 20 and Gammalin 20, respectively (Asante, 1997). An adoption survey conducted by the Farming Systems Unit of CRIG in 1991 indicated that although 72% of the farmers have tried spraying against capsids at one time or another, 10.1% sprayed once, 5.0% twice, 4.2% thrice, and only 0.4% applied full recommendation (Donkor *et. al.,* 1991). In a more recent nation-wide survey, only 3.2% of farmers used the recommended insecticides applied at the recommended dosages and frequencies (Padi, *et. al.,* 2000a) It is estimated that the proportionate contribution of pest control to production costs are 6.33 per cent for capsid control and 23.73 per cent for black pod control (Okali, 1975; Rourke, 1974; Asante, 1993). Reasons for low adoption rates were given as high cost of the insecticides but, as stated by Asante (1997), it was traceable to the farmers risk awareness. Thus their unwillingness to invest in their farms has resulted in persistently low yields.

It appears the recommended chemical method is ineffective for capsid control on new cocoa hybrids being released to the Ghanaian farmer. Reasons attributed

include the fact that these hybrids have higher vigour and carry fruits throughout the year (Asante,1997) thus resulting in the availability of food (chupons, fan tissue and pods) all year round. Moreover, the major production area has shifted from the Eastern to the Western Region. Thus a nation-wide study on the population dynamics of capsids (and other insects) is in progress (Padi and Adu-Acheampong, 2001). Findings on the temporal distribution of the pests will form the basis for revising the frequency of application of control measures.

2.5.2 Biocontrol and the use of Sex Pheromones

In Malaysia the egg parasitoid *Erythmelus helopeltidis* Gahan (Hymenoptera: Mymaridae) was reported to parasitize 36% of eggs of *Helopeltis cinchonae* Mann on tea (Leverr, 1949).

Several predatory insects of mirid species have been recorded in Papua New Guinea. The pentatomid *Amyotea reciprours* (Walk), has been recorded feeding on both *H. clavier* and a *Pseudodoniella species* (Entwistle, 1972). The predator *Anlocagonia cheesmanae* Miller was recorded attacking *P. typica* on New Britain Island. The most successful control of mirids by ants has been achieved in Malaysia (Way and Khoo, 1991) and Indonesia with the use of *Dolichoderus thoracicus (bituberculatus)* (Smith). Way and Khoo (1991) stated that 200–20,000 *D. thoracicus* ants on a cocoa tree can effectively protect the tree against the Malaysian cocoa mirid *H. theobromae*.

The use of fungi as natural enemies for biological control of insect pests of cocoa has proved feasible in Papua and New Guinea (Lomer and Prior 1991). Laup (1999) observed that biological control of pests such as mirids is potentially feasible with the use of an entomopathogenic fungi such as the white muscardine fungus *Beauveria*

bassiana (Balsamo), Vuillemin (Deuterimycotina, Monilialiacae: Hyphomycetes).

In an IPM study on the possible use of biocontrol agents and sex pheromones Ackonor and Nkansah (2000) showed that natural enemies of capsids collected from CRIG experimental plots yielded no parasitoids from 71 *D. theobroma* dissected. Parasitism rate of *Sahlbergella singularis* was very low with only one parasitoid, *Euphorus sahlbergellae,* recorded from 108 *S. singularis* dissected. The low level of parasitism might be the result of intensive use of insecticides. A hyperparasitoid, reared from *E. sahlbergellae* was identified as *Mesochorus melanothorax*. The ant, *Oecophylla longinoda* was observed attacking both capsid species in the field. Two pathogenic fungi, *Entomophaga grilli* and *Fusarium sp.* were isolated form both species of capsids at Tafo and Bieni. A *B. bassiana* isolate has been found associated with *S. singularis* larvae collected from Ghana (Ackonor and Nkansah, *in press*)

In a pheromone study (Padi, *et. al.*, 2000b), the chemical structure of the sex pheromones of *D. theobroma* has been identified and synthesised. Since the compound is similar to that of *S. singularis* it is being tested for attraction to both capsid species.

2.5.3 Cultural Control

Capsids are attracted to their food by light and so can be controlled by good shade management and proper cocoa pruning to provide optimum shade levels (Smith, 1985; Laup 1994; Padi, 1997). Taylor (1954) observed that both excessive and depleted shade render the cocoa susceptible to attack or reduce its power of regeneration from injury. He observed further that the shade conditions which are most suitable for the healthy growth of cocoa are those in which capsid injury is least likely to be serious. Alternative host plants such as *Ceiba pentandra, Citrus* spp., *Cola* spp. *Gossypium* spp and *Adansonia digitata* in cocoa farms should be destroyed. Mistle-

Gossypium spp and *Adansonia digitata* in cocoa farms should be destroyed. Mistletoes and epiphytes should also be removed from the cocoa plants. Posnette (1943) tested his hypothesis that *D. theobroma* had preference for seedlings up to six years old whilst *S. singulars* prefers mature trees, but concluded that neither species exercised any constant choice.

2.5.4 Use of Resistant/Tolerant Varieties

Painter (1951) defined plant resistance to insects as the amount of heritable qualities possessed by the plant which negatively influences the ultimate degree of damage done by the insect. He divided host-plant resistance into three major categories namely: tolerance, antibiosis and preference/non-preference. Tolerance refers to that condition whereby the plant is capable of supporting a population of insects without loss of vigour whilst antibiosis refers to the phenomenom whereby the plant is able to cause adverse effect on the biology of the insect. Preference/non-preference refers to plant characters which affect the behaviour of the insect during orientation for food, shelter and oviposition. With respect to cocoa, resistance can imply any of the following: unpalatability of the cocoa type, cocoa proving to be an unsuitable host for oviposition and ability to withstand the effect of capsid toxins or the fungus associated with capsid damage.

The use of resistant/tolerant varieties to control cocoa capsids was considered a remote possibility by Bell and Rogers (1956). Padi (1997), however, discussed the prospects and advantages of the use of such varieties for capsid control and suggested that screening for capsid resistance/tolerance should be incorporated into the CRIG breeding programme aimed at developing vigorous and high yielding cocoa types that are also resistant to pests and diseases.

In Java, hybrids obtained from crosses between Djate Roengo Criollo and

Trinitario are resistant to capsid attack as evidenced by a rapid canopy regeneration after attack (Hall, 1932).

The first annual report of the West African Cocoa Research Institute (Anon, 1943), mentioned a tree at Asuansi (SCI) which had remained untouched by capsids in an otherwise 'blasted' area and reported that varying degrees had been observed in the "yield and quality" of clones at Tafo. Anon (1947b), on other hand, described a comparison of rooted cuttings of SCI and TF7 and concluded that "SCI showed neither resistance nor tolerance to *S. singularis*". A severe attack of *D. theobroma* over three years on a 16 acre progeny trial at Tafo killed many young plants, and caused a general check in growth, but there "were very marked differences in the amount of damage between the seedlings; and the progeny of certain selections seemed to have escaped damage and made excellent growth" (Nicol, 1945).

In 1944, new cocoa material from Trinidad was introduced partly to obtain breeding stock for CSSVD resistance (Posnette, 1951). Results from a susceptibility trial at Tafo (Anon, 1945) gave a "very strong indication that *S. singularis* and *D. theobroma* caused less damage to the Trinitario selection SCI than to the common West African Amelonado.

Anon (1947b) reported that "the progeny of the Nigerian cocoa selection T38 had shown field "resistance" to capsids at Tafo, but had been severely attacked and had shown the symptoms of fungal infection at Owena in Nigeria.

Owen (1956) found that different Amelonado and Trinitario clones varied in susceptibility to fungus attack. The Trinitarios which he tested included A36, D70, O4, SC2 and SC4, all chosen because of their apparent resistance to mirid injury. Elsewhere, Burle (1953) has reported resistance of a particular tree to attack by *S. singularis* and *D. theobroma* in Ivory Coast, and Coolhous (1939) reported resistance to *Helopeltis* in Indonesia. From a survey of insects occuring on two cocoa

progenies: T85/799xT17/359 and a Series II hybrid at Tafo, it was concluded that the later was more susceptible to attacks by a range of sucking insects (Bigger, 1975). This observation indicates that there is a potential for identifying cocoa types which are resistant/tolerant to capsid attack and which may be incorporated into the breeding programme to reduce capsid attack and damage in the field as suggested by Padi (1997).

In an attempt to determine varietal selection behaviour in the laboratory, Nguyen-Ban (1993) described a simple and quick laboratory screening method for insect preferences. By using this method Bassie (1997) found significant preferences by *S. singularis* for the Mocorongo x P30, Mocorongo, Mocorongo x K5 and APA 5 x K5. He also observed that third and fourth instars did not discriminate between varieties. Nguyen-Ban (1976) has shown in Côte d'Ivoire that cocoa capsids are selective in their choice of cocoa progenies in the field. Such behavioural responses in capsids have also been reported by Piart (1970) and Astide (1990).

Reasons given for preferential selection of cocoa varieties are varied and many. According to Cotterrell (1926), *D. theobroma* prefers cocoa progenies with young and tender chupons. Nguyen-Ban (1993) found significant differences in mirid choice of high Amazonian PA 620, Trinitario UF662 and Amelonado IFCS. He attributed the varietal differences to differences in the physical nature of chupons as well as their relative water status. Thus preferential selection of varieties by *D. theobroma* may be based on properties reflected in their physical nature, coupled with the presence of appropriate phagostimulant.

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

3.1.1 Tafo

The study was conducted at the Cocoa Research Institute of Ghana (CRIG) at New Tafo in the Eastern Region (latitude 6° 17" N; longitude 0°22"E). Tafo is 107.2 km (approximately 67 miles) from Accra on the Accra-Kumasi road through Koforidua (Fig.3. 1). Keay (1959), giving Tafo a broad classification, puts it in the moist forest zone at low and medium altitudes whilst Taylor (1952) locates it within the celtis-Triplochiton subdivision of the moist semideciduous forests with patches of farm bush interspersed with plots of cocoa in some areas. Within CRIG'S grounds, cocoa cultivation is largely on plantation basis.

3.1.2 The Climate

Tafo is located southwest of the Mampong scarp on the Togo hills within the equatorial climatic zone (Udo, 1978). The climate as described by Church (1957) and Boateng (1960), reveals a rainfall pattern with double maxima (March to July and September to November) and a dry harmattan period lasting from November to Mid-February. Mean monthly rainfall ranges from 37.6 to 57.6 mm. The harmattan is characterized by a dry and hazy weather with relative humidity sometimes as low as 40% and correspondingly low night and morning temperatures (Church, 1957; Boateng, 1960).

Rainfall averages 1650 mm/annum, mean daily temperatures range from 22 to 31°C and relative humidities average 77%. The average monthly rainfall for year 2000 was 126.98mm, which is higher than average for 1990-1999 (Fig.3.2).

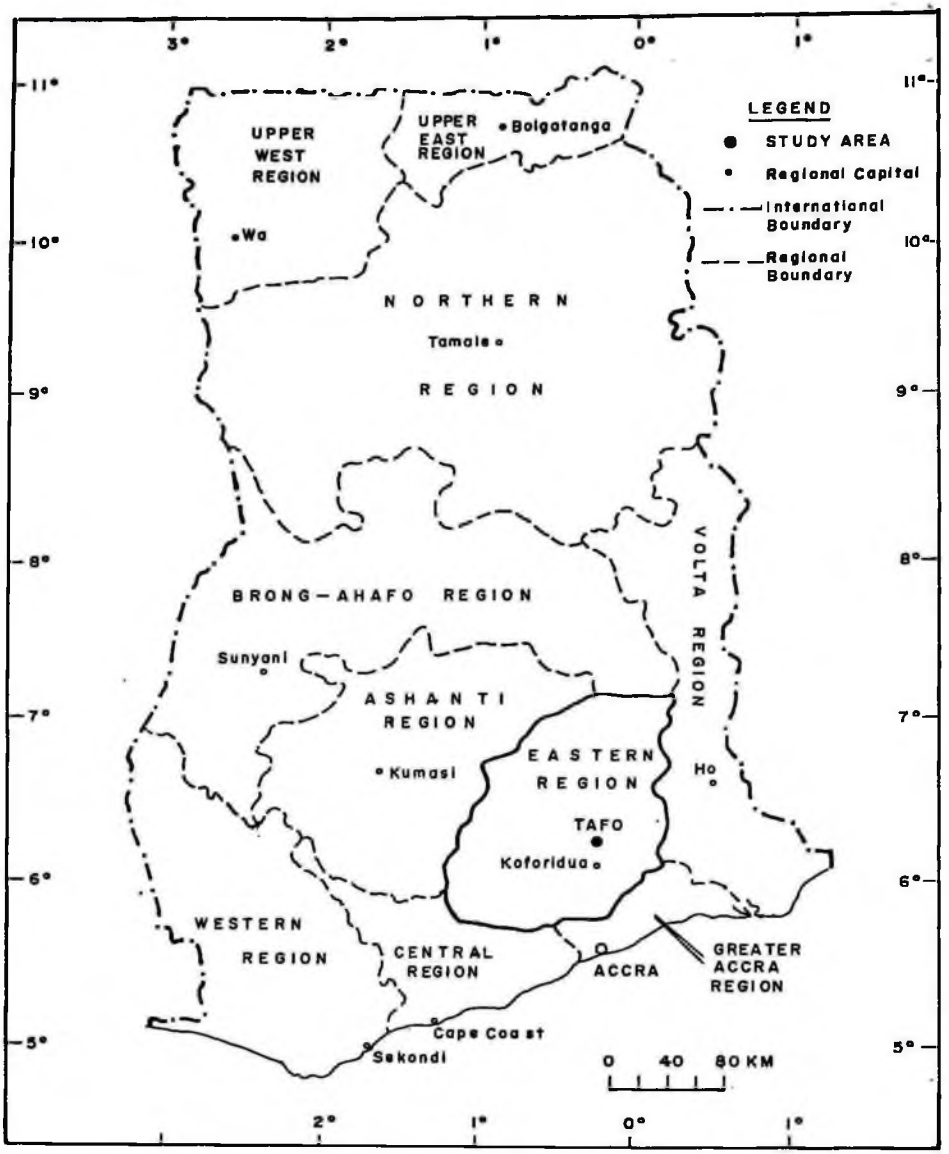

Fig. 3.1 Map of Ghana showing the study area, Tafo, in the Eastern Region

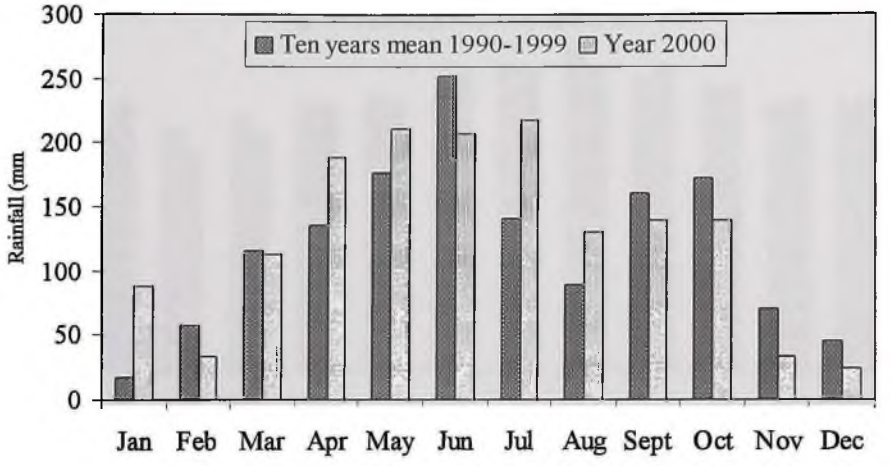

Fig. 3.2 Mean annual rainfall (mm) at Tafo (1990-1999 compared with year 2000)

Mean daily maximum and minimum temperatures range between 20 and 36°C with daily fluctuations of the order of 1 or 2°C. Mean monthly maximum and minimum temperatures from 1990-1999 compared with those for year 2000(Fig.3.3) shows that there have not been much change over the years. Mean annual relative humidities have also not changed much when figures of 1990-1999 are compared with those of year 2000 (Fig.3.4).

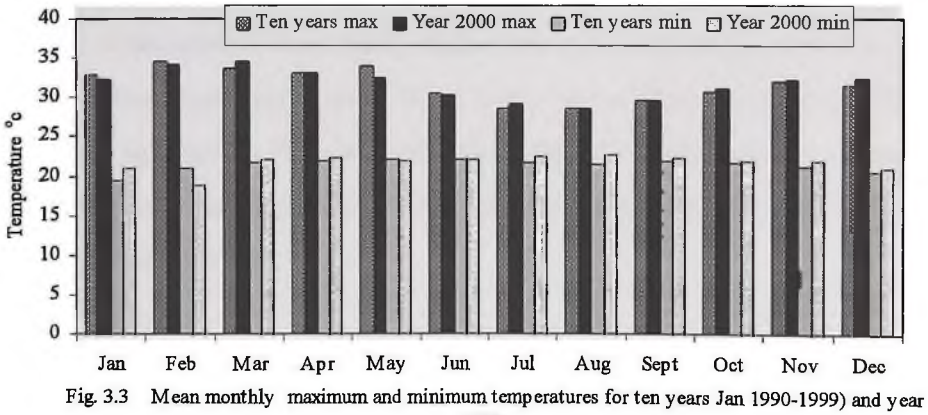

Fig. 3.3 Mean monthly maximum and minimum temperatures for ten years Jan 1990-1999) and year 2000

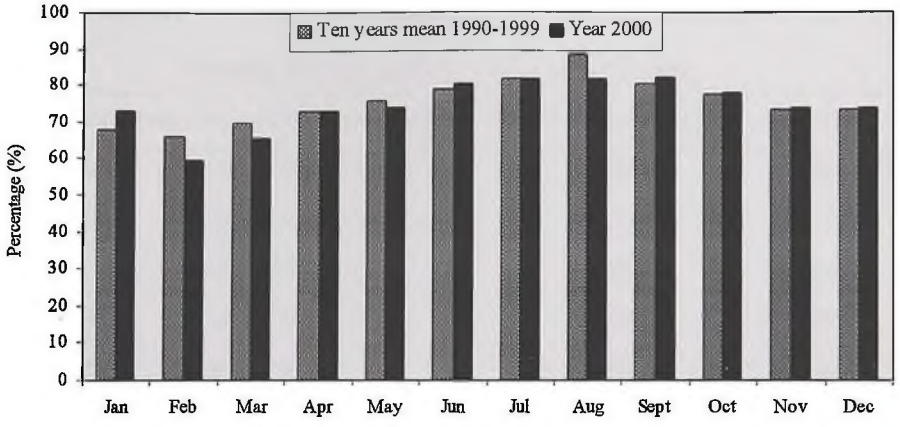

Fig. 3.4 Mean annual relative humidity at Tafo (1990-1999) compared with year 2000

Four seasons have been described for Tafo by Gibbs and Leston (1970). The 'dry-sunny season' in November to mid-February is followed by two 'wet-sunny seasons' in late February to late May and late October to November. Both periods have clearer skies with line squalls (Church, 1957). Two 'wet dull seasons' occur between June/ July and late August to mid-October with the heaviest downpour in June. The period mid-July to late September encompasses the 'dry dull season', a term which may seem a misnomer since relative humidity during this period may be as high as 80%.

3.2 SCREENING FOR ATTRACTIVENESS OF LOCAL COCOA CLONES.

3.2.1 Experiment 1: Laboratory 'microtest': In this experiment, 40 clones, 10 each of four populations namely Nanay (Na), Iquitos Mixed Calabacilo (IMC), Trinidad introduction (T) and Parinari (Pa) (Table 3.1) were screened for their attractiveness to the cocoa mirid, *S. singularis* using the microtest technique described by Nguyen-Ban (1993).

Table 3.1

Varieties of cocoa used for Laboratory screening

Nanays (Na)	quitos Mixed Calabacillo (IMC)	Trinidad introduction (T)	Parinari (Pa)
A. Na 427	A. IMC 68	A. T17/524	A.. Pa 188
B. Na 744	B. IMC 23	B. T85/799	B. Pa 16
C. Na 34	C. IMC 44	C. T16/613	C. Pa 150
D. Na 440	D. IMC 76	D. T63/967	D. Pa 118
E. Na 929	E. IMC 47	E. T79/501	E. Pa 107
F. Na 79	F. IMC 57	F. T63/971	F. Pa7/808
G. Na 33	G. IMC 11	G. T60/887	G. Pa 121
H. Na 279	H. IMC 49	H. T65/238	H. Pa 184
I. Na 260	I. IMC 36	I. T79/467	I. Pa 52
J. Na 225	J. IMC 5	J. T92/1615	J. Pa 186

Table 3.2

CRIG experimental plots (Q6-V3) from which the various genotypes were collected

L6	Q6	M6	N5	Q7	R2	V3
Na 744,Na 279	Na 225,Na 929	Na 34	T17/524	T79/501	T85/799	T92/1615
Na 440	Na 427, Na 79	T63/971				
Pa 186, Pa 107	Na 260, Na 33	T63/967				
	All IMCs	T79/467				
	T65/238	T60/887				
	All other PAs					

FIELD INVESTIGATIONS
AT . .
COCOA RESEARCH INSTITUTE OF GHANA
TAFO
2000/2001

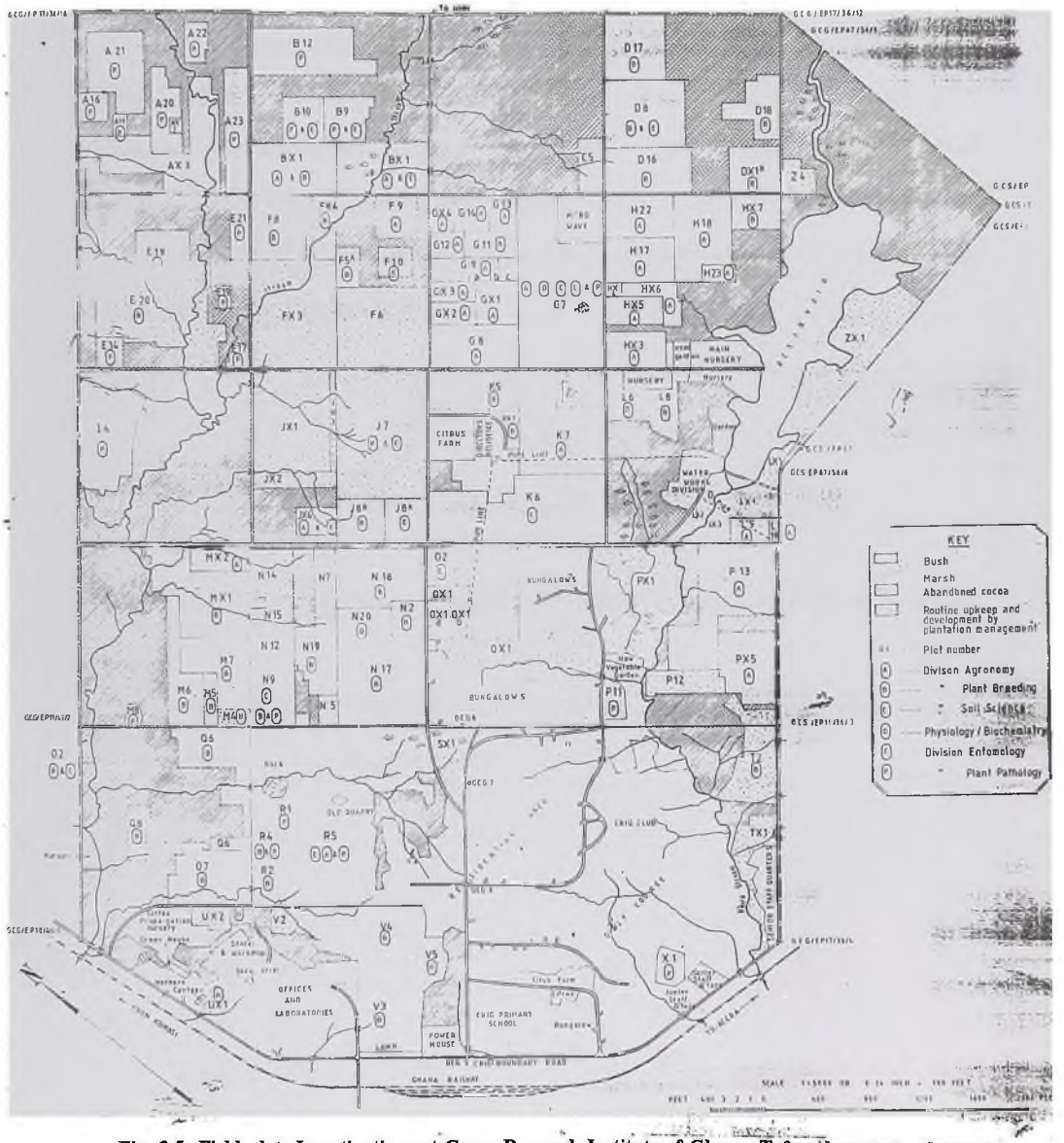

Fig. 3.5 Field plots Investigations at Cocoa Research Institute of Ghana, Tafo, where test chupons of four populations (genotypes) were collected

Fresh chupons (soft branches) for the test genotypes were variously collected from the CRIG experimental plots listed in Table 3.2. Fresh chupons and/or young flushes were cut, labelled and taken to the laboratory where they were cut into 50 mm pieces, with each clone in a separate petri dish. Fourth or 5th instar nymphs of *Sahlbergella singularis* were used in the experiment since it was the species successfully reared in sufficient numbers under laboratory conditions. Following Nguyen-Ban's method the clones (same size, freshness and texture) were screened three at a time, arranged in a triangle (Fig.3.6) and stapled together with staple pins in a 120mm diameter petri dish lined with a 120 mm filter paper.

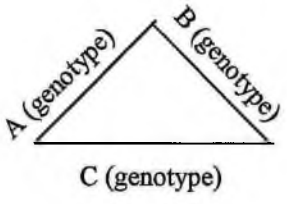

Fig.3.6 Model of laboratory arrangement (A, B and C represent chupons of three different genotypes)

Ten series each with 15 replications were cnducted. The series were as follows:

1.	ABC	15 replications
2.	BCD	"
3.	CDE	"
4.	DEF	"
5.	EFG	"
6.	FGH	"
7.	GHI	"
8.	HIJ	"
9	IJA	"
10.	JAB	"

By this arrangement each of the 40 clonal materials tested (Table 3.1) was screened 45 times. One fourth or fifth instar nymph of *S. singularis* starved for 24 hours was introduced into the petri dish which was then covered and placed inside a dark wooden cupboard. All experiments were conducted at ambient temperature (26 ± 2°C) and relative humidity of approximately 70%. Observations were made after twenty-four hours and the number of feeding lesions (punctures) on each chupon counted and recorded. The feeding lesions were recognized as elongated dark patches parallel with the long axis of the stem (Plate 1). The more the punctures the more attractive the cultivar was considered to be.

3.2.2 Experiment 2: Tolerance Test

The objective of this experiment was to assess the ability of selected cocoa genotypes (parent clones), (Table 3.1) and their progenies, (Table 3.3) to recover from mirid damage. The experiment was conducted between January and June 2001. The methods used were intermediate between the Nguyen-Ban (1993) microtest method and the field antibiosis approach described by N'guessan and Mpe (2000).

Budded clones used for the experiment were collected from the breeding house of Plant Breeding Division, CRIG. The progenies were raised from hand-pollinated pods obtained from the CRIG nursery. After initial height and girth measurements were taken, nine plants were arranged in three rows in an insectary cage measuring 90 x 90 x 90cm^3 (Plate 2a) in such a way that they did not touch each other (Plate 2b). A fourth or fifth instar nymph of *S. singularis* starved for 24 hours was put on to each plant and left for 72 hours after which the number of feeding lesions were counted.

Altogether five plants of each clone were screened using this method. Five other plants of each clone had no capsids on them and served as controls. The treated plants, together with the control, were then randomly arranged under inverted cages

in the field behind the insectary (Plate 3). Height measurements were taken weekly on both treated and control plants for a period of 8 weeks using a metre rule. Girth measurements were also taken weekly using a venier caliper. The ability of plants to recover from feeding wounds was assessed using a five point rating (1 – 5) of the vegetative status as follows:

Rating	% dead twigs
1	>75
2	>50–75
3	>25–50
4	>0–25
5	0

The number of dead seedlings were also recorded.

Experiments 1 and 2 described above were repeated using 40 hybrid materials (Table 3.3)

Table 3.3

Progenies (hybrids) used for the Insectary and Semi-field test

	Nanays	Parinaris
1.	Na 427 x T16/613	Pa 188 x T16/613
2.	Na 79 x Pa 7/808	Pa 16 x Na 33
3.	Na 33 x Pa 7/808	Pa 150 x IMC 76
4.	Na 34 x IMC 76	Pa 118 x Na 33
5.	Na 929 x Pa 7/808	Pa 107 x IMC 76
6.	Na 744 x Pa 7/808	Pa 7/808 x Na 33
7.	Na 260 x IMC 76	Pa 121 x T16/613
8.	Na 279 x IMC 76	Pa 184 x T16/613
9.	Na 440 x Pa 7/808	Pa 52 x Na 33
10.	Na 225 x IMC 76	Pa 186 x IMC 76

	Trinidad introductions (Ts)	IMCs
1.	T17/524 x IMC 76	IMC 68 x IMC 49
2.	T85/799 x Pa 7/808	IMC 23 xIMC 6
3.	T16/613 x Na 33	IMC 44 x IMC 49
4.	T63/967 x Pa 7/808	IMC 76 x IMC 5
5.	T79/501 x IMX 76	IMC 47 x IMC 63
6.	T63/971 x IMC 76	IMC 57 x IMC 67
7.	T60/887 x Na 33	IMC 11 x IMC 22
8.	T65/238 x Na 33	IMC 49 x IMC 68
9.	T79/467 x Pa 7/808	IMC 36 x IMC 47
10.	T92/1615 x Pa 7/808	IMC 5 x IMC 11

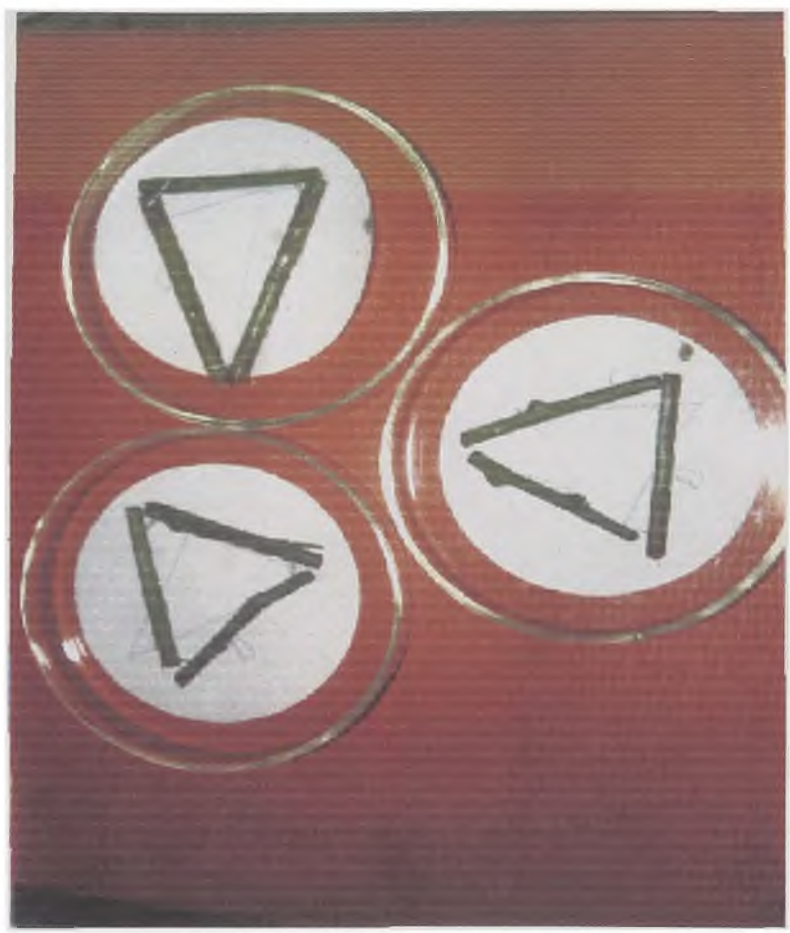

Plate 1: Distribution of capsid feedings lesions on cocoa genotypes under laboratory conditions

Plate 2a: Cages used for the insectary study

Plate 2b: Cocoa seedlings arranged in an insectary cage where one fourth or fifth instar *S. singularis* was allowed to feed on each for 72 hours

Plate 3: Cages used for the semi-field study

3.4 EXPERIMENTAL DESIGN AND ANALYSIS

The laboratory experiment was set up by pairing three clones at a time in a completely randomized design (CRD) with each clone replicated 45 times. The data was transformed using square root transformation ($x=\sqrt{y}+0.5$). The data was analysed by performing an analysis of variance (ANOVA) with the various clones as treatments using the Statistical Package for Social Sciences (SPSS). Significant diffrerence between means for each clone was tested using Duncan's Multiple Range Test (DMRT).

The number of feeding lesions on clones and hybrids in the insectary test were analysed using ANOVA. Also analysis of variance for height and girth increments was performed for the different clones and hybrids. Overall analysis of variance was performed on girth and height for both clones and hybrids.

CHAPTER FOUR

4.0 RESULTS

4.1 LABORATORY MICROTEST AND INSECTARY SCREENING

4.1.1 Laboratory Screening

Of the four populations, the Parinaris (Pa) were the most preferred (2,737 lesions/ 450 chupons) (Appendix 2), followed by the Trinidad introductions (Ts) with 2,548 lesions/450 chupons (Appendix 5); IMCs, 1,939 lesions/450 chupons (Appendix 4), and Nanays, 1160 lesions/450 chupons (Appendix 3; Fig. 4.1).

The mean number of feeding lesions on the Nanays (1.554 lesions/chupon) followed by the IMCs (1.968 lesions/chupon) were significantly different from each other and were significantly lower ($P<0.05$) than those on the Ts (2.202 lesions/ chupon) and Parinaris (2.275 lesions/chupon) which were the better preferred (Appendix 6, Table 4.1).

A ranking of preference among clones within the four populations showed Pa7/808 (524 lesions/450 chupons) to be the most preferred (Fig. 4.2, Appendix 2). This was followed by T79/501 (392 lesions/450 chupons), (Appendix 5), then Pa 184 (382 lesions/450 chupons) and Pa 107 (327 lesions/450 chupons), (Appendix 2) in decreasing order of preference but the differences were statistically not significant ($P>0.05$). The least preferred among the 40 clones were Na 744 (43 lesions/450 chupons), Na 225 (48 lesions/450 chupons) and Na 427 (63 lesions/450 chupons) (Appendix 3) in that order but again the differences were statistically not significant ($P>0.05$). The results showed that even the most preferred Nanay clone, Na 79 (195 lesions/450 chupons) would rank 7th on the Pa scale, 5th on IMCs and 8th on the Ts scale. It is also important to note that the least preferred T, T16/613 (139 lesions/450 chupons) would rank 4th among the Nanays..

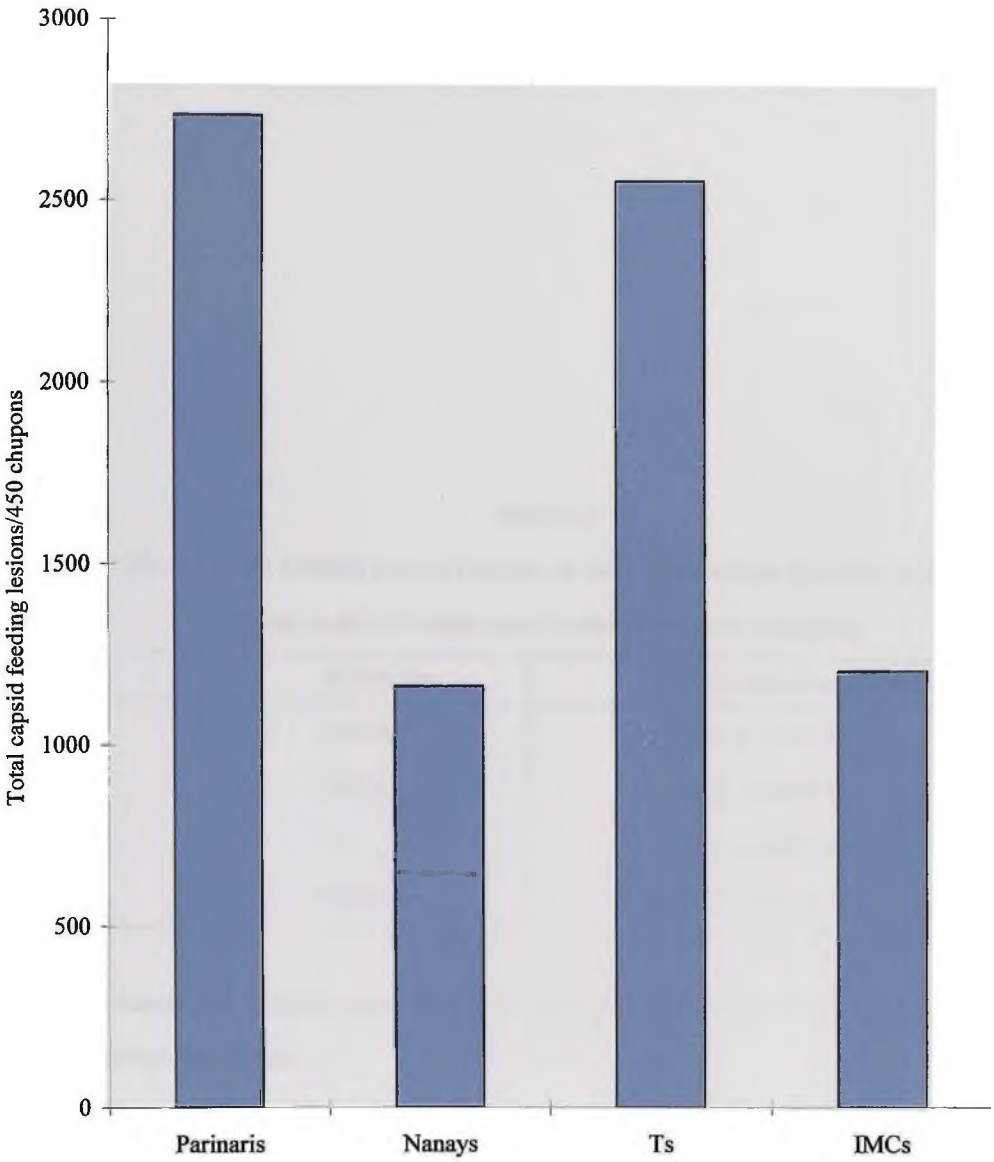

Fig. 4.1 Distribution of capsid feeding lesions/450 chupons for four cocoa populations (10 clones per population) under laboratory condition

Table 4.1

***Mean capsid feeding lesions/chupon on four populations (4 levels) with 10 clones each (40 levels) used in the laboratory screening**

Genotype	Mean number of lesions
Nanays	1.554 ± 0.049 **a**
IMCs	1.968 ± 0.049 **b**
Ts	2.202 ± 0.049 **c**
Parinaris	2.275 ± 0.049 **c**

*Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

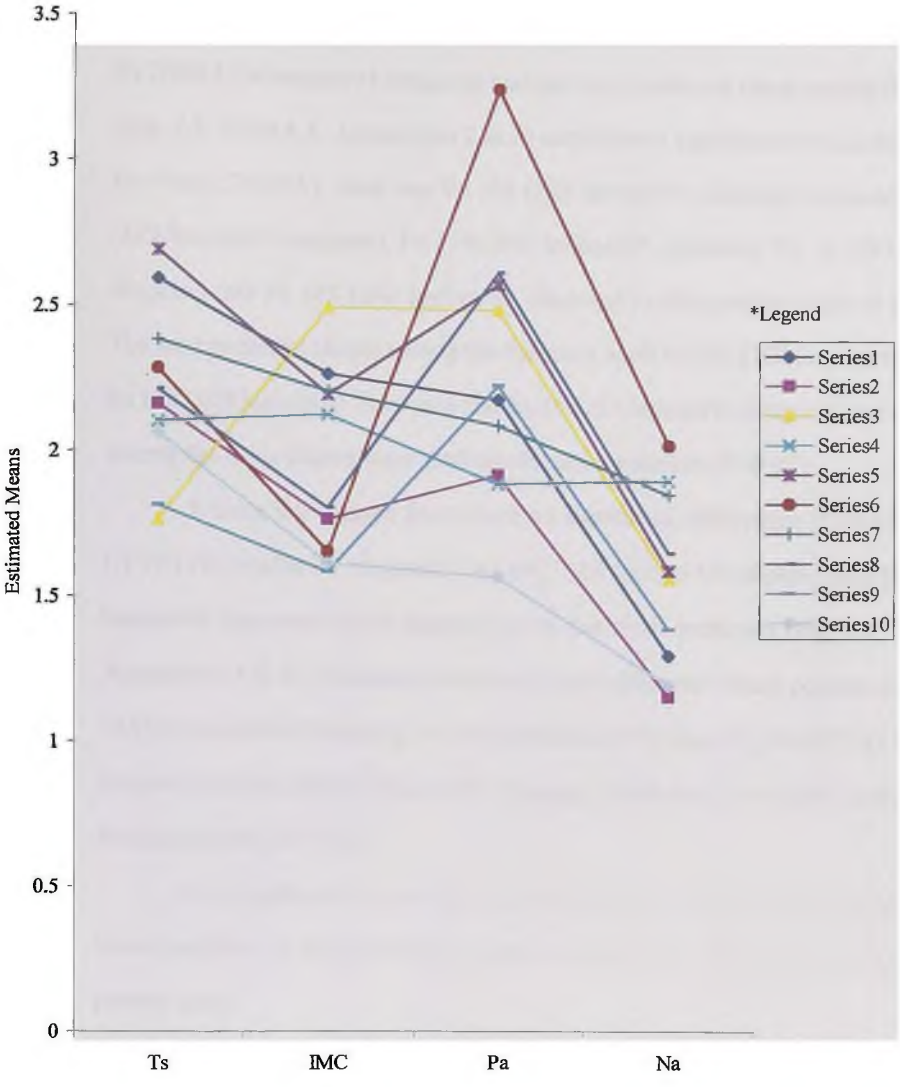

Fig. 4.2 Ranking of mean capsid feeding lesions to determine preferences on four populations (4 levels) of 10 clones each (40 levels) under laboratory conditions

***Series 1-10 are clones in each population labelled A-J in Table 3.1**

Pa 7/808 (524 lesions/45 chupons) was the most preferred clone among the Parinaris (Fig. 4.3, Table 4.2, Appendices 2 & 7) and differed significantly from the remaining Pa clones ($P<0.05$). Next was Pa 184 (382 lesions/45 chupons) followed by Pa 107 (327 lesions/45 chupons), Pa 150 (303 lesions/45 chupons), Pa 52 (257 lesions/45 chupons) and Pa 188 (243 lesions/45 chupons) in descending order of preference. The least preffered clones among the Parinaris were Pa 186 (108 lesions/45 chupons) Pa 118 (169 lesions/45 chupons) and Pa 16 (187 lesions/45 chupons) but differences among the three clones were statistically not significant ($P>0.05$).

Among the Nanays there were no significant differences ($P>0.05$) between Na 79 (195 lesions/45 chupons) , Na 440 (186 lesions/45 chupons) and Na 33 (178 lesions/45 chupons) which appered to be the most preffered (Fig 4.4, Table 4.3, Appendices 3 & 8). The least attractive clones within the Nanay population were Na 744 (43 lesions/45 chupons), Na 225 (48 lesions/45 chupons), Na 427 (63 lesions/45 chupons) and Na 260 (81 lesions/45 chupons) which were not significantly different from each other ($P>0.05$).

It is significant to note that Na 744, Na 225, Na 427 and Na 260 had the lowest number of capsid feeding lesions among all the 40 clones screened in the present study.

Among the Ts, T79/501 (392 lesions/45 chupons), T17/524 (357 lesions/45 chupons), T60/887 (306 lesions/45 chupons), T63/971 (259 lesions/45 chupons), T65/238 (256 lesions/45 chupons), and T85/799 (235 lesions/45 chupons) were to be the most preferred clones in that order. The differences were, however, not statistically significant ($P>0.05$) (Fig. 4.5, Table 4.4, Appendices 5 & 9). Also T16/613 (139 lesions/45 chupons), T63/967 (218 lesions/45 chupons), T79/467 (147 lesions/45 chupons), T92/1615 (221 lesions/45 chupons), T65/238 (256 lesions/

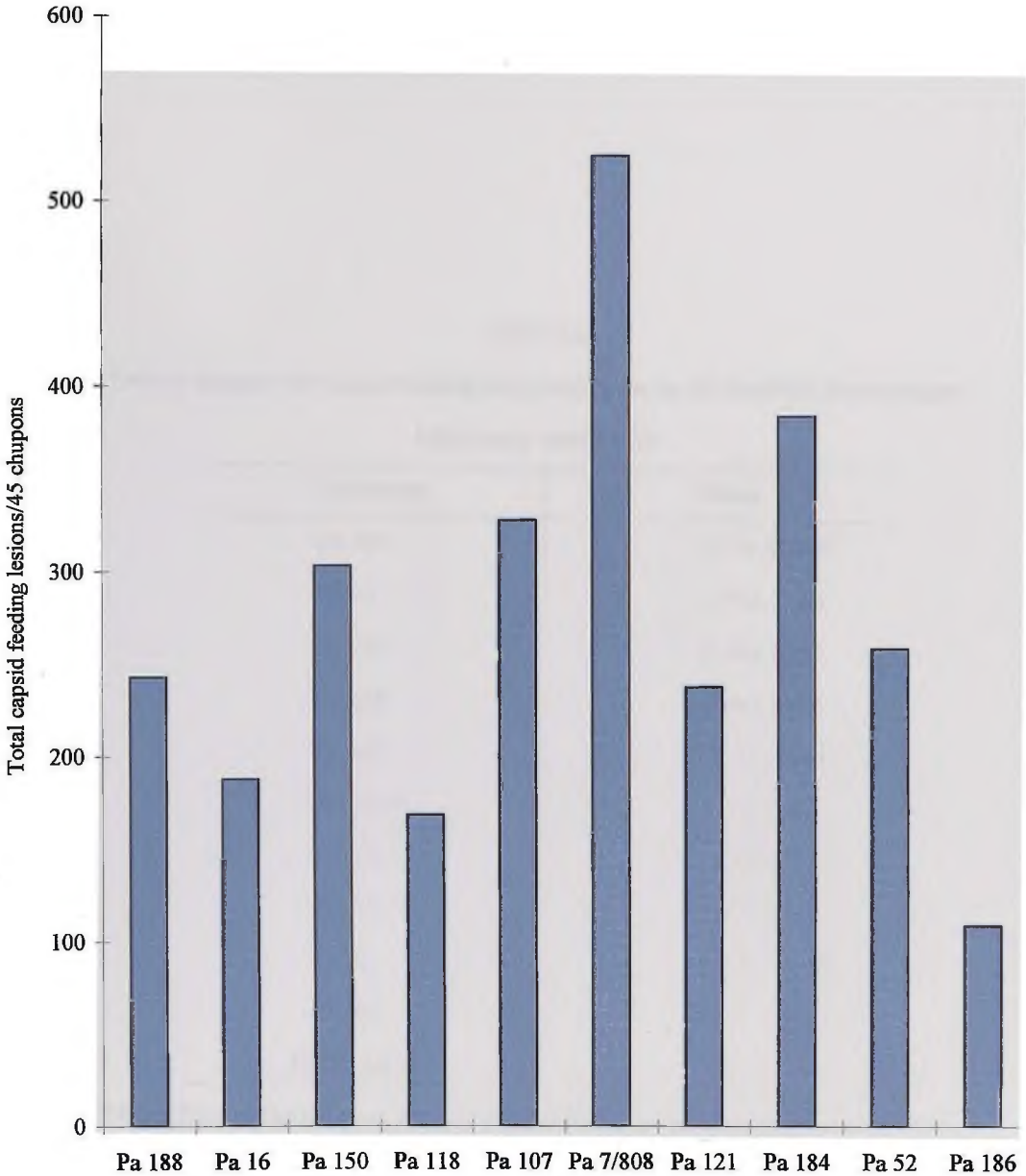

Fig. 4.3 Distribution of capsid feeding lesions/45 chupons on 10 Parinari clones under laboratory conditions

Table 4.2

***Mean number of capsid feeding lesions/chupon on 10 Parinari clones under laboratory conditions**

Genotype	Mean
Pa 188	2.17±.16**bcd**
Pa 16	1.90±.14**ab**
Pa 150	2.48±.16**cd**
Pa 118	1.88±.13**ab**
Pa 107	2.57±..16**cd**
Pa 7/808	3.25±.19**e**
Pa 121	2.09±.18**bc**
Pa 184	2.61±.22**d**
Pa 52	2.22±.17**bcd**
Pa 186	1.56±.10**a**
Grand Mean	2.27

*Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

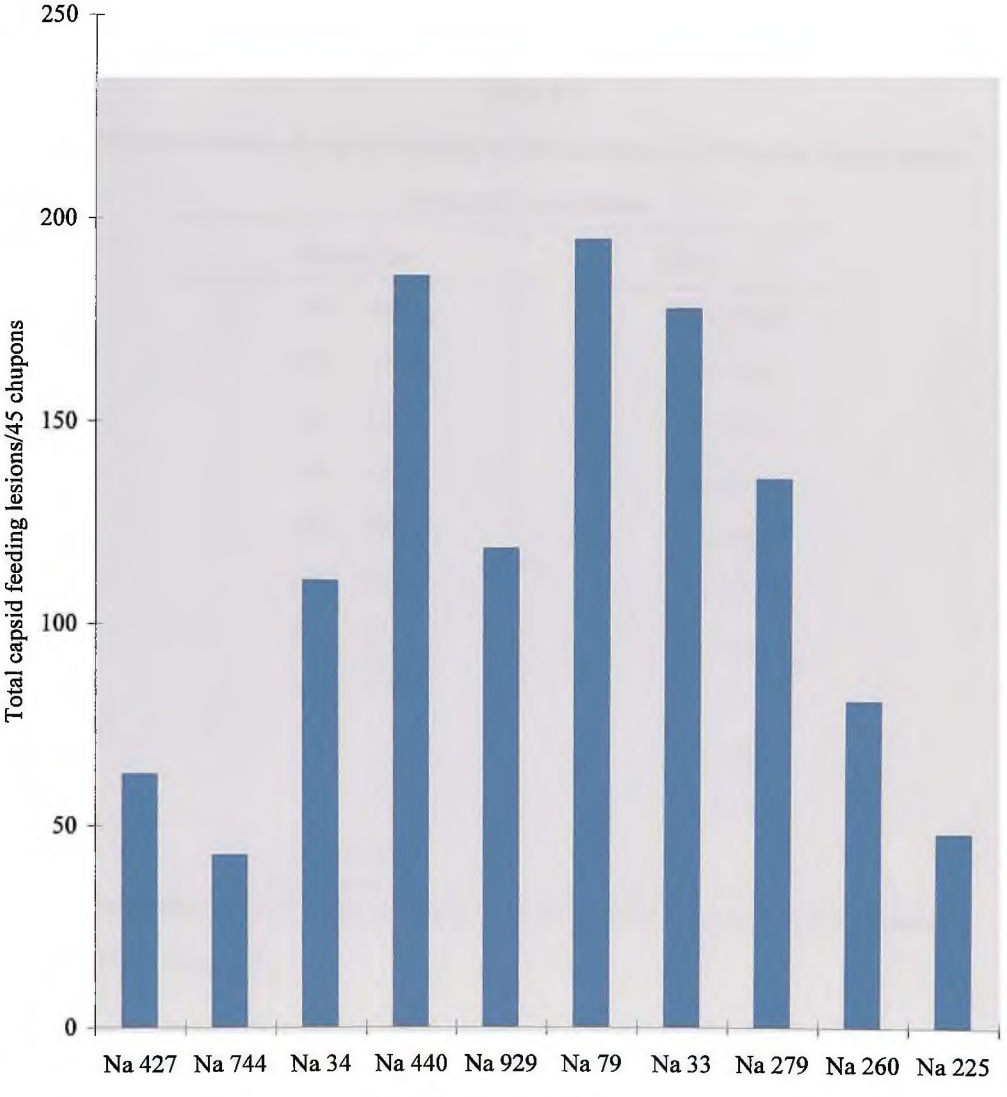

Fig. 4.4 Distribution of capsid feeding lesions/45 chupons on 10 Nanay clones under laboratory conditions

Table 4.3

***Mean number of capsid feeding lesions/chupon on 10 Nanay clones under laboratory conditions**

Genotype	Mean
Na 427	1.29±.16**ab**
Na 744	1.15±.16**a**
Na 34	1.55±.10**bc**
Na 440	1.89±.15**cd**
Na 929	1.58±.12**bc**
Na 79	2.01±.14**d**
Na 33	1.84±.16**cd**
Na 279	1.64±.15**bc**
Na 260	1.38±.16**ab**
Na 225	1.19±.16**a**
Grand Mean	1.55

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

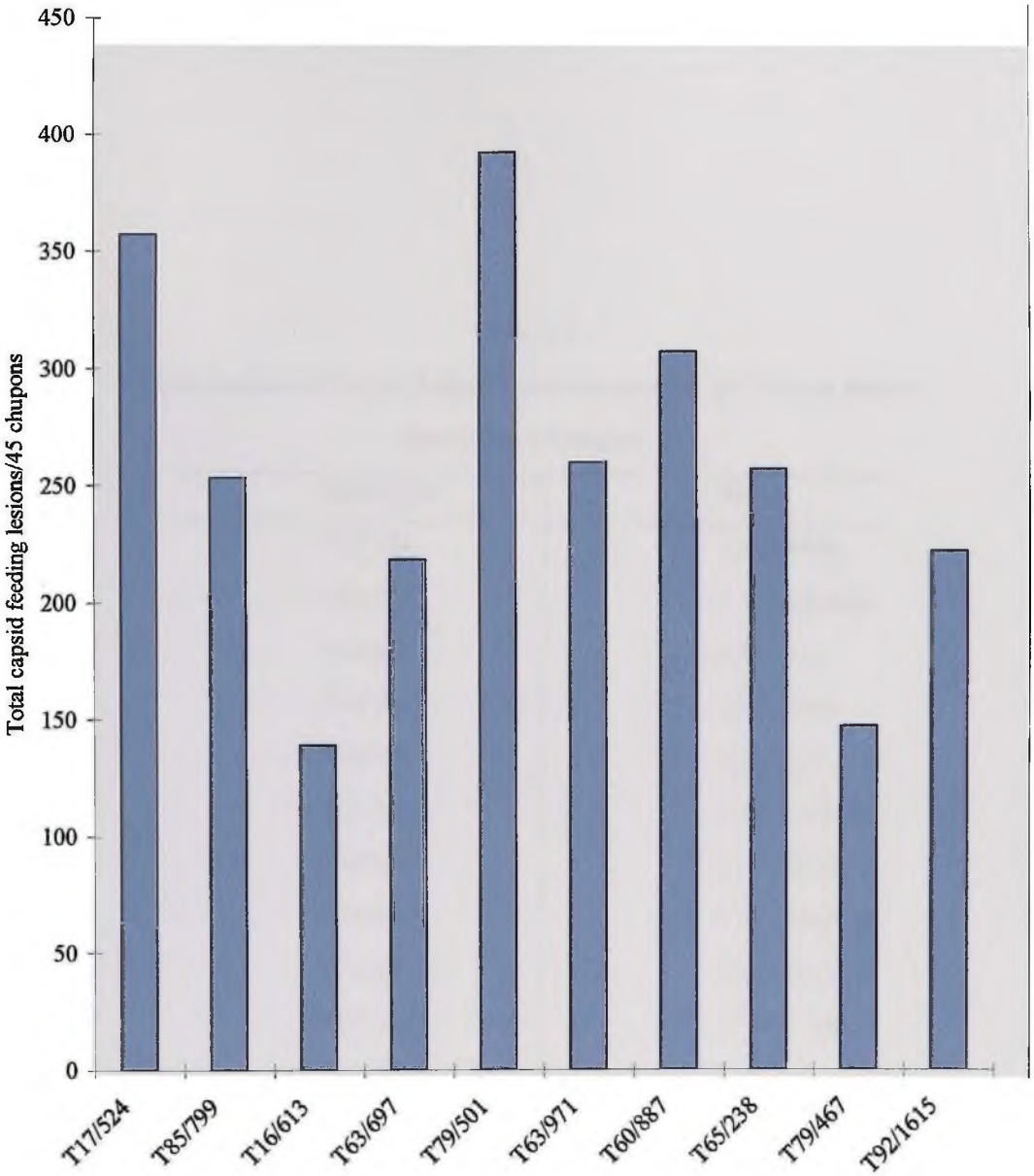

Fig. 4.5 Distribution of capsid feeding lesions/45 chupons on 10 T clones under laboratory conditions

Table 4.4

Mean number of capsid feeding lesions/chupon on 10 T clones under laboratory conditions

Genotype	Mean
T17/524	2.62±.19**de**
T85/799	2.16±.19**abcd**
T16/613	1.75±.12**a**
T63/967	2.09±.15**ab**
T79/501	2.69±.22**e**
T63/971	2.28±.16**bcde**
T60/887	2.38±.20**cde**
T65/238	2.18±.17**abcde**
T79/467	1.81±.11**ab**
T92/1615	2.06±.17**abc**
Grand Mean	2.20

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

45 chupons) were the least preffered.

The most preferred clones among the IMCs were, IMC 68 (306 lesions/45 chupons), IMC 44 (297 lesions/45 chupons), IMC 11 (271 lesions/45 chupons), IMC 47 (255 lesions/45 chupons), IMC 76 (248 lesions/45 chupons) but these were not significantly different from each other ($P>0.05$), (Fig. 4.6, Table 4.5, Appendices 4 & 10). IMC 36 (114 lesions/45 chupons), IMC 5 (122 lesions/45 chupons), IMC 57 (125 lesions/45 chupons), IMC 49 (145 lesions/45 chupons), IMC 23 (156 lesions/ 45 chupons) appeared the least preferred and were not significantly different from each other ($P>0.05$).

4.1.2 Insectary Screening

4.1.2.1 Clones

The trend of capsid preferences for the four clonal populations in the insectary test was similar to that observed in the laboratory microtest screening (Appendices 2,3,4 &5). Differences among the populations were highly significant ($P<0.05$) (Table 4.6, Appendix 11).

The Parinaris (628 lesions/30 seedlings, 6 clones) appeared to be the most preferred and were significantly different ($P<0.05$) from the other three populations. Next were the Ts, (577 lesions/45 seedlings, 9 clones); IMCs, (385 lesions/50 seedlings) and the Nanays (340 lesions/50 seedlings) in that order (Fig. 4.7). Preferences for the IMC and Nanay populations were not statistically different from each other, ($P>0.05$). It must be noted that only six Parinari and nine T clones were tested (due to unavailability) whilst 10 clones each of Nanays and IMCs were screened.

Among the Parinari clones Pa 118 (165 lesions/5 seedlings) appeared to be the most preferred, followed by Pa 121 (130 lesions/5 seedlings) and Pa 107 (125

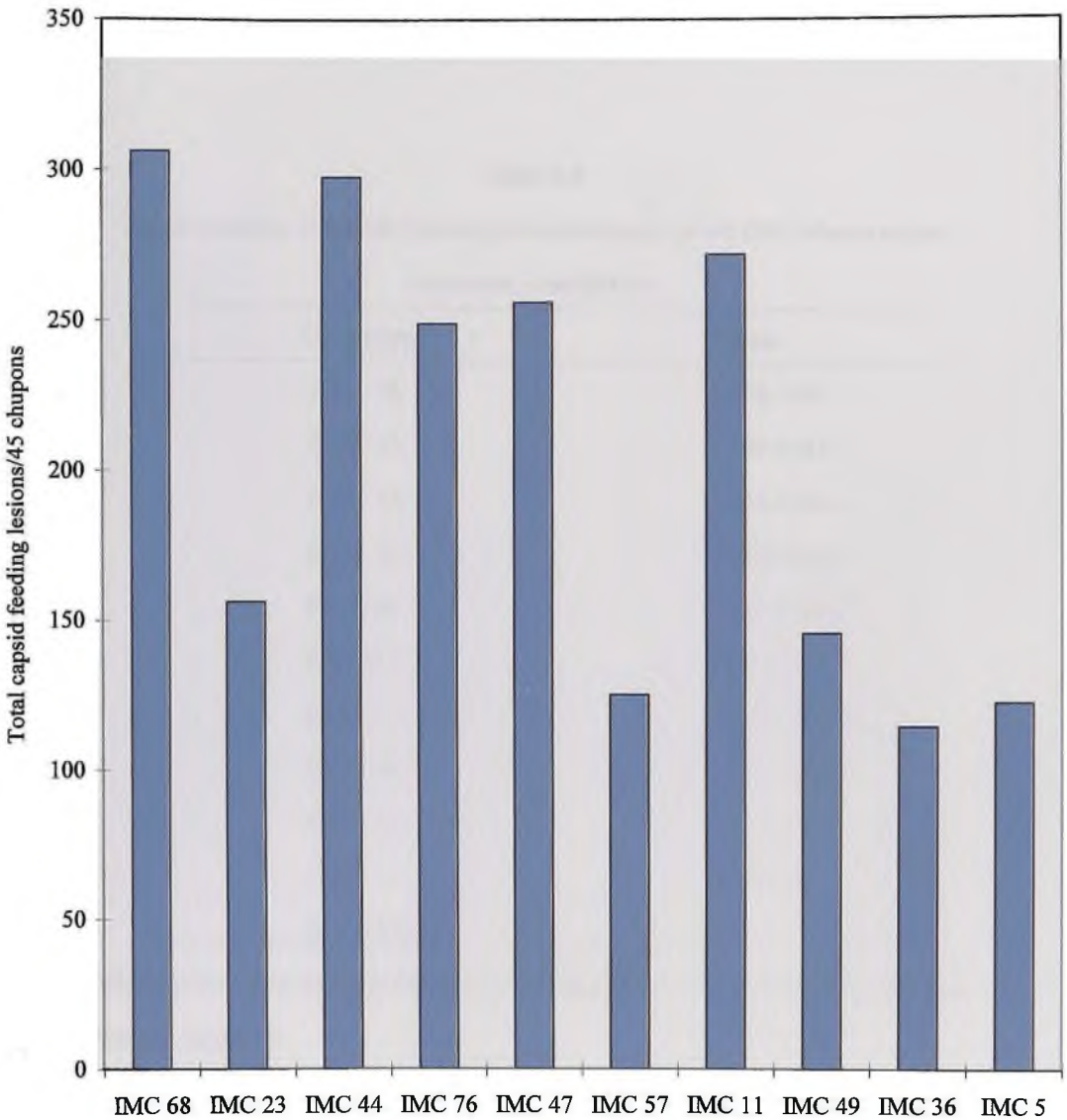

Fig. 4.6 Distribution of capsid feding lesions/45 chupons on 10 IMC clones under laboratory conditions

Table 4.5

Mean number of capsid feeding lesions/chupon on 10 IMC clones under laboratory conditions

Genotype	Mean
IMC 68	2.49±.14**d**
IMC 23	1.76±.14**ab**
IMC 44	2.26±.22**cd**
IMC 76	2.12±.18**bcd**
IMC 47	2.19±.17**bcd**
IMC 57	1.65±.11**a**
IMC 11	2.22±.19**bcd**
IMC 49	1.79±.11**abc**
IMC 36	1.58±.11**a**
IMC 5	1.61±.12**a**
Grand Mean	1.97

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

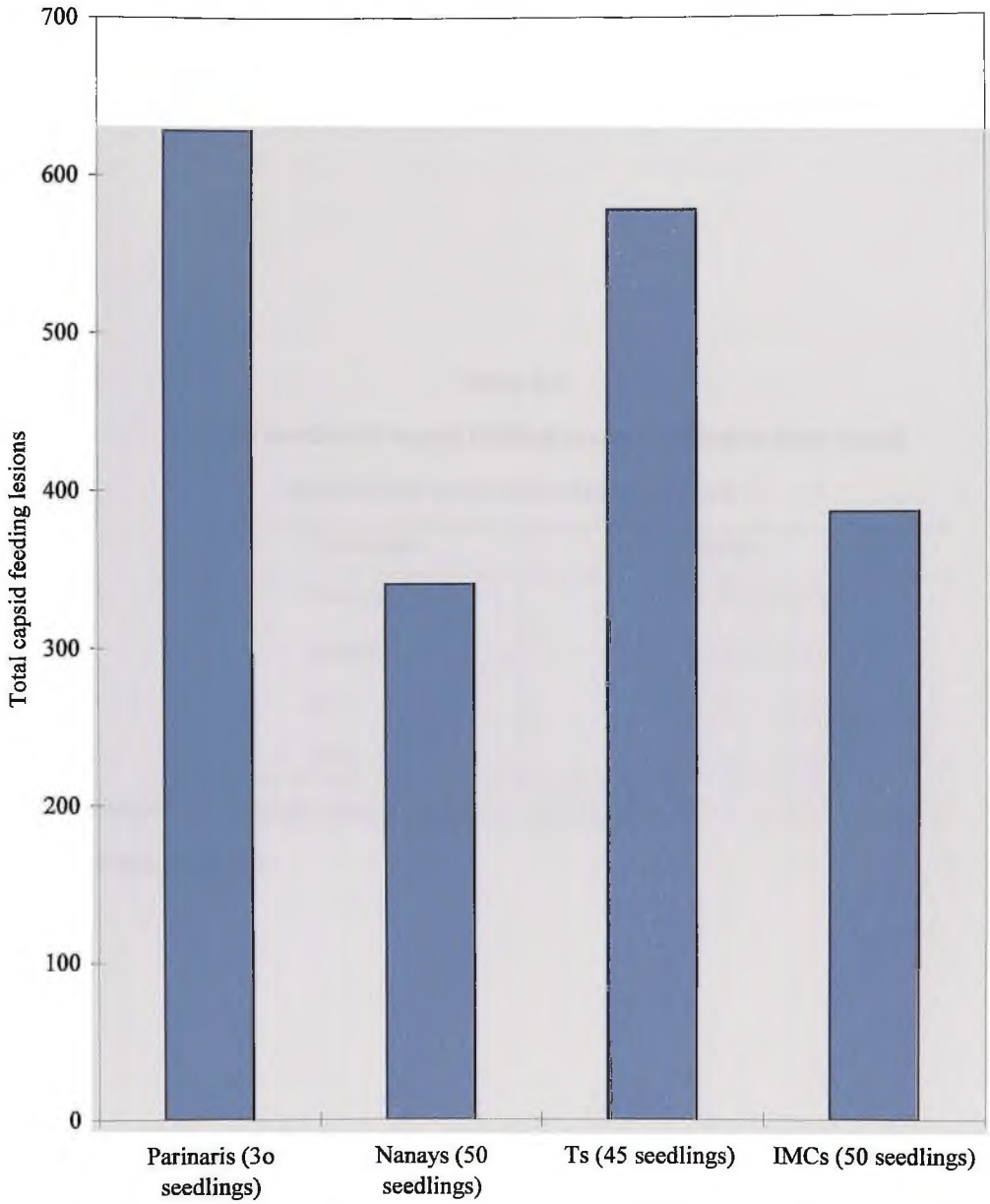

Fig 4.7 Distribution of capsid feeding lesions on four clonal populations under insectary conditions

Table 4.6

Mean number of capsid feeding lesions/seedling on four clonal populations under insectary conditions

Genotype	Mean
Parinaris	4.407 ± 0.185**c**
Nanays	2.626 ± 0.134**a**
Ts	3.515 ± 0.144**b**
IMC	2.735 ± 0.134**a**

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

lesions/5 seedlings) in that other whilst Pa 150 (51 lesions/5 seedlings) appeared to be the least preferred (Fig. 4.8, Appendix 2).

Among the Nanay clones Na 225 (53 lesions/5 seedlings) appeared as the most preferred followed by Na 744 (43 lesions/5 seedlings) and Na 260 (41 lesions/ 5 seedlings) in that order. Na 929 (21 lesions/5 seedlings) and Na 33 (25 lesions/5 seedlings) were the least preferred (Fig. 4.9, Appendix 3).

Among the Ts clones, Ts T17/524 (100 lesions/5 seedlings) followed by T63/ 967 (88 lesions/5 seedlings) were the most preferred whilst T85/799 (44 lesions/5 seedlings) and T92/1615 (45 lesions/5seedlings) and T79/501 (55 lesions/5 seedlings) were the least preferred (Fig. 4.10, Appendix 5). It must be noted here that although T79/501 was among the most preferred clones under laboratory conditions it was among the least preferred under insectary conditions.

IMC 11 (64 lesions/5 seedlings) appeared as the most preferred whilst IMC 57 (21 lesions/5 seedlings) was the least preferred among clones of the IMC population under insectary conditions (Fig. 4.11, Appendix 4). It is also worth noting that IMC 68 which was among the most preferred clones under laboratory conditions (306 lesions/45 chupons) was among the least preferred clones under insectary conditions (33 lesion/5 seedlings).

4.1.2.2 Hybrids

With the hybrids, the IMCs (1,365 lesions/50 seedlings) surprisingly emerged as the most preferred, followed by the Ts (1,195 lesions/50seedlings), then the Parinaris (1,105 lesions/50 seedlings) and the Nanays, (936 lesions/50 seedlings) in that order (Fig. 4.12, Table 4.7, Appendices 2,3,4,5 & 12). Differences in preference between the IMC, Pa and T hybrids were statistically not significant ($P>0.05$). However,

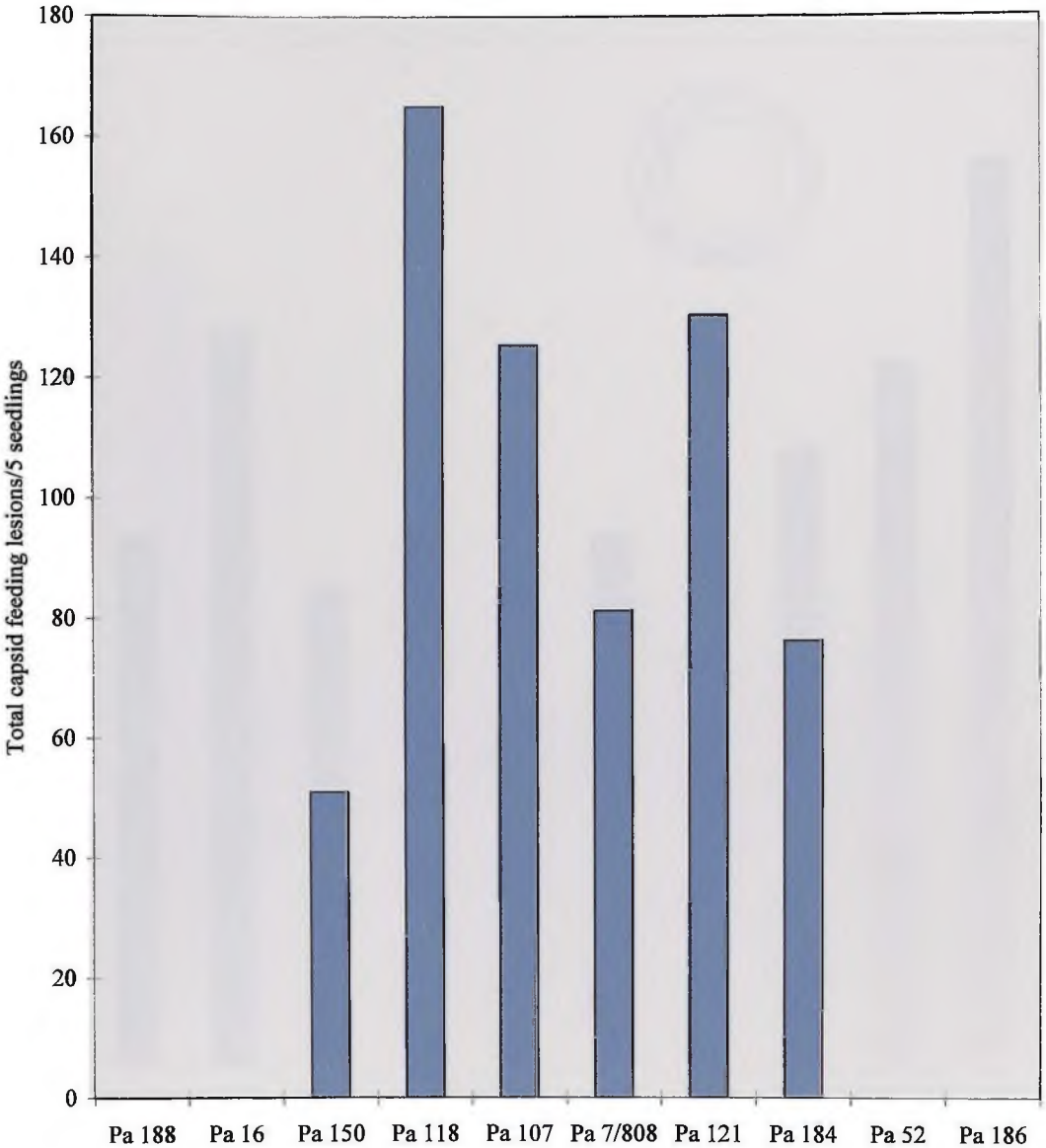

Fig. 4.8 Distribution of capsid feeding lesions/5 seedlings on 6 Parinari clones under insectary conditions

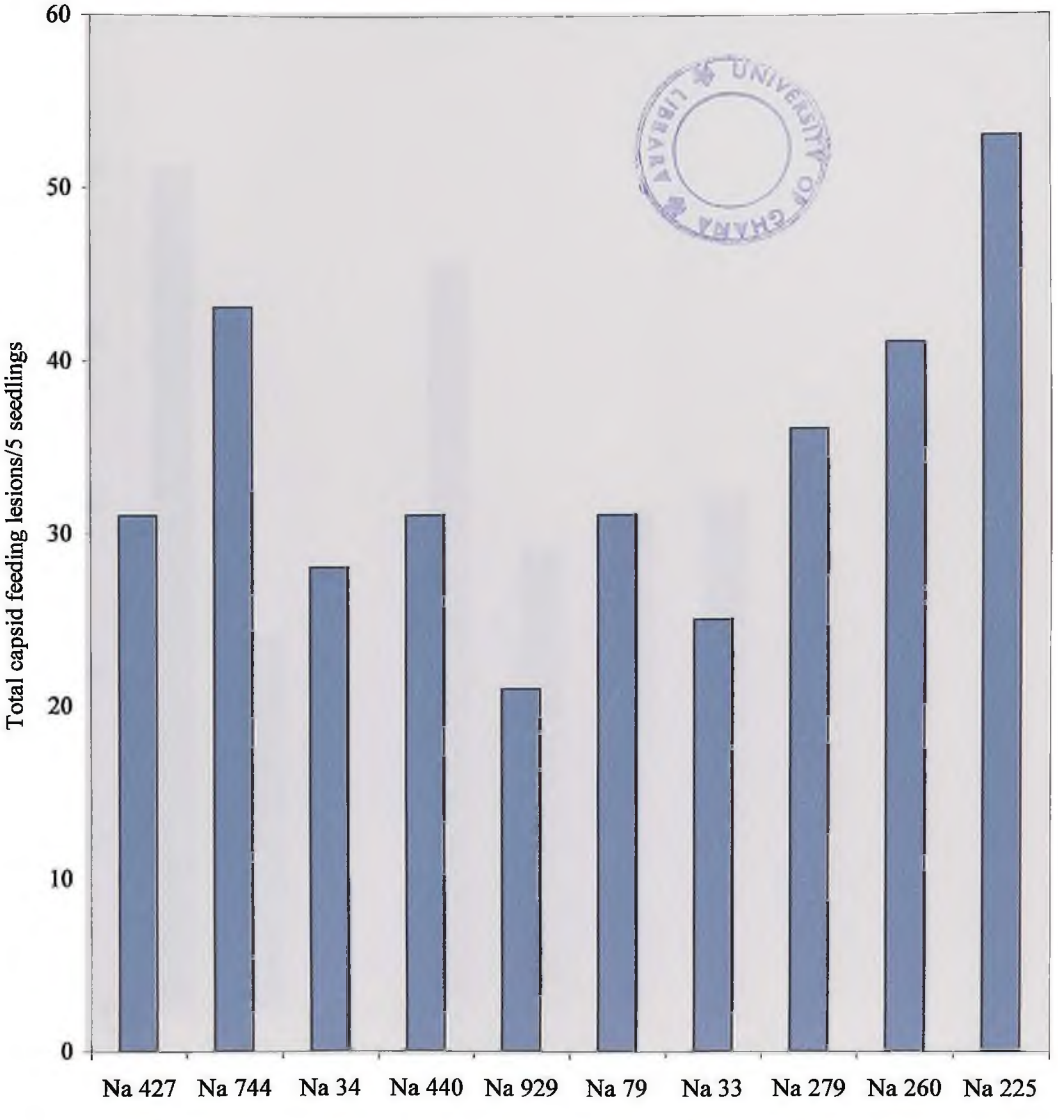

Fig 4.9 Distribution of capsid feeding lesions/5 seedlings on 10 Nanay clones under insectary conditions

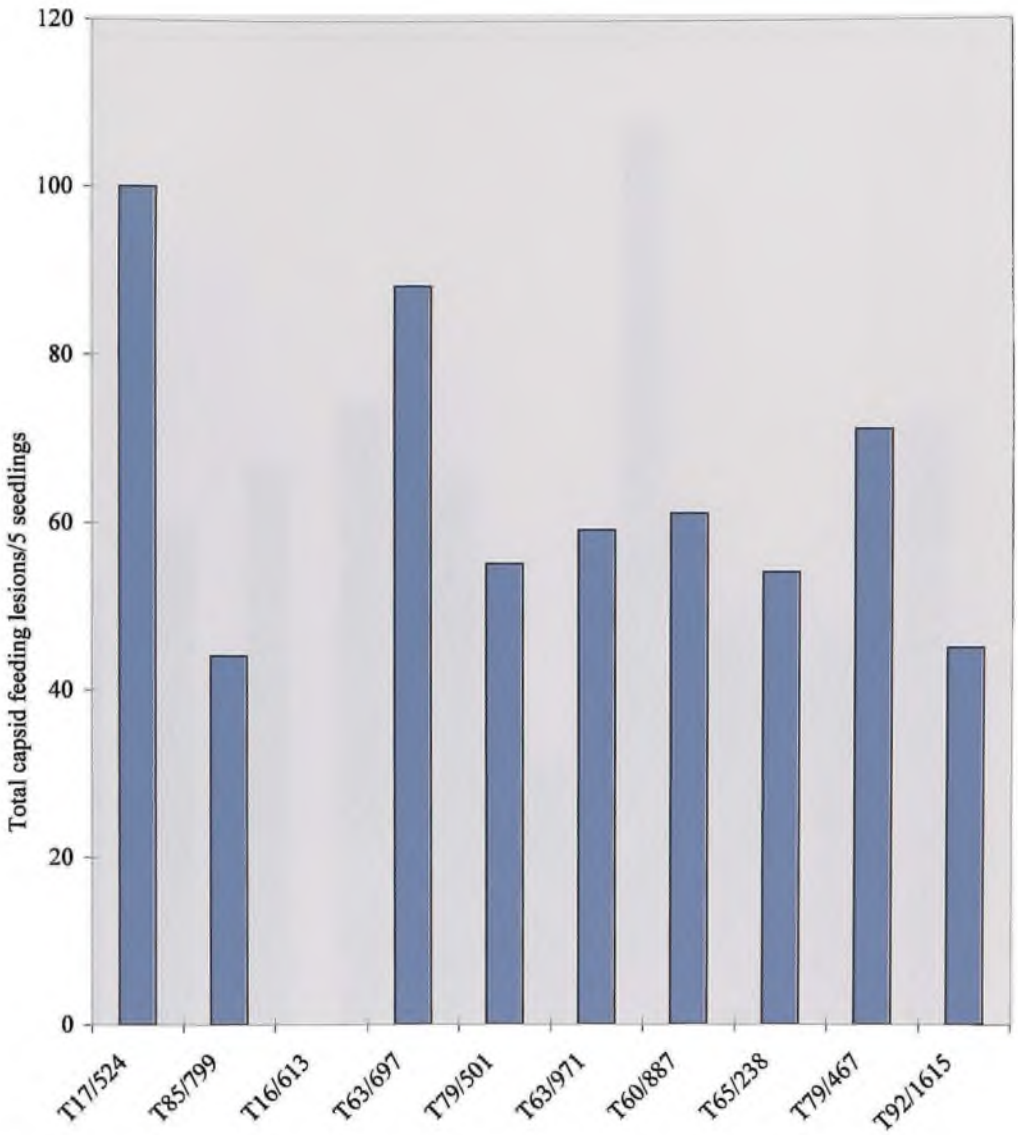

Fig. 4.10 Distribution of capsid feeding lesions/5 seedlings on 9 T clones under insectary conditions

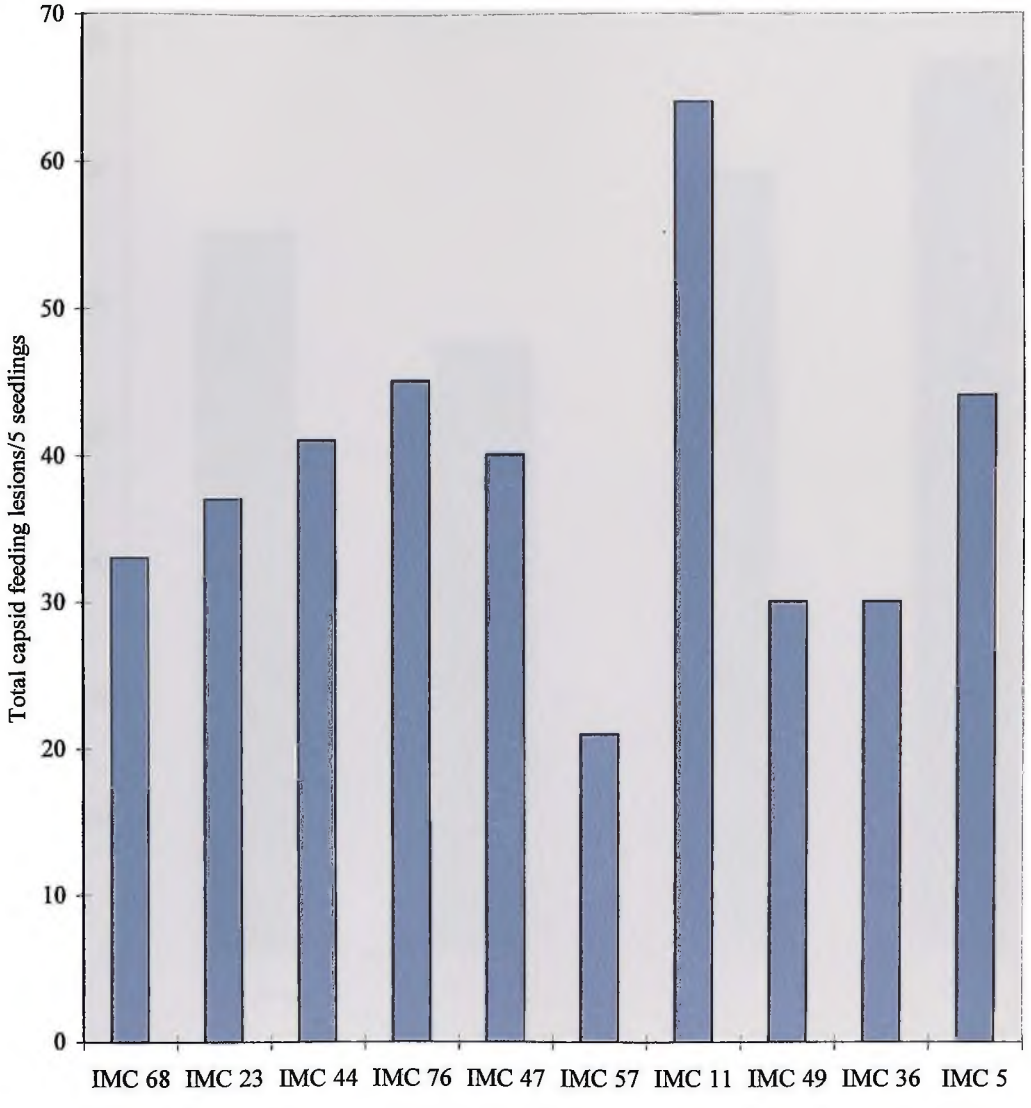

Fig. 4.11 Distribution of capsid feeding lesions/5 seedlings on 10 IMC clones under insectary conditions

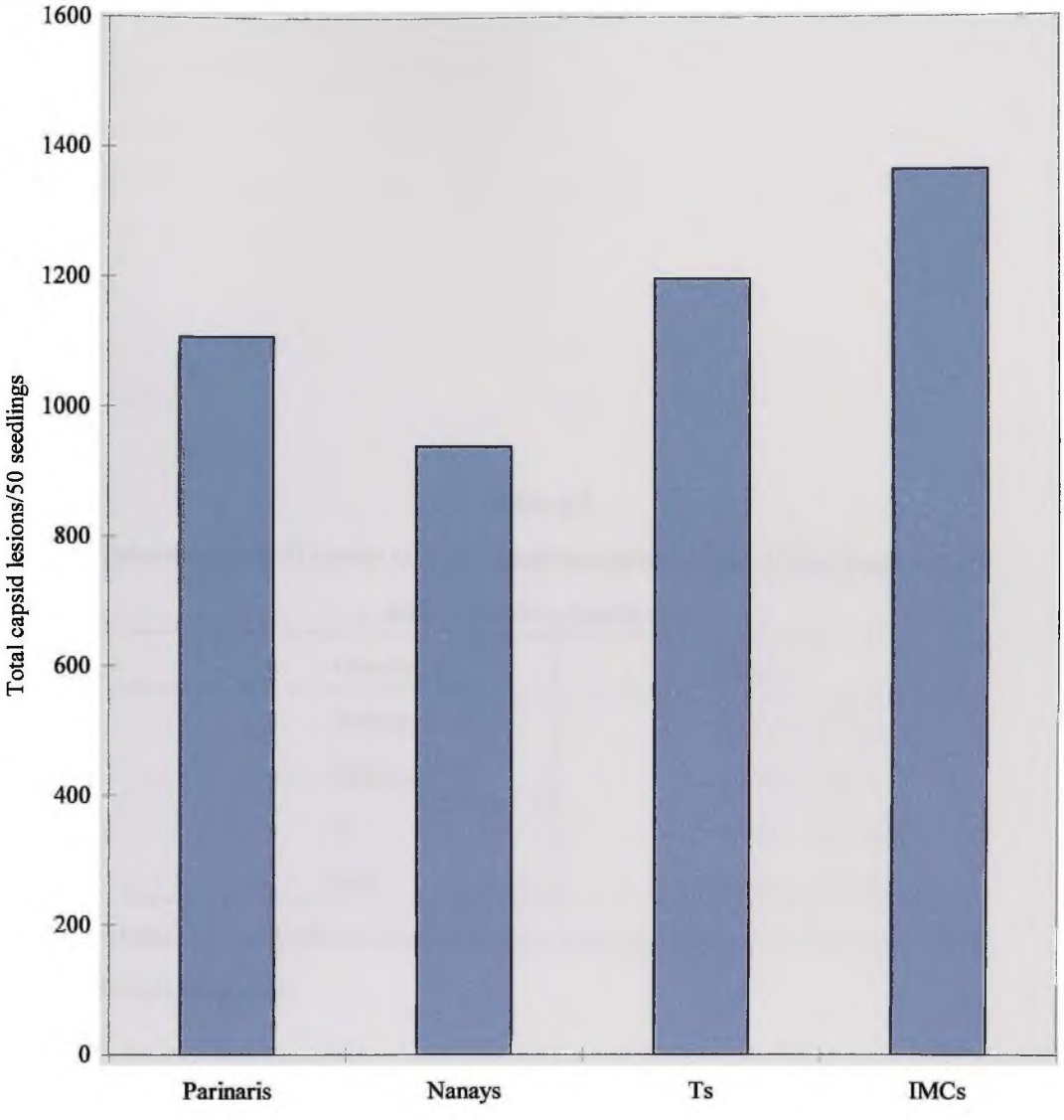

Fig. 4.12 Distribution of capsid feeding lesions/50 sedlings on four hybrid populations (10 varieties per population) under insectary conditions

Table 4.7

***Mean number of capsid feeding lesions/seedling on four hybrid populations under insectary conditions**

Genotype	Mean
Parinaries	4.786 ± 0.212**ab**
Nanays	4.181± 0.212**a**
Ts	4.711 ± 0.212**ab**
IMC	4.996 ± 0.212**b**

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

differences between the IMCs and the Nanays were statistically significant ($P<0.05$). As with the laboratory microtest and the insectary test on clones, the Nanay hybrids were the least preferred. Capsids showed higher preference in all populations for the hybrids than for the clones.

4.1.2.3 Comparison of preference for clones and hybrids in the insectary

The number of capsids lesions were generally higher on hybrids than on the clones in all populations at the insectary.

With the exception of Pa 118 (clones 165 lesions/5 seedlings, hybrids 129 lesions/5 seedlings) and Pa 121 (clones 130 lesions/5 seedlings, hybrids 57 lesions/5 seedlings) all Parinari hybrids were better preferred than their counterpart clones (Fig. 4.13, Appendix 2).

Among the Pa hybrids, Pa 52 x Na 33 (196 lesions/5 seedlings) emerged as the most preferred followed by Pa 107 x IMC 76 (152 lesions/5 seedlings) and Pa 188 x T16/613 (146 lesions/5 seedlings) whilst Pa 121 x T16/613(57 lesions/5 seedlings) was the least preferred. It is important to note that Pa 107 was consistently preferred under laboratory and insectary conditions for both clones and hybrids.

All the Nanay hybrids were better preffered than their counterpart clones (Fig. 4.14). Na 427 x T16/613 (155 lesions/5 seedlings) followed by Na 744 x Pa 7/ 808 (147 lesions/5 seedlings) appeared as the most preferred whislt Na 34 x IMC 76 (54 lesions/5 seedlings) appeared as the least preferred.

For T hybrids, with the exception of T17/524 x IMC 76 (98 lesions/5 seedlings, clones 100 lesions/5 seedlings) and T65/238 x Na 33 (52 lesions/5 seedlings, clones, 54 lesions/5 seedlings), among which the number of lesions on clones and hybrids did not differ much, all hybrids were better preffered than their counterpart clones.

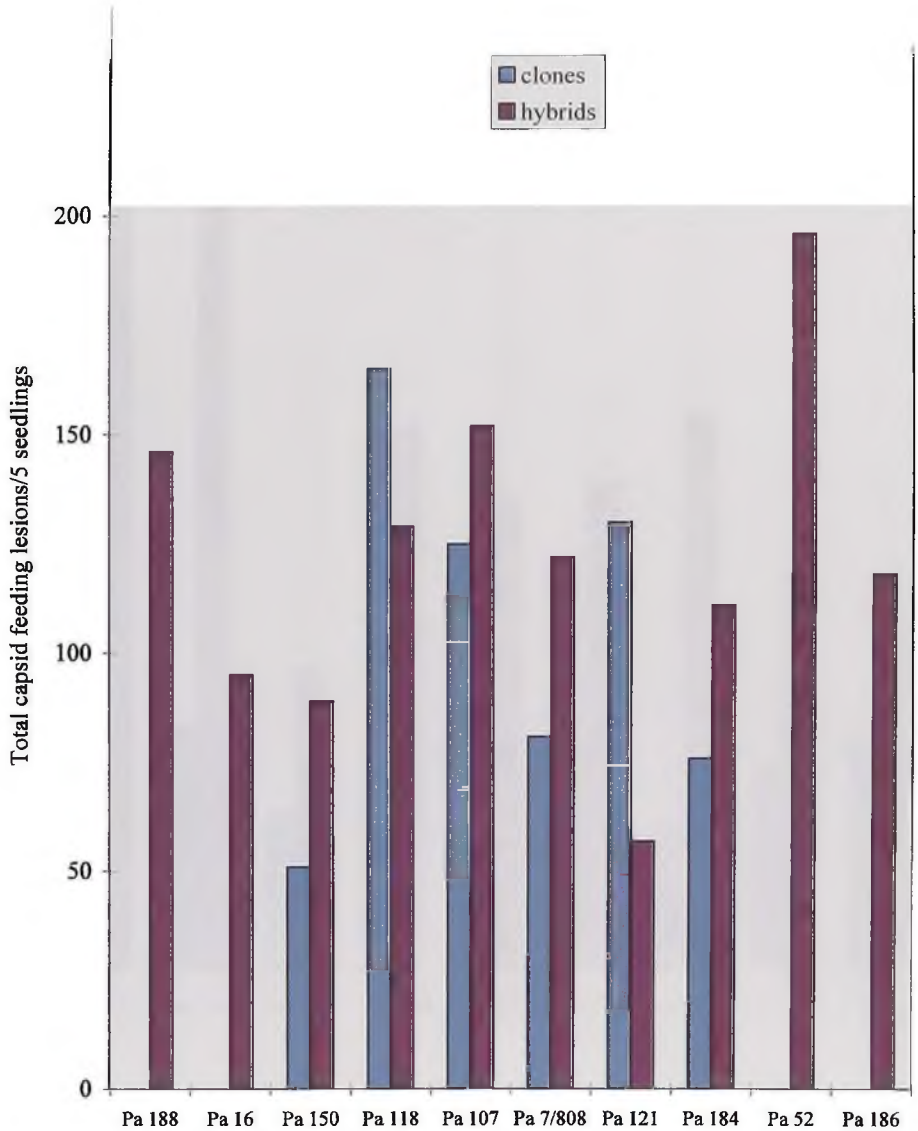

Fig 4.13 Comparison of capsid feeding lesions on Parinari clones and hybrids under insectary conditions

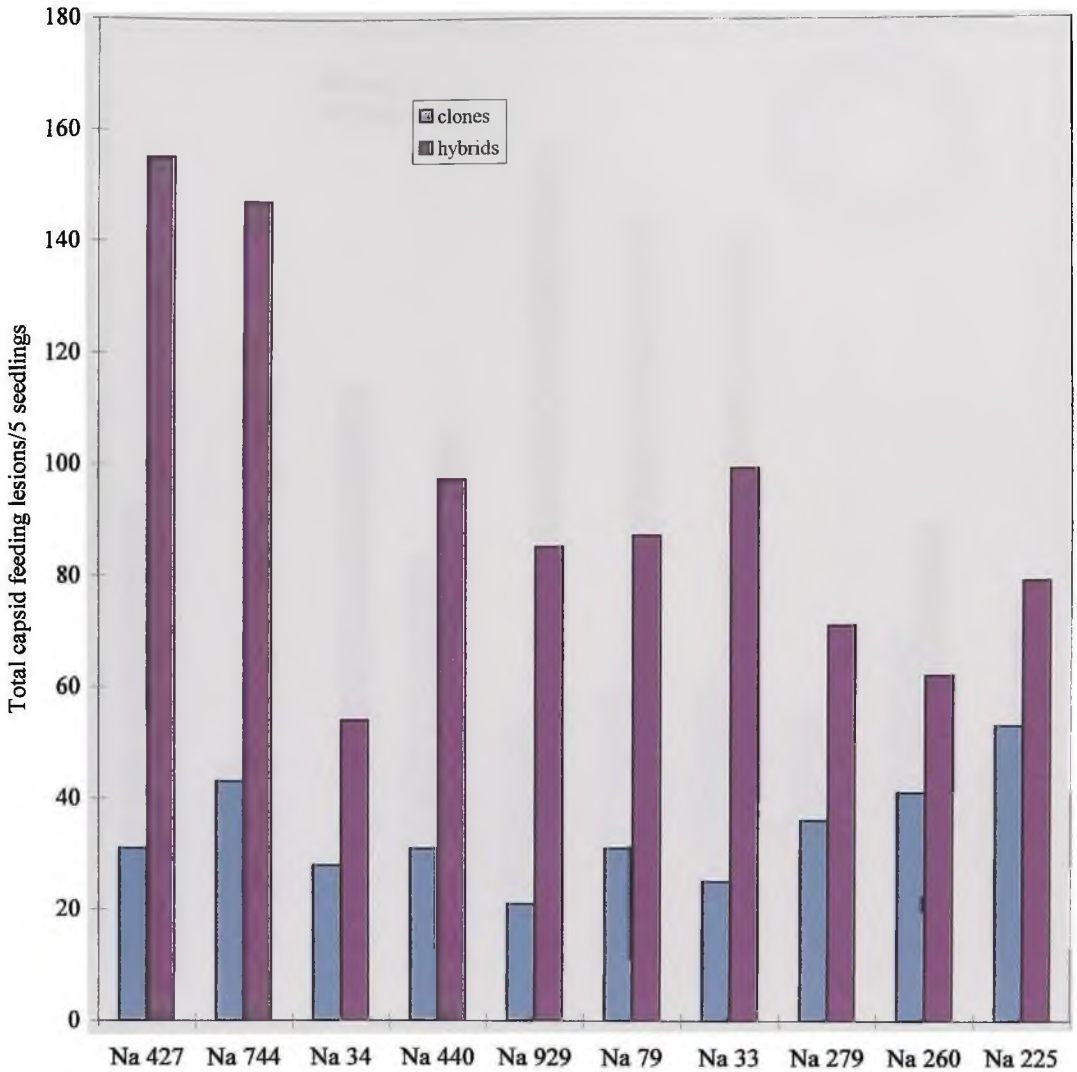

Fig. 4.14 Comparison of capsid feeding lesion/5 seedlings on Nanay clones and hybrids under insectary conditions

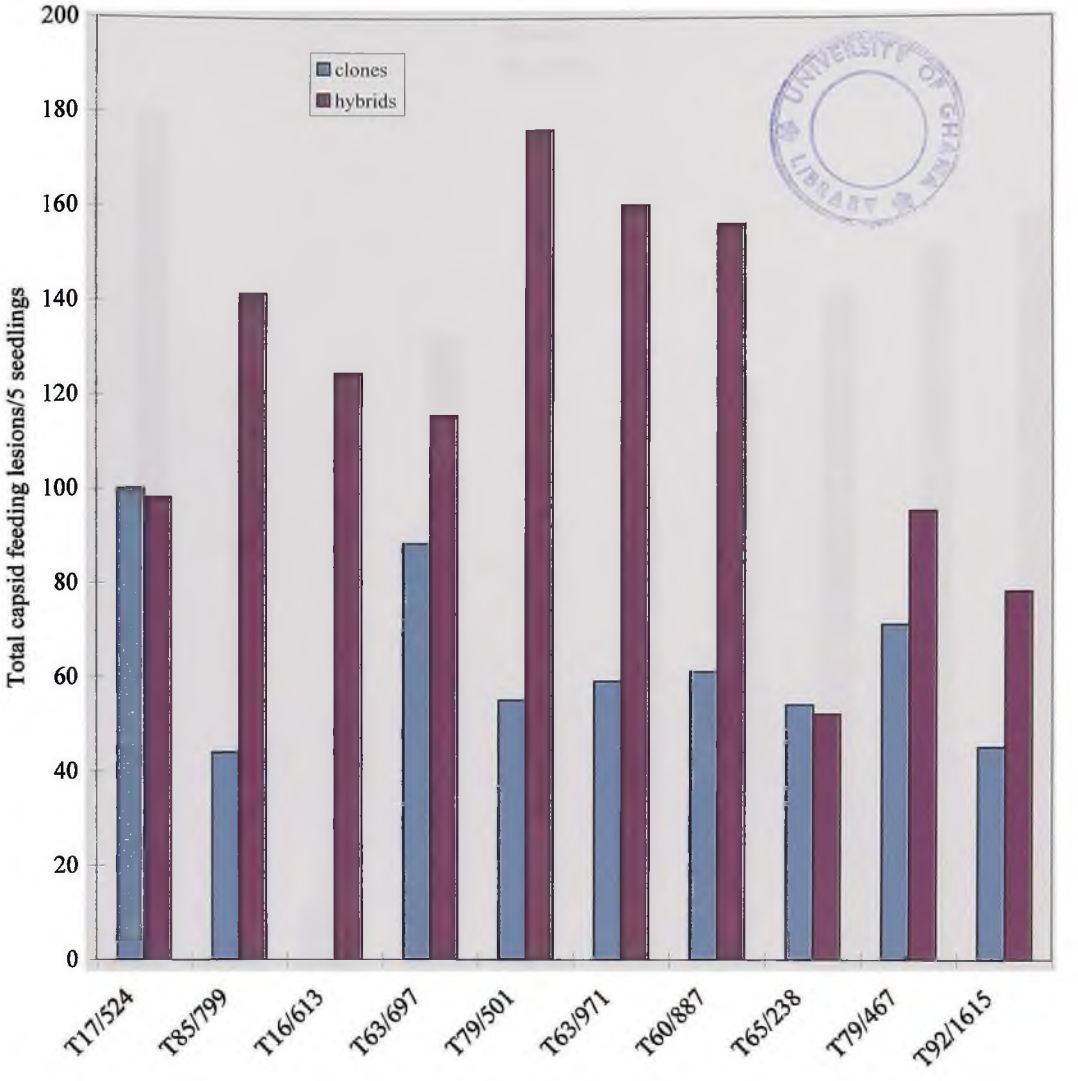

Fig. 4.15 Comparison of capsid feeding lesions/5 seedlings on T clones and hybrids under insectary conditions

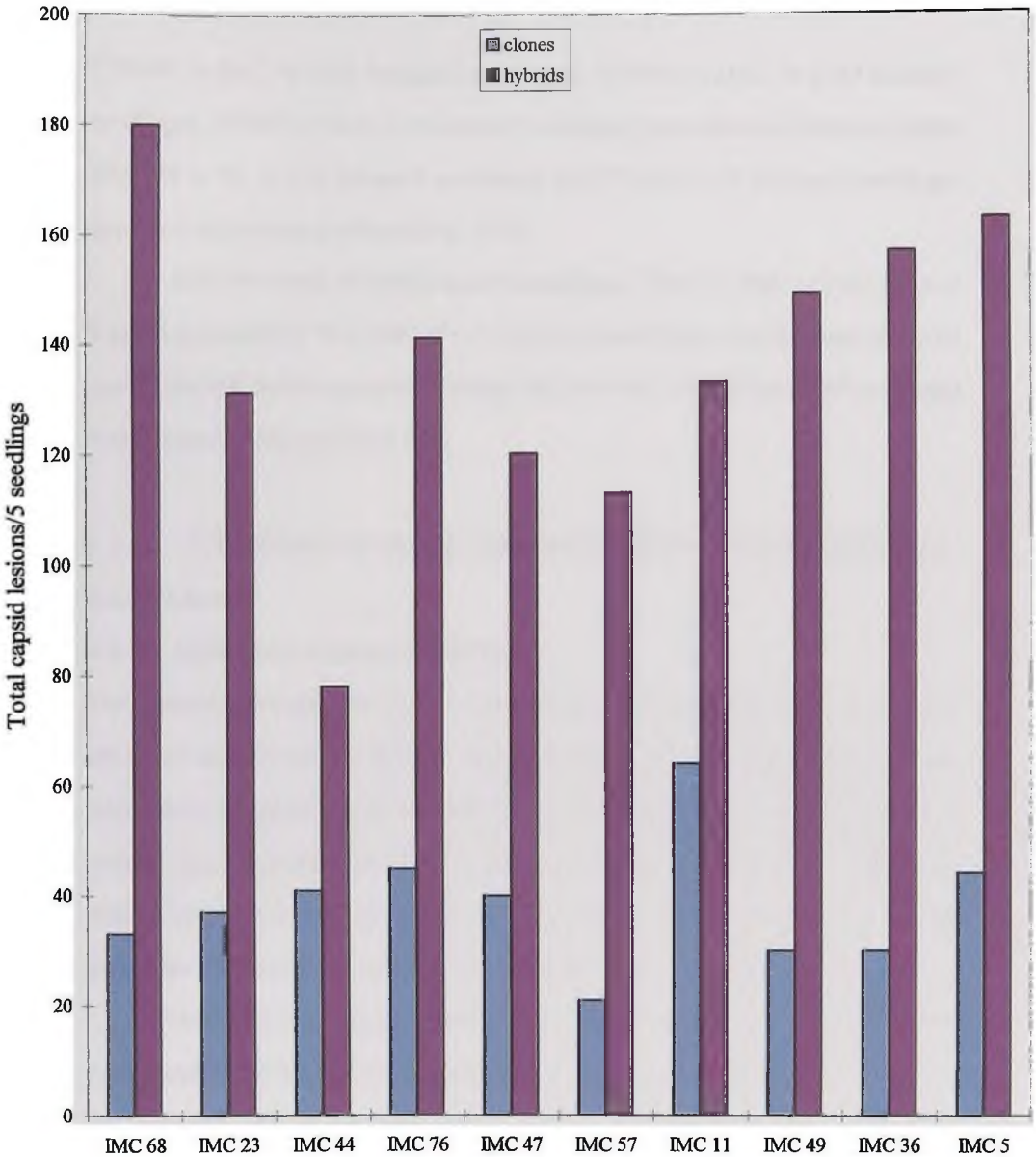

Fig. 4.16 Comparison of capsid feeding lesions/5 seedlings on IMC clones and hybrids under insectary conditions

T79/501 x IMC 76 (176 lesions/5 seedlings), T63/971 x IMC 76 (160 lesions/5 seedlings), T60/887 x Na 33 (156 lesions/5 seedlings) were the most preferred whilst T65/238 x Na 33 (52 lesions/5 seedlings) and T92/1615 (78 lesions/5 seedlings) appeared as the least preffered (Fig. 4.15).

IMC 68 x IMC 49 (180 lesions/5 seedlings), IMC 5 x IMC 11 (163 lesions/ 5 seedlings) and IMC 36 x IMC 47 (157 lesions/5 seedlings) were the most preferred among the IMC hybrid population whilst IMC 44 x IMC 49 (78 lesions/25 seedlings) was the least preferred (Fig.4.16).

4.2 SCREENING OF SEEDLINGS UNDER SEMI-FIELD CONDITIONS

4.2.1 Clones

4.2.1.1 Differences among Populations

The Parinaris recorded the largest mean increment in height (25.8cm) within the period of eight weeks and differed significantly ($P<0.05$) from the remaining three populations but among the Nanays (5.9cm), Ts (8.9cm) and IMCs (9.5cm), there were no significant differences ($P>0.05$) in height increases among clones in the three populations (Table 4.8, Appendix 13). With a few exceptions, there were high significant differences ($P<0.05$) between treatment and control plants.

Mean girth increments were also largest (2.5cm) in the Parinaris which differed significantly ($P<0.05$) from the Nanays (1.4cm), Ts (1.8cm) and IMCs (1.8cm) (Table 4.9, Appendix 14). As was the case with height increment there were no significant differences in girth among clones within the four populations. Also as observed with height increments, the treated and control plants differed significantly ($P<0.05$) with respect to girth increments except in a few cases.

Table 4.8

Mean height increments among clonal populations under semi-field conditions

Genotype	Mean (cm)
Parinaries	25.825 ± 3.305**b**
Nanays	5.880 + 2.393**a**
Ts	8.898 ± 2.585**a**
IMCs	9.500 ± 2.393**a**

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

Table 4.9

Mean girth increments among clonal populations under semi-field conditions

Genotype	Mean (cm)
Parinaris	2.475 ± 0.359**b**
Nanays	1.452 ± 0.260**a**
Ts	1.8167 ± 0.281**ab**
IMCs	1.835 ± 0.260**ab**

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

4.2.1.2 Clonal differences within populations

With the exception of the Parinaris, height and girth increments between treated and control plants of the clonal materials, were statistically significant ($P<0.05$) in all populations (Appendices 15, 16). Control plants in the Parinaris performed better except Pa 118 in which the treated plants did better than the control, though these differences were not statistically significant (Fig. 4.17). Height and girth increments seemed to have been equally affected by capsid injury among the Nanay clones. Treated plants differed significantly from their controls ($P<0.05$) except in Na 440 (Fig. 4.18, Appendices 17, 18) where both height and girth of treated plants did better than their controls. It interesting to note that no treated plant did better in height or girth than the control in the T popluations screened (Fig. 4.19). There were very high significant differences ($P<0.001$) between treated and control plants (Appendices 19, 20). The treated and control plants in the IMCs were not different from the Ts in their sensitivity to capsid damage for both height and girth. Except for IMC 47 in which the girth treatment was higher than the control, girth increments in treated plants were significantly lower ($P<0.05$) than in their controls (Fig 4.20, Appendices 21, 22).

4.2.1.3 Dead Plants

Dead plants were recorded in all clonal populations (Table 4.10). As much as 68% of Ts clonal seedlings died two weeks after exposure to capsid in the field whilst 8% of control plants died. It is interesting to note that although the Parinaris were the most preferred clones in the insectary they recorded the lowest number of dead plants (33%). Untreated seedlings of the Nanay clones recorded the highest death (28%) whilst no untreated plant of the Parinari clones died (Appendices 23, 24, 25, 26).

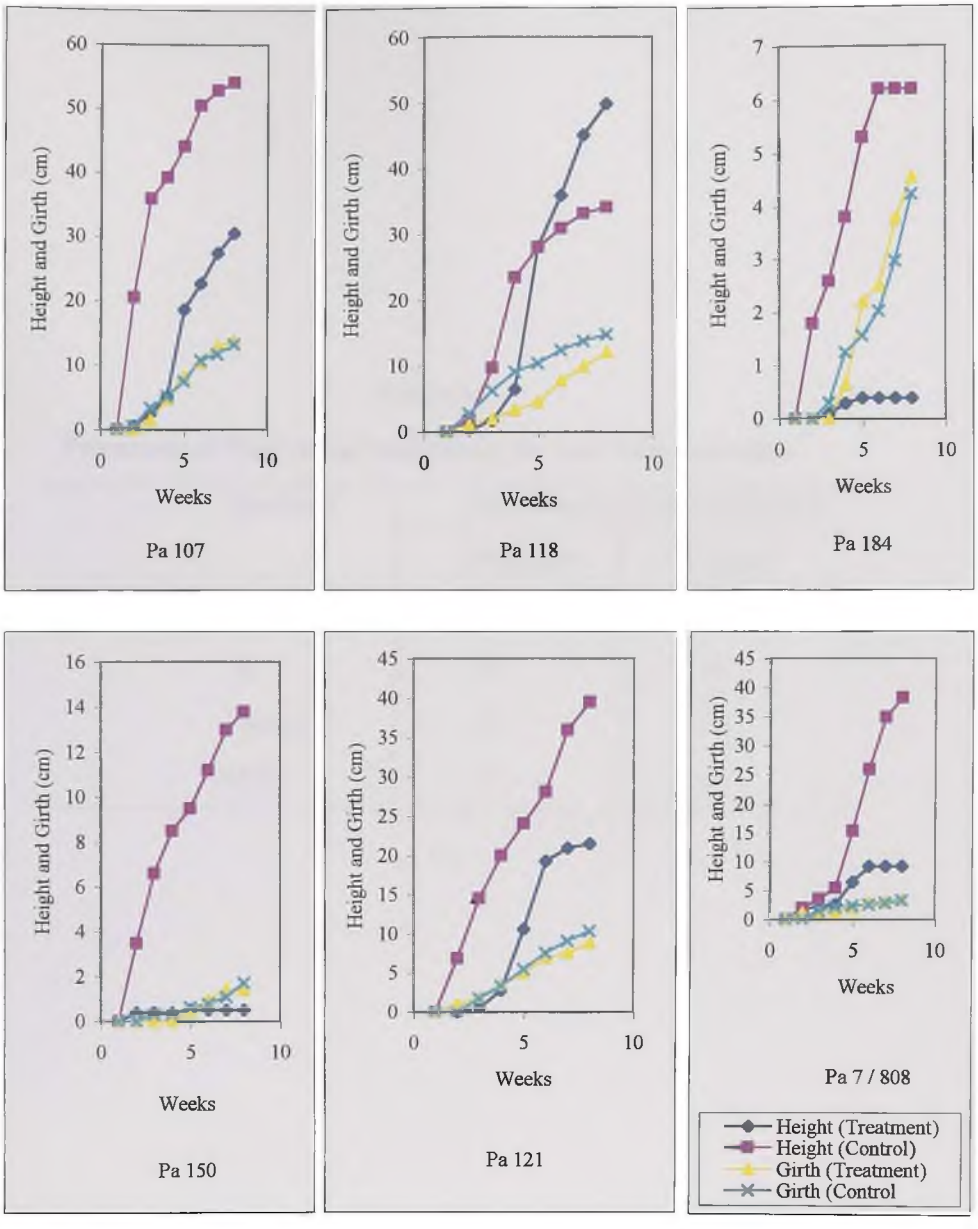

Fig 4.17: Growth curves for the Parinari Clones under semi-fied conditions

Table 4.10

Percentage of dead clonal seedlings under semi-field conditions

Genotype	Percentage (%) of dead plants	
	Treatment	Control
Parinaris	33	0
Ts	68	8
Nanays	42	28
IMCs	36	10

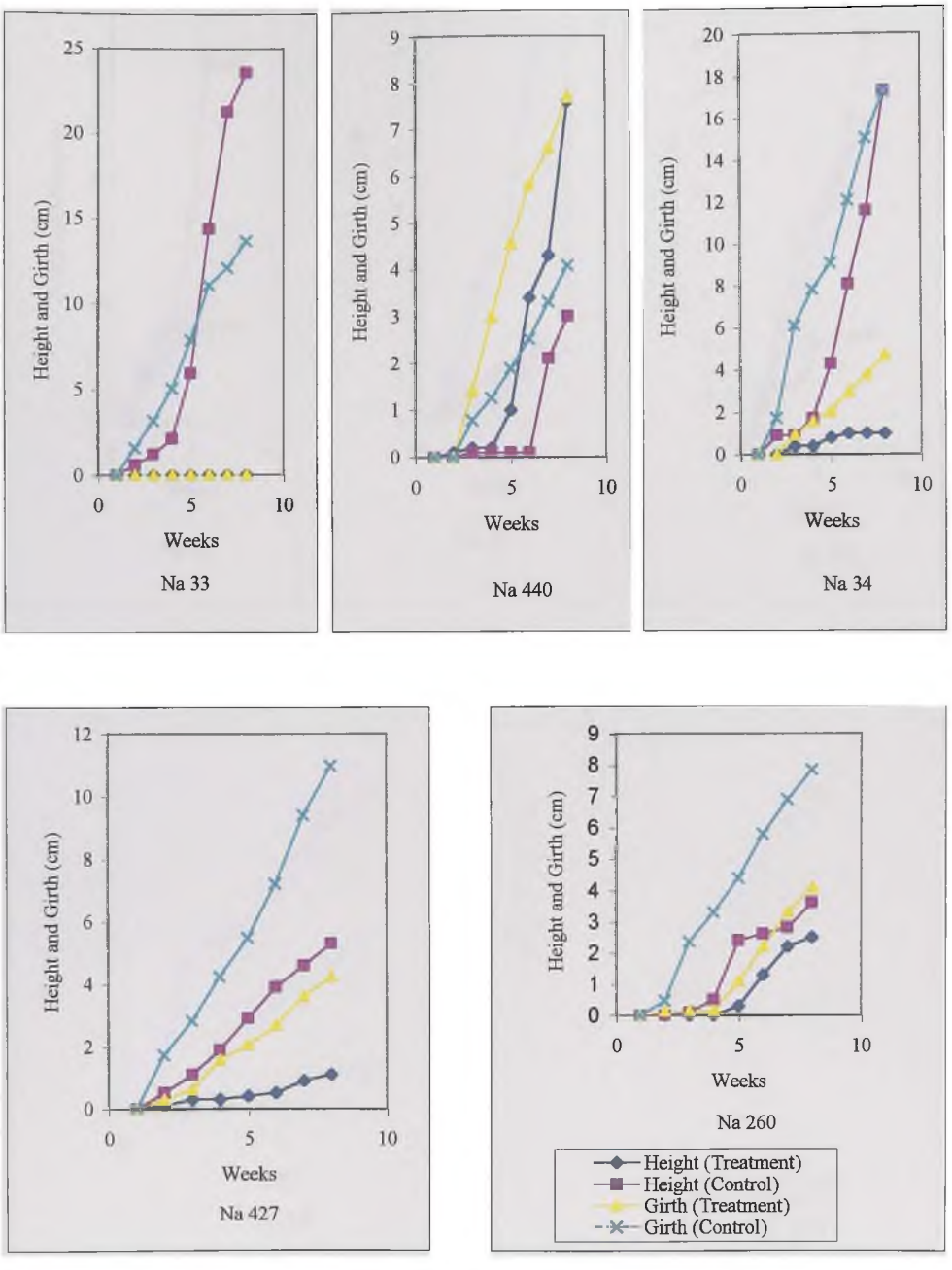

Fig 4.18a: Growth curves for the Nanay Clones under semi-field conditions

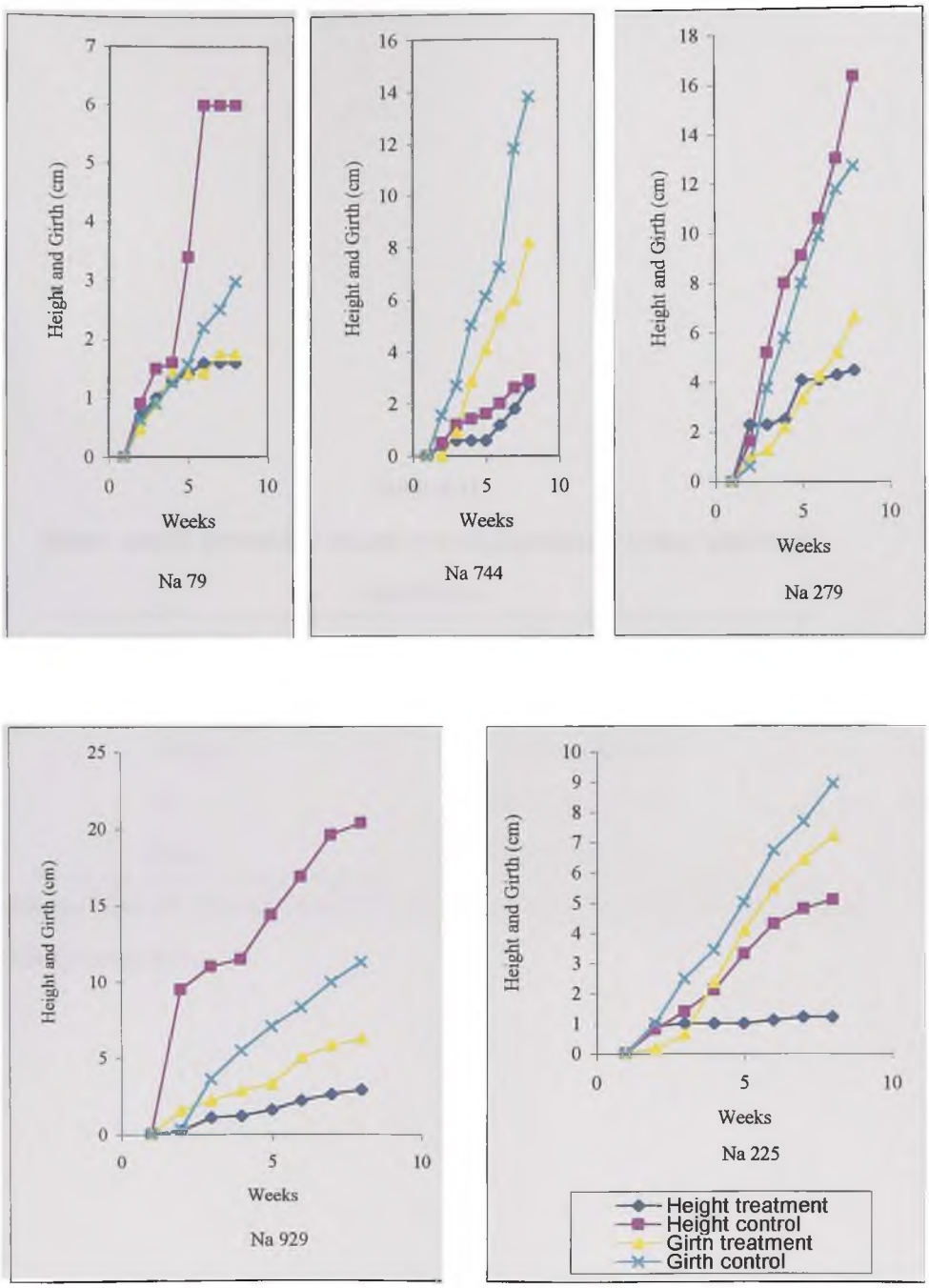

Fig 18b: Growth curves for Nanay Clones under semifield conditions (continued)

Table 4.11

Mean height increments among hybrid populations under semi-field conditions.

Genotype	Mean (cm)
Parinaries	27.689 ± 2.502 **b**
Nanays	32.074 ± 2.502 **b**
Ts	28.964 ± 2.502 **b**
IMC s	19.279 ± 2.502 **a**

* Means followed by the same letter(s) do not differ significantly at P<0.05 by Duncan's Multiple range test.

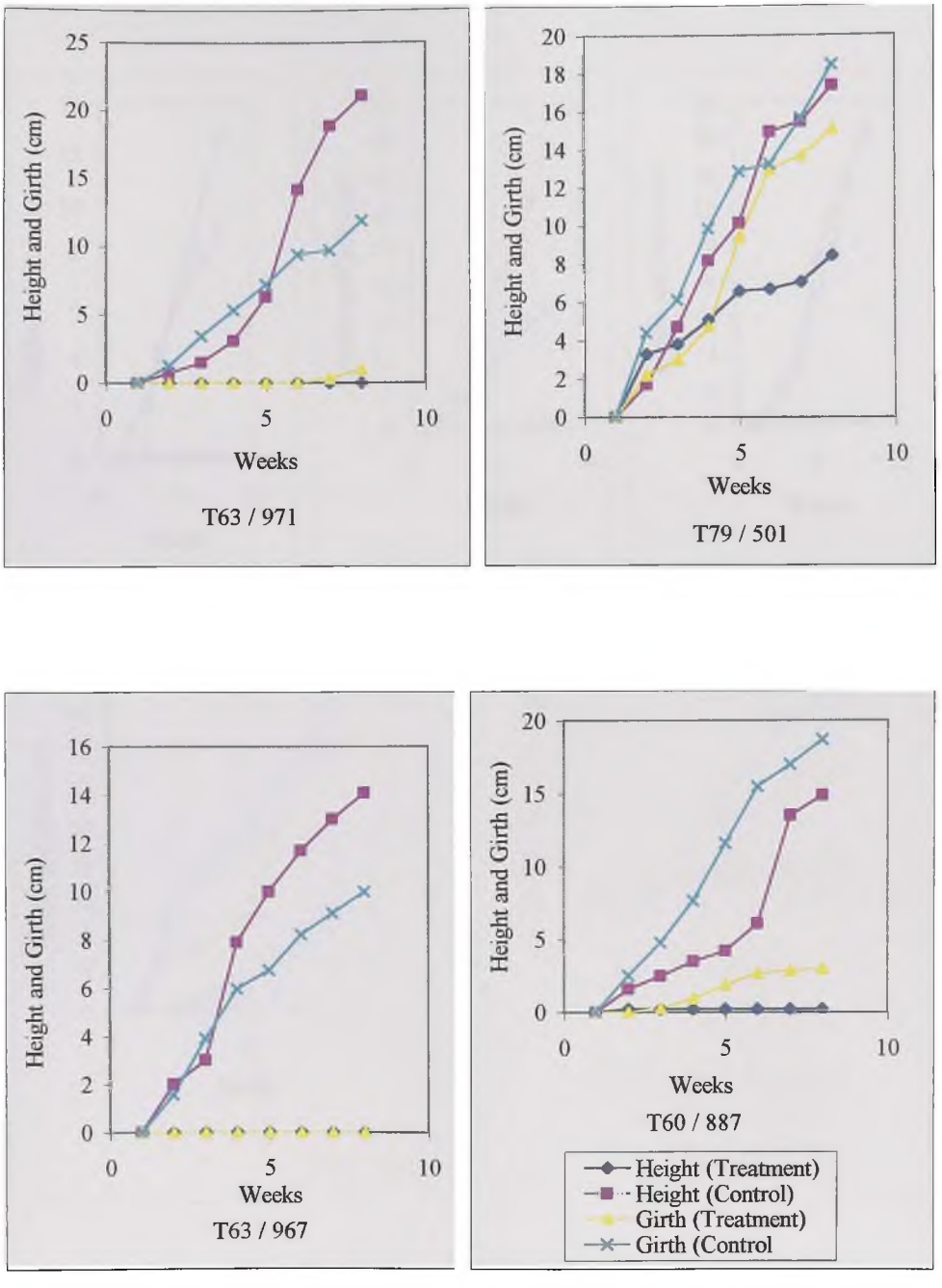

Fig 19a: Growth curves for T clonesunder semi-field conditions

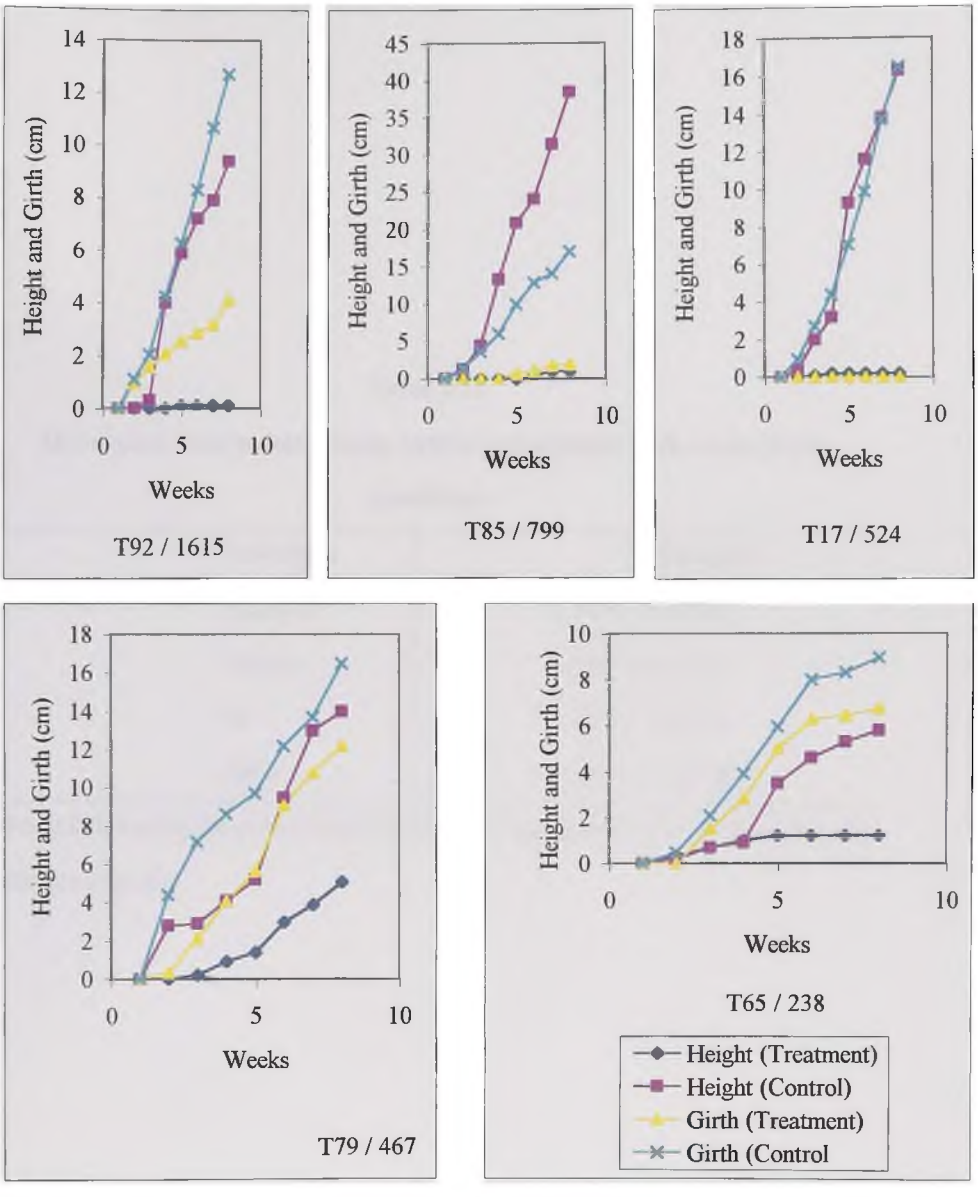

Fig 4.19b: Growth curves for the T clones under semi-field conditions (continued)

Table 4.12

Mean girth increments among hybrid populations under semi-field conditions

Genotype	Mean (cm)
Parinaris	2.800 ± 0.122 **b**
Nanays	2.870 ± 0.122 **b**
Ts	2.357 ± 0.122 **a**
IMCs	2.590 ± 0.122 **ab**

* Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test.

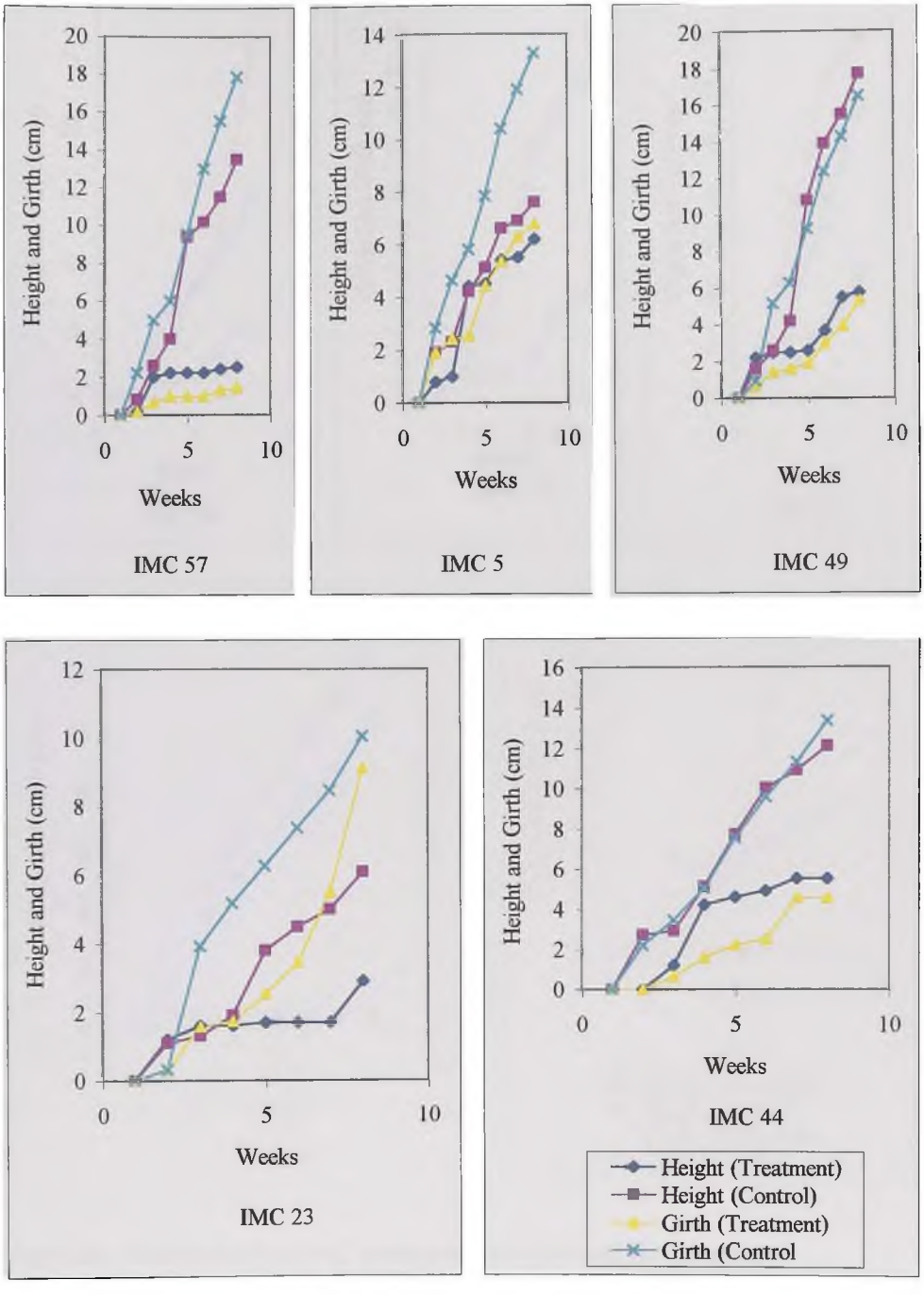

Fig 4.20a: Growth curves for IMC Clones under semi-field conditions

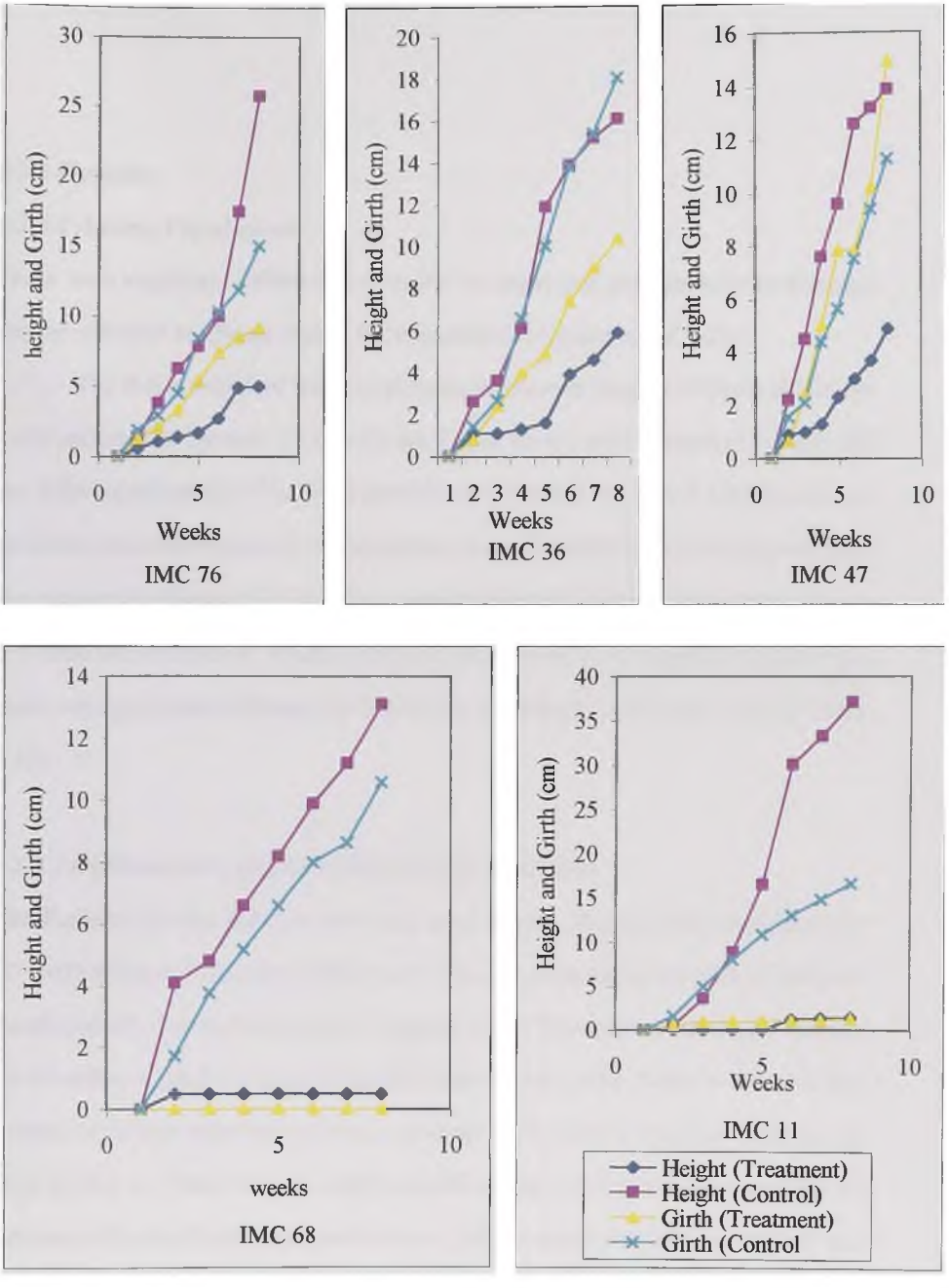

Fig 4.20b: Growth curves for IMC clones under semi-field conditions (continued)

4.2.2 Hybrids

4.2.2.1 Among Populations

There were significant differences ($P<0.05$) in height and girth between treated and untreated hybrid seedlings among the populations (Appendices 27, 28).

The IMCs exhibited the lowest mean increase in height (19.3cm) within the study period. The Nanays (32.07cm), the Ts (28.96cm) and Parinaris (27.69cm) did not differ significantly ($P>0.05$) in growth rate (Table 4.11). The T hybrids showed the lowest increase in girth (2.36cm) during the study period but the increments were not statistically different ($P>0.05$) from increments in the IMCs (2.59cm). The Nanays (2.87cm) and Parinaris (2.80cm) had the highest increments in girth but these were again not significantly different ($P>0.05$) from increments in the IMC hybrids (Table 4.12).

4.2.2.2 Differences in growth within hybrid populations

The Parinari hybrids did not show any significant within-population differences ($P>0.05$) in height increment, neither were there any significant differences between the treated and control hybrid plants (Appendix 29). This implies that capsid damage did not affect growth in height of the Parinari hybrids in this study despite the high number of lesions recorded on them, an observation which was also made on the Parinari clones. There were no significant differences in girth increments among the hybrids within the Parinari population but girth increases between the treated and control plants were statistically different ($P<0.05$) (Appendix 30). It was only in Pa 52 x Na 33 where both height and girth of treated seedlings were greater than in the control plants (Fig. 4.21).

The Nanay hybrids showed no significant differences in height increments within the population but, there were significant differences ($P<0.05$) between treated and control plants (Appendix 31). Girth increments were also not significantly different among the Nanay hybrids but the treated and control plants showed significant differences ($P<0.05$) as also observed in height (Appendix 32). In all cases for both height and girth in the Nanay hybrid population, the control plants performed better than the treated plants (Fig. 4.22).

The IMC hybrids also exhibited no significant differences ($P>0.05$) in height and girth inrements withtin the population (Fig. 4.23, Appendices 33, 34). There were no significant differences in height between the treated and control plants despite the fact that IMC hybrids recorded the highest number of capsid lesions in the insectary. This is an indication that the treated plants had the capacity to outgrow capsid damage.

Increments in height, but not in girth were significantly different ($P<0.05$) among the T hybrids (Table 4.13, Fig.4.24, Appendices 35, 36). The treated and control plants, however, showed significant differences ($P<0.05$) in girth but not in height increments. Thus, it seems that T hybrids responded differently to capsid attack with respect to height increments (Table 4.14). T65/238 x Na33 which attracted the lowest number of capsid lesions (52 lesions/5 seedlings) in the insectary recorded the highest height increment (45.8cm) in the field and was not significantly different from four others which came out as the most tolerant among the T hybrids. It is also interesting to note that T79/501 x IMC 76 which recorded the highest number of capsid lesions (176 lesions/5 seedlings) among the T hybrids in the insectary did not differ statistically, ($P>0.05$), in height (31cm) from T65/238 x Na33 which recorded the highest height increment. The poor performance of T17/524 x IMC 76 (13.6cm) and T92/1615 x Na 33 (16.45cm) in the current study appears to have aslo been

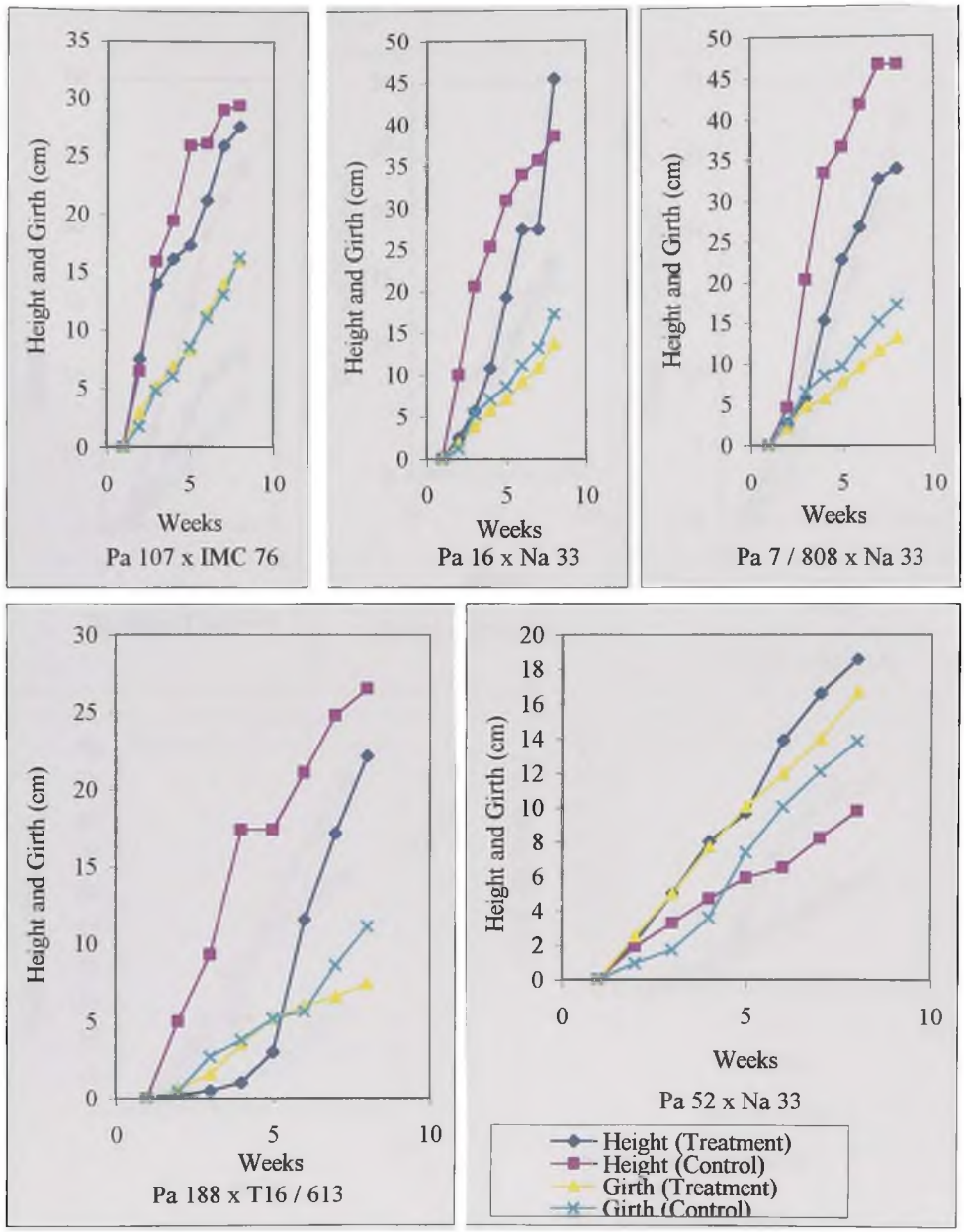

Fig 4.21a: Growth curves for Parinari Hybrids under semi-field conditions

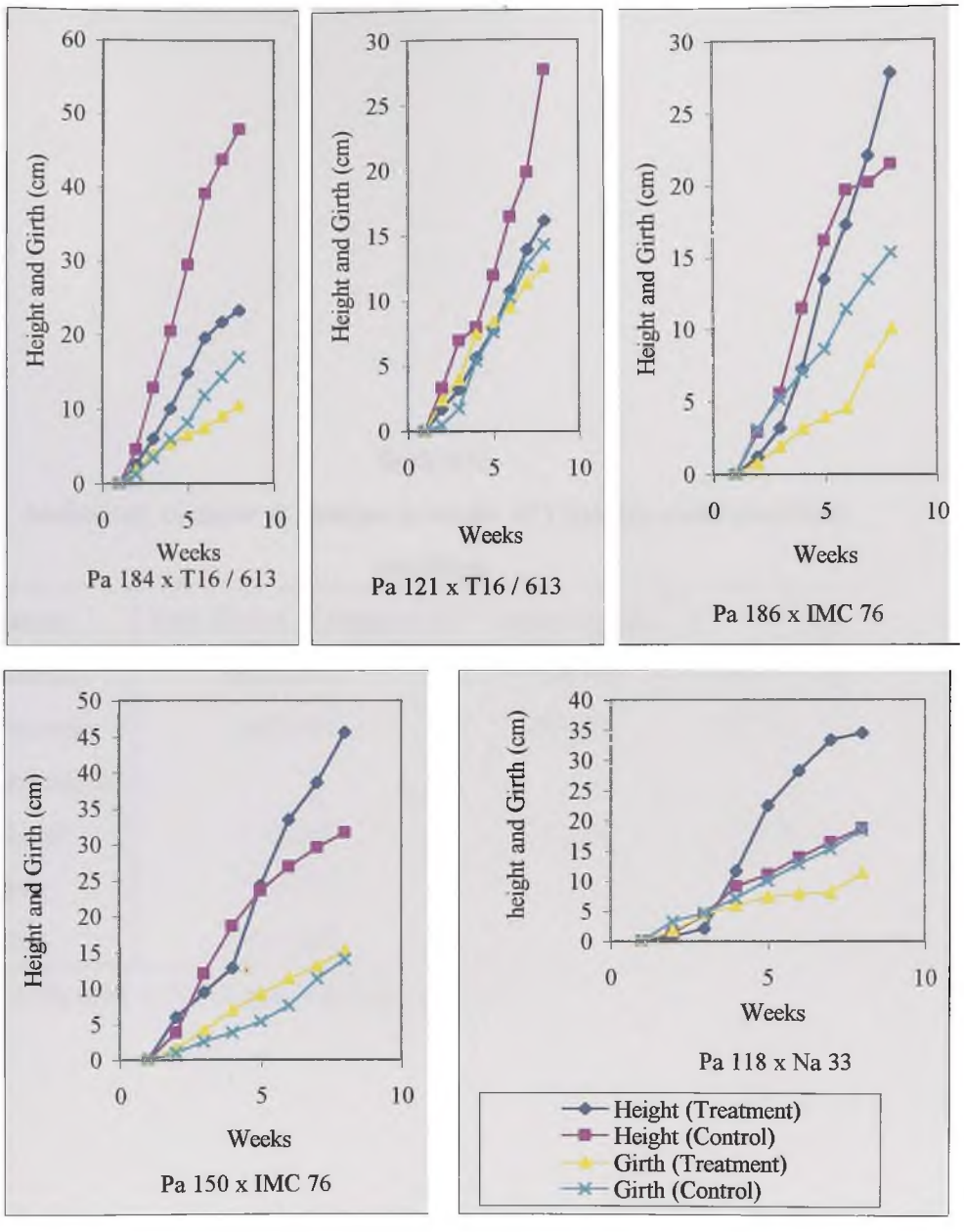

Fig. 21b Growth curves for Parinari Hybrids under semi-field conditions (continued)

Table 4.13

Analysis of variance of changes in height of T hybrids under semi-field conditions

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	19403.260a	11	1763.933	31.191	.000
Genotype	2647.462	9	294.162	5.202	.011
Treament & control	22.685	1	22.685	.401	.542
Error	508.971	9	56.552		
Total	19912.230	20			

a. R Squared = .974 (Adjusted R Squared = .943

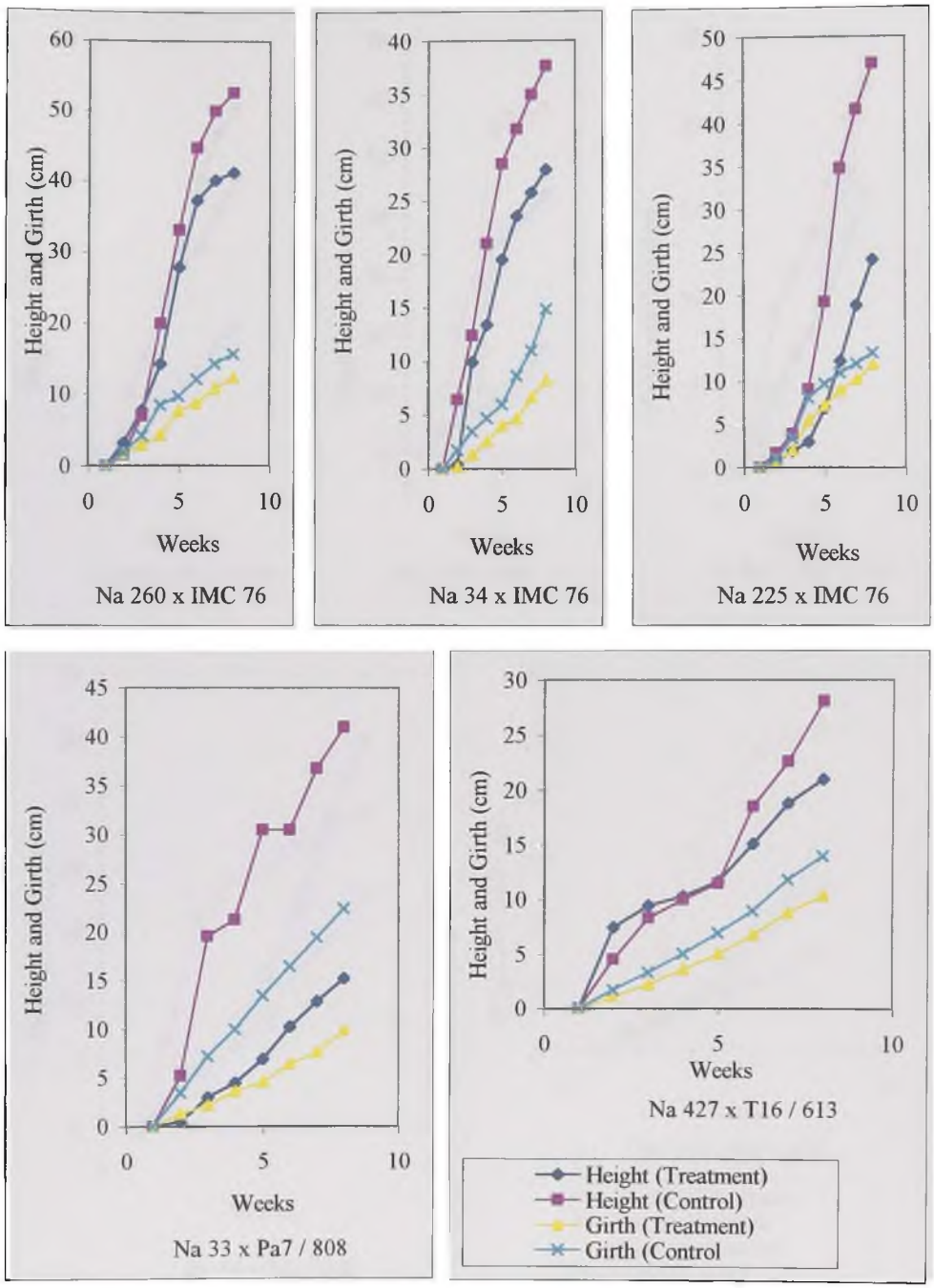

Fig 4.22a: Growth curves for Nanay Hybrids under semi-field conditions

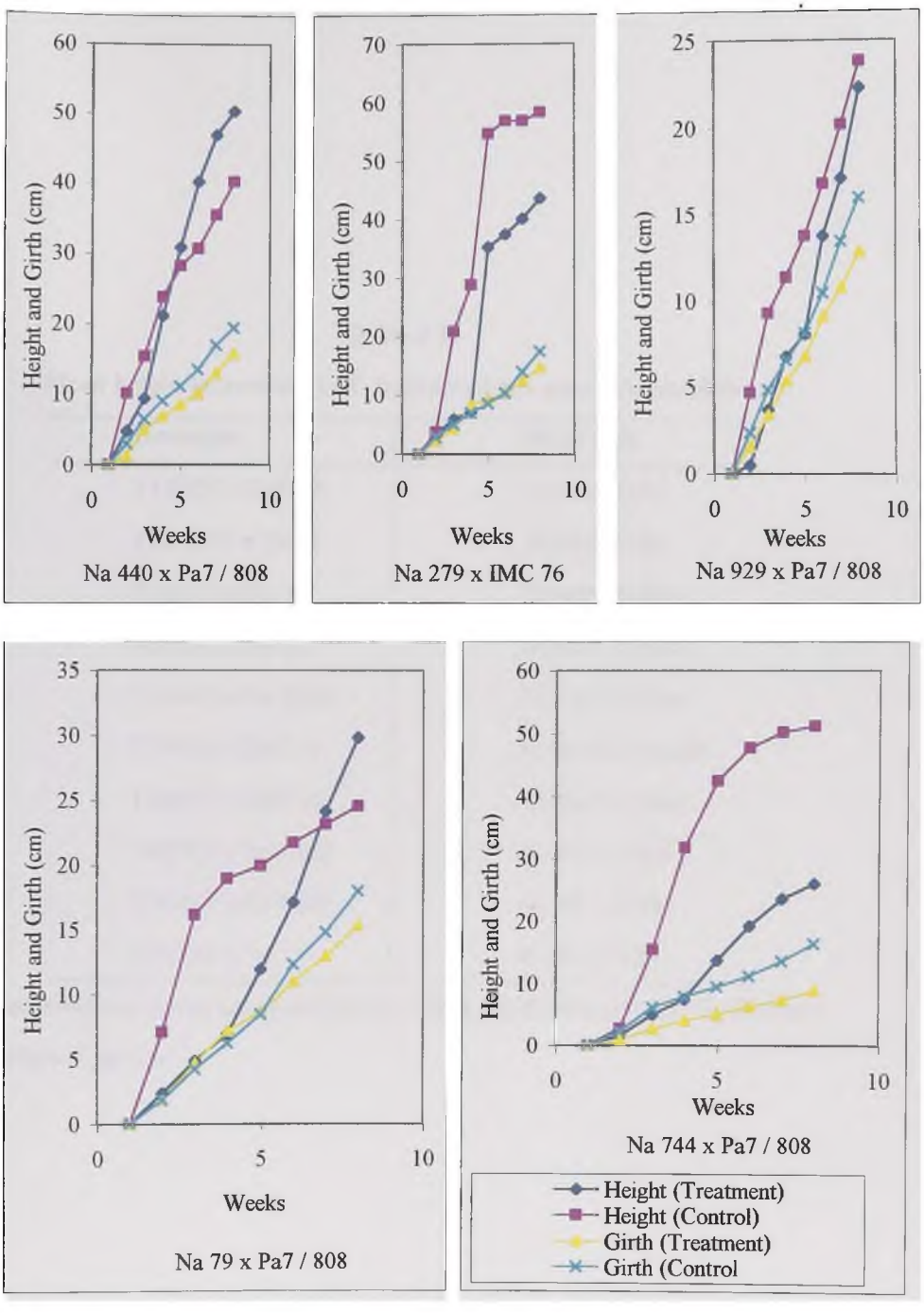

Fig 4.22b : Growth curves for the Nanay Hybrids under semi-field conditions (continued)

Table 4.14

Mean height increments in T hybrids under semi-field conditions

Genotype	Mean (cm)
T17/524 x IMC 76	13.60±5.318**a**
T92/1615 x Na 33	16.45±5.318**a**
T16/613 x Na 33	18.00±5.318**ab**
T60/887 x Na 33	19.40±5.318**ab**
T63/967 x Pa 7/808	24.35±5.318**abc**
T79/501 x IMC 76	31.20±5.318**abcd**
T63/971 x IMC 76	35.90±5.318**bcd**
T85/799 x Pa 7/808	40.40±5.318**cd**
T79/467 x Pa 7/808	44.10±5.318**d**
T65/238 x Na 33	45.85±5.318**d**

*Means followed by the same letter(s) do not differ significantly at P=0.05 by Duncan's Multiple range test

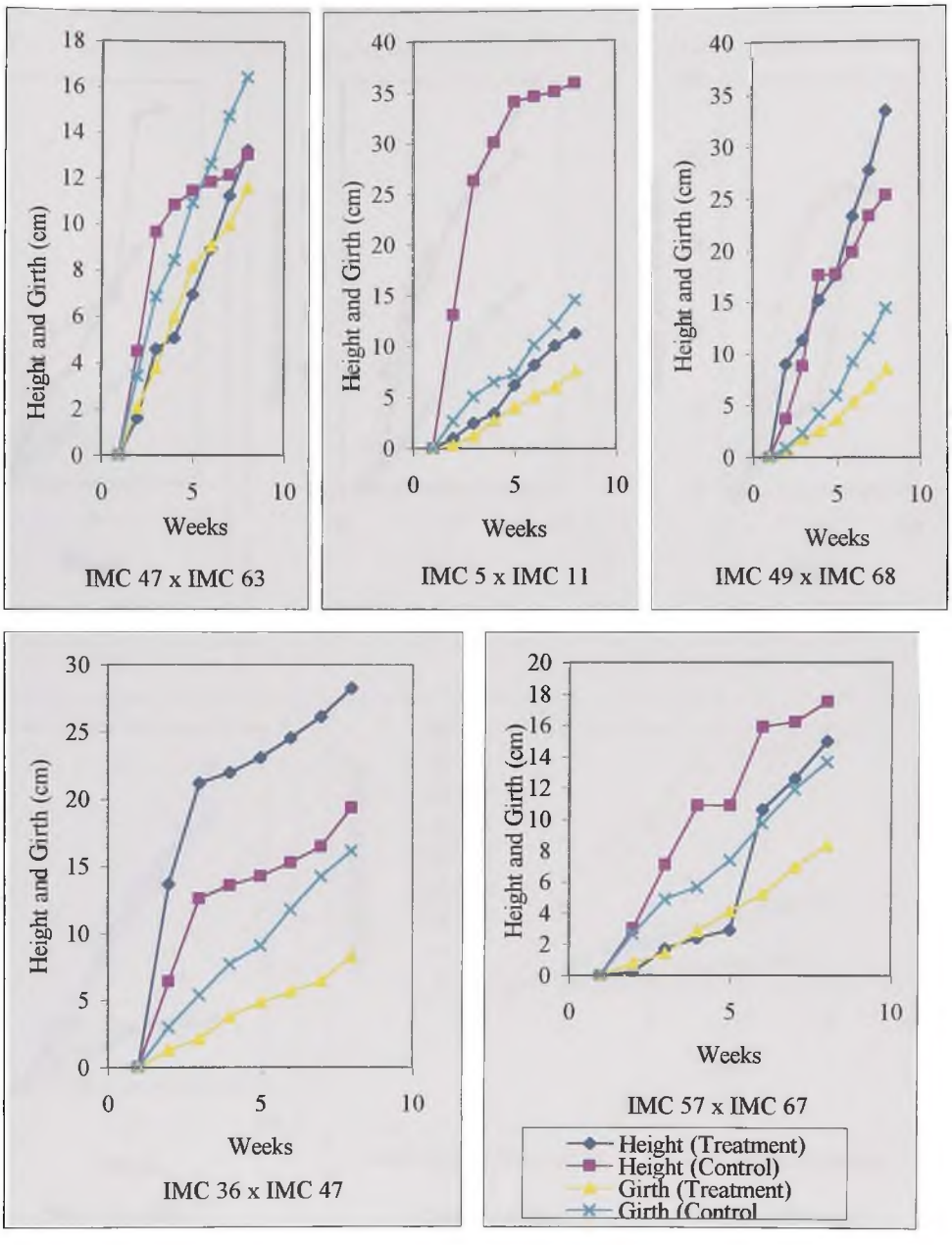

Fig 4.23a : Growth curves for the IMC Hybrids under semi-field conditions

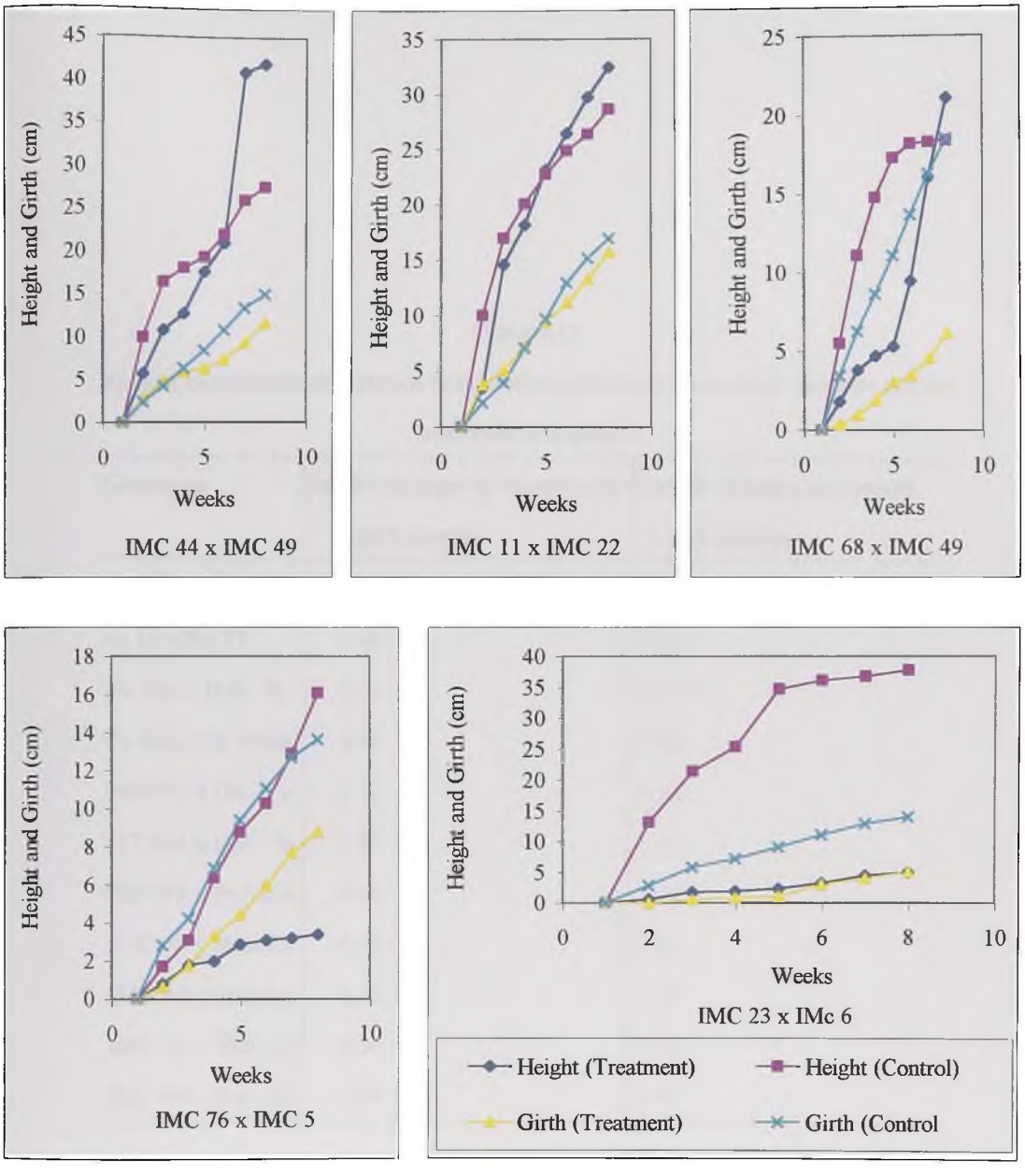

Fig 4.23b: Growth curves for IMC Hybrids under semi-field (continued)

Table 4.15

Height increments in hybrids that performed better than their controls under semi-field conditions

Genotype	Height changes in treatments (cm/8 weeks)	Height changes in control (cm/8 weeks)
Pa 150 x IMC 76	8.58	6.34
Pa 16 x Na 33	9.10	7.62
Pa 186 x IMC 76	5.24	4.30
Na 440 x Pa 7/808	9.88	7.80
T63/971 x IMC 76	8.68	5.68
T17/524 x IMC 76	3.90	1.54
T85/799 x Pa7/808	8.92	7.24
IMC 68 x IMC 49	4.18	3.56
IMC 47 x IMC 63	2.66	2.62
IMC 11 x IMC 22	6.50	5.74
IMC 49 x IMC 68	6.68	4.90

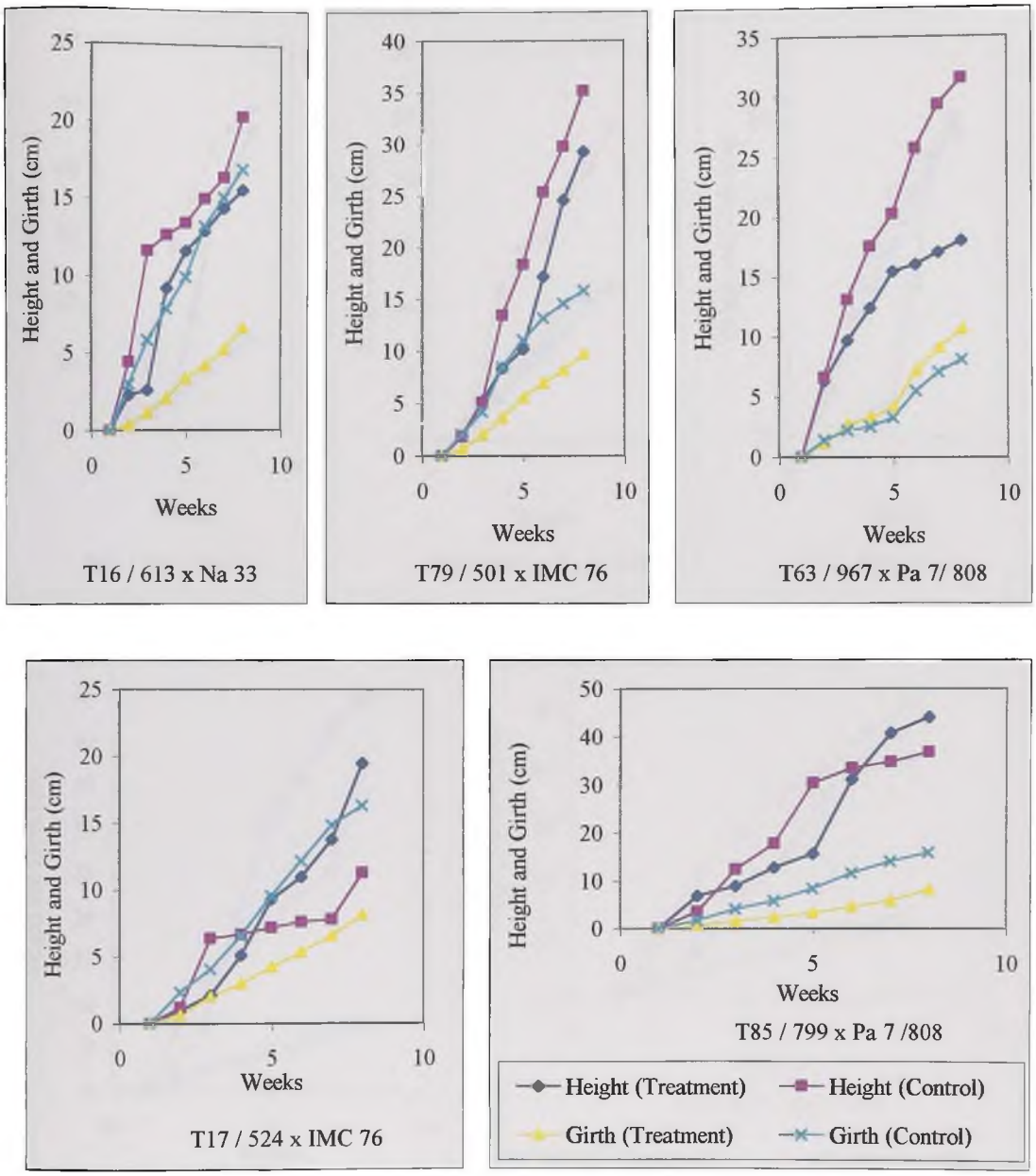

Fig 4.24a: Growth curves for theT Hybrids under semi-field conditions

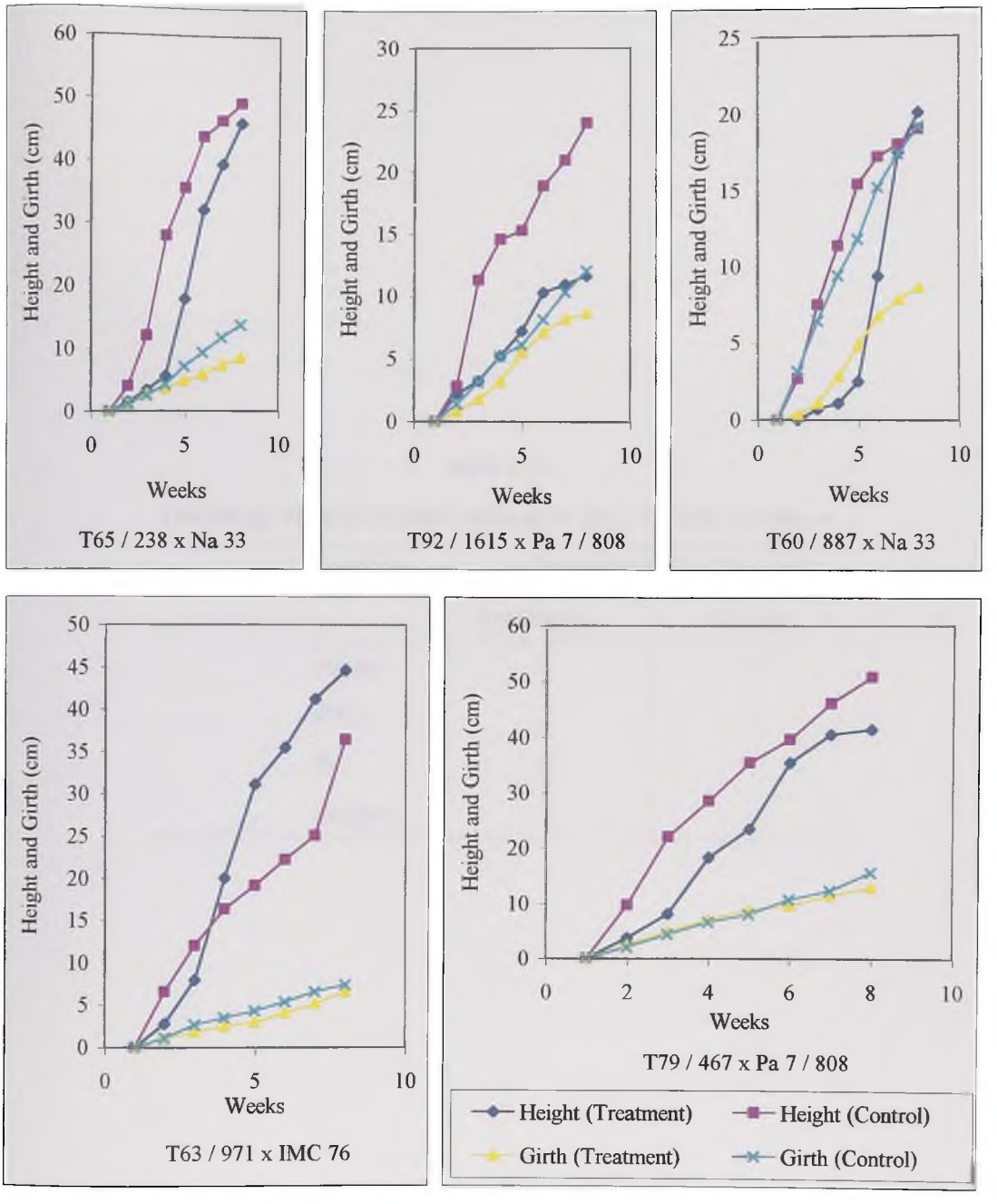

Fig 4.24b: Growth curves for the T Hybrids under semi-field conditions (continued)

Table 4.16

Percentage of dead hybrids seedlings in the semi-field condition

Genotype	Percentage(%) of dead plants	
	Treatment	**Control**
Nanays	2	0
IMCs	2	0
Ts	6	2
Parinaris	4	0

manifested by their counterpart clones (Appendices 25 & 40).

Table 4.15 shows that there were hybrids in all the four populations screened which performed better than their controls, indicating that there were vigorous hybrids within each population.

4.2.2.3 Dead hybrid seedlings

Generally, the death rate of hybrid seedlings exposed to capsid damage was significantly lower (8/200 seedlings) than among the clones (80/175 seedlings) (Appendices 23, 24, 25, 26, 37, 38, 39, 40). The death rate in control plants was similarly lower among the hybrids (1/200 seedlings) than among the clones (23/175 seedlings).

It was only among T hybrid control plants that plant deaths were recorded (2%). Moreover, the T hybrids recorded the highest death among the treated plants (6%). The Nanays and IMCs recorded the lowest death amonag the treated plants (2%) (Table 4.16).

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 LABORATORY MICROTEST

The present study has shown that the Parinari and Trinidad introduction clones tested were more attractive to *S. singularis* than the Nanay and IMC populations. Nguyen-Ban (1993) also found significant differences in mirid preference for high Amazonian Pa 620, Trinitario UF 662 and Amelonado IFC5 and attributed findings to differences in water status of chupons as well as their physical nature. Thus the higher capsid preference for the Parinaris and Ts in the present study might also be due to their higher water content and the same reason may also account for the differences in preferences for the clones and hybrids within each of the four populations. Piart (1970) and Astide (1990) also reported of selective behavioral response of capsids to cocoa progenies.

Cross *et. al,* (1996) attributed the sensitivity of some cocoa clones (ICS 95 and UF 669) to mirids to the presence of large quantities of two flavonols (quercetin and kaempferol oil) in their leaves. Thus it would be useful to analyse and compare the flavonoid content of the different clones listed in the present study and to relate the quantities to attractiveness of the clones to capsids. Giannasi (1988) also established the presence of flavonoids in the family Sterculiaceae, to which *T. cacao* belongs.

On the other hand, the low preference showed by *S. singularis* for the Nanays in the present investigation may be due to the presence of some feeding deterrents

rather than to their woody nature since *S. singularis* is known to feed on both soft and hard cocoa chupons (Entwistle and Youdeowei, 1964). Recent advances in genetic engineering have made it possible to produce improved varieties of cocoa which have been shown to vary with respect to their suitability for colonization by insect pests in the field (Bigger 1975, Firempong 1984, Decazy and Coulibaley 1982, Asante *et. al.* 1988, Campbell 1990, Ackonor *et. al.* 1993) hence it should be possible to manipulate certain cocoa types for reistance to capsids. It must be cautioned that such field observations need to be compared with findings generated from laboratory/ insectary screening studies.

5.2 INSECTARY TEST AND FIELD OBSERVATION

5.2.1 Clones

Results from the insectary screening followed the same trend as those from the microtest. Thus the Parinaris were the most preferred, followed by the Ts, then the IMCs and the Nanays. It is significant to note that Nguyen-Ban (1998) also observed that a Parinari clone Pa 7 was more attractive than Sca 2. Within the T population T79/501 emerged as one of the least attractive clones although it was highly preferred in the laboratory microtest. Sounigo *et. al.*, (1993) concluded that the clone T79/501 presents high yield and low susceptibility to mirids and to pod rot. Their findings on T79/501 support the present results from the insectary but conflicts with the micotest results. There is, therefore, the need for further work to resolve differences in laboratory and insectary findings in the current study. The conflicting results are not surprising as Southwood (1978) has warned that short-term ecological studies are quite complex and the results difficult to interprete. Also within the Nanays, Na 225 which was among the least preferred clones in the laboratory microtest emerged as

the most preferred under insectary conditions. Similarly, the most preferred Nanay clone Na 79 in the laboratory was among the least preferred under insectary conditions. Such differences could be attributed to the small numbers of seedlings used in the insectary. Further work could be done with higher replications in the insectary to confirm the laboratory results.

The generally low attractiveness of the Nanay clones to capsids as observed in the present study agrees with observations by Nguyen-Ban (1998) who established that Na 32 was less attractive to capsids than Sca 2 in the field.

There were significant differences ($P<0.05$) in growth increments between treated and untreated seedlings with the seedlings exposed to capsids showing retarded growth among the clones. This confirms earlier reports that capsid damage delays establishment of young cocoa (Wills, 1962). The only exceptions were the Parinaris in which growth of treated and control seedlings were not significantly different implying that although the Parinaris recorded the highest number of capsid lesions, they were vigorous and were able to outgrow the effects of capsid damage. It was also observed that there were no significant differences ($P>0.05$) in height increment among the clones in each population which means that the performance of clones within the various populations were generally uniform.

Growth rate of the Parinari clones (25.83cm/8 weeks), IMCs (9.5cm/8 weeks) and the Ts (8.76cm/8 weeks) in the current study are comparable to the average increase of 10.9±2.0 cm/flush reported by Greathouse *et. al.* (1971) on some cocoa varieties. However, the period considered by Greathouse *et. al.* (1971) as a flush period and the varieties of cocoa used were not specified. On the other hand, Bonaparte (1979) reported flushing peaks for four cocoa cultivars; Amelonado, T85/799 x Na 34, T85/799 x Amelonado and T85/799 in January, March, May–June and October–November, with minor peaks in July or August. Thus the growth rate observed in the

present study for both clones and hybrids were within the peak flushing periods. The Nanay clones (5.88cm/8 weeks) fell below the average which could be due to effect of capsid damage. This seems to agree with observation by Wilson (1999) that the seedling root stock may modify the performance of buded clones; improving a poor clone but reducing the performance of a good one.

In the present study, the effects of capsid damage became apparent in (January–March), the dry season, the period when the effects of capsid damage becomes apparent in the field. For example in Na 33 and T63/967 all treated seedlings died whilst in Pa 150, Pa 184, T79/501, T63/971, T17/524, T85/799, IMC 68, IMC 57, four plants each of treatment died. It was only in a few clones (Pa 107, Pa 7/808 and IMC 47) that none of the treated plants died. Relatively fewer plants died in the controls, with Na 440 recording the highest death of four. None of the control plants died in the Parinaris and in Na 33 and Na 34 for the Nanays. Among the Ts only four control plants, two each of T65/238 and T63/967 died. For the IMCs one control plant of IMC 49 and two each of IMC 68 and IMC 23 died. The cause of death in the few control seedlings could be attributed the dry season.

The fungus *Calonectria rigiduiscula,* a wound pathogen, is known to aggravate capsid damage and can gain access to cocoa plants through capsid lesions or wounds originating from other causes. Thus it is possible that the control plants that died had wounds caused by factors other than capsids.

5.2.2 Hybrids

In the current study IMC hybrids came out as the most preferred population with a total of 1,365 lesions/50 seedlings as against 1,195 and 1,105 lesions/50 seedlings for the Ts and the Parinaris, respectively, but the differences were statistically not

significant ($P>0.05$). As observed from the microtest and the insectary test the Nanay hybrids were the least prefered with 936 lesions/50 seedlings. With the exception of the IMCs, the order of capsid preferences for the different populations was maintained as that recorded in the microtest and insectary tests. This deviation with respect to the IMCs could be due to the fact that the IMC hybrids were mostly intra-population crosses whilst the other three populations were all mixed hybrids.

Within each population, specific clones/hybrids emerged as better preferred or more resistant/tolerant than others. For example in the insectary Pa 118, Pa 121, and Pa 107 were the most preferred clones whereas Pa 150 was the least preferred. For the hybrids, the Pa 107 and Pa 118 hybrids were among the most preferred. On the other hand Pa 121 hybrid (Pa 121 x T16/613) behaved differently from its clonal counterpart, indicating that in combination with other materials, the resulting hybrids sometimes behaved differently from their parental clones. Whereas the results from the "microtest" and insectary agreed for most of the clonal materials, the results for some of the clones (T79/501, Na 225 and Na 79) from the two studies were conflicting. Reasons for the conflicting results need to be identified and resolved.

Hybrid vigour has been demonstrated in the current study in all four populations in view of the fact that fewer hybrid than clonal seedlings died and the growth rate was also higher among the hybrids. This confirms findings by Posnette (1948) who first observed heterosis when he crossed the Upper Amazon selections. This also confirms Toxopeus (1972) who indicated that breeding experience has shown that trees from different populations, when crossed, almost always produce progeny with hybrid vigour.

The Nanay hybrids recorded a mean growth rate of 32.04cm/8 weeks, the Ts, 28.93cm/8 weeks and the Parinaris, 27.65cm/8 weeks but the differences were not

statistically significant (P>0.05). The IMCs recorded the least increase in height (19.24cm/8 weeks). This could be due to a contribution of high level of capsid damage and loss of vigour possibly resulting from the intra-population crosses.

A greater number of treated and control plants recorded heights which were greater than or equal to 10.9 ± 2.0 cm/flush reported by Greathouse *et. al.* (1971). The control hybrids performed better than the treated ones as also was the case with the clones although the differences were not statistically different (P>0.05). The IMC hybrids generally recorded increments that fell below the average 10.9cm height indicating lower vigour which could have arisen from the intra-population crossses.

The T population was the only one that exhibited significant differences in height increases among its hybrids (Table 4.14). T92/1615 x Pa 7/808 (8.9cm/8 weeks) performed poorly with respect to growth increments though none of the treated plants died. It is perhaps significant to note that the T17/524 x IMC 76 control plants recorded the least height increase (1.54cm/8 weeks) among all the hybrids screened in the current study. T65/238 x Na 33 and T79/467 x Pa 7/808 emerged the best in height increments among T hybrids though their performances were not significantly different from those of T85/799xPa7/808, T63/971 x IMC 76, and T79/501 x IMC 76.

CHAPTER 6

CONCLUSION

Findings from the microtest and insectary studies have shown that the Parinari clones, followed by the Trinidad introductions, were generally the most attractive to cocoa capsids. The results also show that the Parinari clones, though attractive, were the most vigourous among the four populations screened and were, therefore, able to outgrow capsid damage when taken to the field.

Among the hybrid materials, the IMCs were the most attractive to capsids. They also performed poorly with respect to growth increments and are, therefore, considered unsuitable breeding materials for capsid resistance. It is, however, to be noted that some IMC clones were among the least attractive materials and could offer promising breeding materials for capsid resistance. Attractiveness among the Parinari, T and Nanay hybrids followed a similar trend as that recorded for their clonal counterparts. In addition, all three populations exhibited high growth rates, with the Nanays performing slightly better than the Ts and Parinaris. Generally, the Nanays (both clones and hybrids) were the least attractive. In addition, the Nanay hybrids were vigorous and were able to outgrow capsid damage.

Results from the present study, therefore, indicate that some of the Nanay hybrids (Na 744 x Pa 7/808, Na 440 x Pa 7/808, Na 279 x IMC 76, Na 260 x IMC 76), some Parinari hybrids (Pa 16 x Na 33, Pa 150 x IMC 76, Pa 107 x IMC 76, Pa 7/808 x T16/613, Pa 184 x T16/613), and some T hybrids (T85/799 x Pa 7/808, T79/501 x IMC 76, T63/971 x IMC 76, T65/238 x Na 33, T79/467 x Pa7/808) are potential

materials for development of cocoa genotypes that are resistant/tolerant to capsid attack. The Parnari clones, especially Pa 107, Pa 118 Pa 121 and Pa 7/808 together with T79/501, T79/467, and T85/799 in addition to IMC 76 could be further investigated in future expriments to confirm their potential as breeding materials for capsid control. Other hybrid materials as IMC 68 x IMC 49, IMC 11 x IMC 22, IMC 36 x IMC 47 and IMC 49 x IMC 68 which exhibited significant increases in height and girth, comparable to their untreated controls could also be further investigated.

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APPENDICES

Appendix 1

Orgin of Trees Selected from Pound's Upper Amazon Material

T Number: These are seedlings within pod progenies introduced from Trinidad in 1944.

Thus T17/524 is a seedling of pod number T17:

Code	Progeny
T12	Sca 12 open pollinated
T16	IMC 24 open pollinated
T17	IMC 53 open pollinated
T44	Pound's refractario selection made in 1937 at Hacienda Bolivar, Ecuador
T60	PA 7 x NA 32 (reciprocal of T79)
T63	PA 37 x NA 32 (reciprocal of T82)
T65	PA 7 x IMC 47
T72	NA 32 x IMC 60
T73	NA 33 x IMC 60
T76	PA 35 x NA 31
T79	NA 32 x PA7 (reciprocal of T60)
T82	NA 32 x PA35 (reciprocal of T63)
T85 & T87	IMC 60 x NA 34
T90 & T101	IMC 76 x Na 32
T92	Na 32 x Na 31

Sources: Adu-Ampomah *et. al.* 1996.

Adomako, B and Y. Adu-Ampomah, 2000.

Appendix 2

Comparison of total capsid lesions of laboratory microtest and insectary tests of Parinari population

Genotype	Laboratory Microtest (45 reps)	Insectary (5 reps)	
		Clones	hybrids
Pa 107	327	125	152
Pa 7/808	524	81	122
Pa 150	303	51	89
Pa118	169	165	129
Pa 188	243	–	146
Pa 16	187	–	95
Pa 52	257	–	196
Pa 186	108	–	118
Pa 121	237	130	57
Pa 184	382	76	111
Total	**2737**	**628**	**1105**
Mean	**273.7**	**101.67**	**110.5**

Appendix 3

Comparison of total capsid lesions of laboratory microtest and insectary tests of Nanay population

Genotype	Laboratory Microtest (45 reps)	Insectary (5 reps)	
		Clones	hybrids
Na 929	119	21	85
Na 79	195	31	87
Na 34	111	28	54
Na 440	186	31	97
Na 33	178	25	99
Na 279	136	36	71
Na 427	63	31	155
Na 744	43	43	147
Na 260	81	41	62
Na 225	48	53	79
Total	**1160**	**340**	**936**
Mean	**116**	**34**	**93.6**

Appendix 4

Comparison of total capsid lesions of laboratory microtest and insectary tests of T population

Genotype	Laboratory Microtest (per 45 chupons)	Insectary (per 5 seedlings)	
		Clones	hybrids
IMC 68	306	33	180
IMC 23	156	37	131
IMC 47	255	40	120
IMC 57	125	21	113
IMC 11	271	64	133
IMC 49	145	30	149
IMC 44	297	41	78
IMC 76	248	45	141
IMC 36	114	30	157
IMC 5	122	44	163
Total	**1939**	**385**	**1365**
Mean	**193.9**	**38.5**	**136.5**

Appendix 5

Comparison of total capsid lesions of laboratory microtest and insectary tests of T population

Genotype	Laboratory Microtest (per 45 chupons)	Insectary (per 5 seedlings)	
		Clones	hybrids
T79/501	392	55	176
T63/971	259	59	160
T65/238	256	54	52
T17/524	357	100	98
T85/799	253	44	141
T79/467	147	71	95
T92/1615	221	45	78
T16/613	139	–	124
T63/967	218	88	115
T60/887	306	61	156
Total	**2548**	**577**	**1195**
Mean	**254.8**	**64.1**	**119.5**

Appendix 6

Analysis of variance of x√Y + 0.5 lesions of *Sahlbergella singularis* on four populations (4 levels) with 10 clones each (40 levels) in the laboratory microtest

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	7546.097a	40	188.652	181.588	.000
Populations	142.122	3	47.374	45.600	.000
Clones	84.672	9	9.408	9.056	.000
Population x Clones	122.503	27	4.537	4.367	.000
Error	1828.466	1760	1.039		
Total	9374.563	1800			

a. R Squared = .805 (Adjusted R Squared=.801)

Appendix 7

Analysis of variance of x√Y + 0.5 capsid lesions/45 chupons of *Sahlbergella singularis* on Parinari clones in the laboratory microtest to determine preference

Sources of variation	Sum of Shares	df	Means Square	F	Sig.
Between Groups	92.069	9	10.230	8.502	0.000
Within Groups	529.424	440	1.203		
Total	621.494	449			

Appendix 8

Analysis of variance of x√Y + 0.5 capsid lesions/45 chupons of *Sahlbergella singularis* on Nanay clones in the laboratory microtest to determine preference

Sources of Variation	Sum of Squares	df	Means Square	F	Sig.
Between Groups	36.213	9	4.024	6.543	.000
Within Groups	270.588	440	.615		
Total	306.802	449			

Appendix 9

Analysis of variance of $x\sqrt{Y} + 0.5$ capsid lesions/45 chupons of *Sahlbergella singularis* on T clones in the laboratory microtest to determine preference

Sources of Variation	Sum of Squares	df	Means Square	F	Sig
Between Groups	38.11	9	4.23	3.41	0.000
Within Groups	547.23	440	1.24		
Total	585.34	449			

Appendix 10

Analysis of variance of $x\sqrt{Y} + 0.5$ capsid lesions/45 chupons of *Sahlbergella singularis* on IMC clones in the laboratory microtest to determine preference

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	42.447	9	4.716	4.352	0.000
Within Groups	476.827	440	1.084		
Total	519.274	449			

Appendix 11

Analysis of variance of $x\sqrt{Y} + 0.5$ capsid lesions/5 seedlings of *Sahlbergella singularis* on clonal populations in the insectary to determine preference

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	1872.595a	13	144.046	161.019	.000
Populations	62.532	3	20.844	23.300	.000
Clones	15.300	9	1.700	1.900	.055
Error	144.923	162	.895		
Total	2017.519	175			

a. R Squared = .928 (Adjusted R Squared = .922)

Appendix 12

Analysis of variance of $x\sqrt{Y} + 0.5$ capsid lesions/5 seedlings of *Sahlbergella singularis* on hybrid populations in the insectary to determine preference

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	4391.792a	13	337.830	150.878	.000
Populations	18.034	3	6.011	2.685	.048
Hybrids	15.060	9	1.673	.747	.665
Error	418.711	187	2.239		
Total	4810.503	200			

a. R Squared = .913 (Adjusted R Squared = .907)

Appendix 13

Analysis of variance of increases in height of clonal populations in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	15718.990a	14	1122.785	16.168	.000
Populations	3298.580	3	1099.527	15.833	.000
Clones	1195.755	9	132.862	1.913	.069
Treatment & Control	2640.200	1	2640.200	38.018	.000
Error	3889.000	56	69.446		
Total	19607.990	70			

a. R Squared = .802 (Adjusted R Squared = .752)

Appendix 14

Analysis of variance of increases in girth of clonal populations in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	277.45a	14	19.818	27.547	.000
Populations	7.231	3	2.410	3.350	.025
Clones	5.004	9	.556	.773	.642
Treatment & Control	36.605	1	36.605	50.881	.000
Error	40.288	56	.719		
Total	317.742	70			

a. R Squared = .873 (Adjusted R Squared = .842)

Appendix 15

Analysis of variance of increases in height of Parinari clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	10876.186a	7	1553.741	9.010	.014
Genotype	2038.018	5	407.604	2.364	.183
Treatment & control	835.001	1	835.001	4.842	.079
Error	862.224	5	172.445		
Total	11738.410	12			

a. R Squared = .927 (Adjusted R Squared = .824)

Appendix 16

Analysis of variance of increases in girth of Parinari clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	71.916a	7	10.274	7.445	.021
Genotype	1.356	5	.271	.196	.951
Treatment & control	3.630	1	3.630	2.630	.166
Error	6.900	5	1.380		
Total	78.816	12			

a. R Squared = .912 (Adjusted R Squared = .790)

Appendix 17

Analysis of variance of increases in height of Nanay clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	1270.198a	11	115.473	2.648	.077
Genotype	277.622	9	30.847	.707	.693
Treatment & control	301.088	1	301.088	6.905	.027
Error	392.462	9	43.607		
Total	1662.660	20			

a. R Squared = .764 (Adjusted R Squared = .475)

Appendix 18

Analysis of variance of increases in girth of Nanay clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	52.657a	11	4.787	10.138	.001
Genotype	4.419	9	.491	1.040	.477
Treatment & control	6.072	1	6.072	12.860	.006
Error	4.249	9	0.472		
Total	56.907	20			

a. R Squared = .925 (Adjusted R Squared = .834)

Appendix 19

Analysis of variance of increases in height of T clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	2457.830a	10	245.783	14.016	.000
Genotype	184.030	8	23.004	1.312	.355
Treatment & control	890.420	1	890.420	50.776	.000
Error	140.290	8	17.536		
Total	2598.120	18			

a. R Squared = .946 (Adjusted R Squared = .879)

Appendix 20

Analysis of variance of increases in girth of T clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	85.139a	10	8.514	15.441	.000
Genotype	6.720	8	.840	1.523	.283
Treatment & control	19.014	1	19.014	34.484	.000
Error	4.411	8	.551		
Total	89.550	18			

a. R Squared = .951 (Adjusted R Squared = .889

Appendix 21

Analysis of variance of increases in height of IMC clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	3027.168a	11	275.197	4.258	.019
Genotype	433.400	9	48.156	.745	.666
Treatment & control	788.768	1	788.768	12.205	.007
Error	581.632	9	64.626		
Total	3608.800	20			

a. R Squared = .839 (Adjusted R Squared = .642

Appendix 22

Analysis of variance of increases in girth of IMC clones in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	85.537a	11	7.776	10.095	.001
Genotype	7.680	9	.853	1.108	.441
Treatment & control	10.513	1	10.513	13.648	.005
Error	6.933	9	.770		
Total	92.470	20			

a. R Squared = .925 (Adjusted R Squared = .833)

Appendix 23

Growth measurements of Parinari (Pa) clones under semi-field conditions

Genotype	Total change in height (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
Pa 107	30.7	49.4	2.8	2.5	0	0
Pa 7/808	2.2	43.2	3.2	2.6	0	0
Pa 150	0.5	14.1	0.3	3.9	4	0
Pa 118	49.9	34.1	1.9	2.95	1	0
Pa 188	–	–	–	–	–	–
Pa 16	–	–	–	–	–	–
Pa 52	–	–	–	–	–	–
Pa 186	–	–	–	–	–	–
Pa 121	21.5	39.5	1.76	2.07	1	0
Pa 184	0.1	24.7	.91	3.45	4	0

Appendix 24

Growth measurements of Nanay clones under semi-field conditions

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
Na 929	2.2	20.2	1.1	2.2	1	1
Na 79	0.7	4.0	0.22	0.6	3	3
Na 34	0.5	17	0.75	3.11	1	0
Na 440	7.5	2.9	1.35	0.75	2	4
Na 33	0	25.1	0	2.73	5	0
Na 279	3.2	12.7	1.2	2.5	1	1
Na 427	1.0	5	0.75	2.07	2	1
Na 744	2.7	2.5	1.38	2.76	3	1
Na 260	1.9	3.4	0.82	1.44	2	2
Na 225	0.3	4.8	1.44	1.87	1	1

Appendix 25

Growth measurements of T clones under semi-field conditions

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
T79/501	5.1	17.4	1.8	3.7	4	0
T63/971	0	21.1	0	2.4	4	0
T65/238	0.9	5.8	1.2	1.7	2	2
T17/524	0	16.3	0	3.3	4	0
T85/799	1.1	24.5	0.2	3.4	4	0
T79/467	4.1	14	2.5	3.1	2	0
T92/1615	0.2	9.2	0.8	2.5	3	0
T16/613	–	–	–	–	–	–
T60/887	4.2	21	0.6	3.7	3	0
T63/967	0	12.9	0	1.8	5	2

Appendix 26

Growth measurements of IMCclones under semi-field conditions

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
IMC 68	0	12.1	0	0.8	4	2
IMC 23	2.5	4.6	1.4	1.8	2	2
IMC 47	3.5	13.9	2.9	2.3	0	0
IMC 57	0.4	13.5	0.2	3.6	4	0
IMC 11	0	39.9	0.1	3.3	1	0
IMC 49	4.5	17.7	0.9	3.3	3	1
IMC 44	4.9	6.9	0.7	1.9	1	0
IMC 76	4.5	25.8	1.8	2.7	1	0
IMC 36	5.7	16.1	1.9	3.3	1	0
IMC 5	6.2	7.6	1.2	2.6	1	0

Appendix 27

Analysis of variance of increases in height of hybrid populations in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	63224.173a	14	4516.012	36.721	.000
Populations	1793.827	3	597.942	4.862	.004
Hybrids	2628.121	9	292.013	2.374	.022
Treatment & Control	617.742	1	617.742	5.023	.028
Error	8116.707	66	122.980		
Total	71340.880	80			

a. R Squared = .886 (Adjusted R Squared = .862)

Appendix 28

Analysis of variance of increases in girth of hybrid populations in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Table III Sum of Squares	df	Mean Square	F	Sig.
Model	589.503a	14	42.107	141.011	.000
Populations	3.211	3	1.070	3.585	.018
Hybrids	3.386	9	.376	1.260	.275
Treatment & Control	19.355	1	19.355	64.818	.000
Error	19.708	66	.299		
Total	609.212	80			

a. R Squared = .968 (Adjusted R Squared = .961)

Appendix 29

Analysis of variance of increases in height of Parinari hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	17066.381a	11	1551.489	22.740	.000
Genotype	1708.219	9	189.802	2.782	.072
Treatment & control	41.303	1	41.303	.605	.457
Error	614.059	9	68.229		
Total	17680.440	20			

a. R Squared = .965 (Adjusted R Squared = .923)

Appendix 30

Analysis of variance of increases in girth of Parinari hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	162.450a	11	14.768	62.987	.000
Genotype	3.602	9	.400	1.707	.219
Treatment and control	2.081	1	2.081	8.878	.015
Error	2.110	9	.234		
Total	164.560	20			

a. R Squared = .987 (Adjusted R Squared = .972)

Appendix 31

Analysis of variance of increases in height of Nanay hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	23700.110a	11	2154.555	22.434	.000
Genotype	2030.700	9	225.633	2.349	.110
Treatment & control	1144.584	1	1144.584	11.918	.007
Error	864.340	9	96.038		
Total	24564.450	20			

a. R Squared = .965 (Adjusted R Squared = .922

Appendix 32

Analysis of variance of increases in girth of Nanay hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	144.413a	11	13.128	35.739	.000
Genotype	4.801	9	.533	1.452	.294
Treatment & control	5.450	1	5.450	14.835	.004
Error	3.306	9	.367		
Total	147.719	20			

a. R Squared = .978 (Adjusted R Squared = .950)

Appendix 33

Analysis of variance of increases in height of IMC hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	8566.788a	11	778.799	11.361	.001
Genotype	1147.748	9	127.528	1.860	.184
Treatment & control	15.488	1	15.488	.226	.646
Error	616.972	9	68.552		
Total	9183.760	20			

a. R Squared = .933 (Adjusted R Squared =.851)

Appendix 34

Analysis of variance of increases in girth of IMC hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MODEL	144.413a	11	13.128	35.739	.000
Genotype	4.801	9	.533	1.452	.294
Treatment & control	5.450	1	5.450	14.835	.004
Error	3.306	9	.367		
Total	147.719	20			

a. R Squared = .978 (Adjusted R Squared = .950)

Appendix 35

Analysis of variance of increases in height of T hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	19403.260a	11	1763.933	31.191	.000
Genotype	22.685	9	22.685	.401	.542
Treatment & control	2647.462	1	294.162	5.202	.011
Error	508.971	9	56.552		
Total	19912.230	20			

a. R Squared = .988 (Adjusted R Squared = .974

Appendix 36

Analysis of variance of increases in girth of T hybrids in the semi-field study to determine tolerance to *Sahlbergella singularis*

Source	Type III Sun of Squares	df	Mean Square	F	Sig.
MODEL	120.942a	11	10.995	68.203	.000
Genotype	1.803	9	.200	1.243	.376
Treatment & control	8.077	1	8.077	50.105	.000
Error	1.451	9	.161		
Total	122.393	20			

a. R Squared = .988 (Adjusted R Squared = .974

Appendix 37

Growth measurements of Parinari hybrids

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
Pa 188 x T16/613	14.8	26.5	1.2	2.2	1	0
Pa 16 x Na 33	45.5	38.1	2.7	3.5	0	0
Pa 150 x IMC 76	42.9	31.7	3.1	2.8	0	0
Pa 118 x Na 33	14.9	18.6	2.3	3.7	0	0
Pa 107 x IMC 76	26.8	28.3	3.2	3.3	0	0
Pa 7/808 x Na 33	29.2	44.8	2.6	3.5	0	0
Pa 121 x T16/613	16.1	27.7	2.5	2.9	0	0
Pa 184 x T16/613	23.1	47.9	1.9	3.4	1	0
Pa 52 x Na 33	18.6	9.8	3.3	2.8	0	0
Pa 186 x IMC 76	26.2	21.5	2	3.1	0	0

Appendix 38

Growth measurements of Nanay hybrids

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
Na 427 x T16/613	0.4	27.8	2.1	2.8	0	0
Na 744 x Pa 7/808	25.6	49.7	1.8	3.3	0	0
Na 34 x IMC 76	27	37.7	1.6	3	1	0
Na 440 x Pa 7/808	47.7	39.0	2.9	3.9	0	0
Na 929 x Pa 7/808	17.4	23.8	2.5	3.2	0	0
Na 79 x Pa 7/808	29.0	24.6	3.1	3.6	0	0
Na 33 x Pa 7/808	12.6	35.4	2.0	4.5	0	0
Na 279 x IMC 76	28.8	58.4	3.0	3.5	0	0
Na 260 x IMC 76	38.0	52.7	2.4	3.1	0	0
Na 225 x IMC 76	18.2	46.9	2.4	2.7	0	0

Appendix 39

Growth measurements of T clones

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
IMC 68 x IMC 49	20.9	17.8	1.22	3.71	0	0
IMC 23 x IMC 6	4.40	34.	0.91	2.83	1	0
IMC 47 x IMC 63	13.3	13.1	2.32	3.30	0	0
IMC 57 x IMC 67	15.0	16.8	1.66	2.73	0	0
IMC 11 x IMC 22	32.5	28.7	3.36	3.39	0	0
IMC 49 x IMC 68	33.4	24.5	3.14	3.39	0	0
IMC 44 x IMC 49	24.0	27.0	3.23	2.98	0	0
IMC 76 x IMC 5	3.2	16.4	1.76	2.73	0	0
IMC 36 x IMC 47	27.1	19.4	1.6	3.17	0	0
IMC 5 x IMC 11	9.8	3.5	1.48	2.89	1	0

Appendix 40

Growth measurements of T clones

Genotype	Total change in length (cm)		Total change in girth (cm)		Number of dead plants	
	Treatment	Control	Treatment	Control	Treatment	Control
T17/524 x IMC 76	19.5	7.7	1.54	3.27	0	0
T85/799 x Pa 7/808	44.6	36.2	1.63	3.19	0	0
T16/613 x Na 33	15.6	20.4	1.29	3.39	0	0
T63/967 x Pa 7/808	18.1	30.6	1.57	2.26	1	1
T79/501 x IMC76	27.2	35.2	1.95	3.11	0	0
T63/971 x IMC 76	43.4	28.4	1.79	2.32	1	0
T60/887 x Na 33	20.0	18.8	1.73	3.83	0	0
T65/238 x Na 33	42.4	49.3	1.66	2.73	0	0
T79/467 x Pa 7/808	38.9	49.3	2.39	3.39	1	0
T92/1615 x Pa 7/808	8.9	24.0	1.66	2.45	0	0