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GENETICS OF RESISTANCE TO APHIDS (*Aphis craccivora* Koch) AND UTILITY OF LINE MIXTURES IN COWPEA (*Vigna unguiculata L. Walp*)

By

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THESIS

submitted in partial fulfilment of the requirement for the degree

DOCTOR OF PHILOSOPHY IN HORTICULTURE

Faculty of Agriculture
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Department of Olericulture
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1990

To

My beloved son

Sharon

DECLARATION

I hereby declare that this thesis entitled **"Genetics of resistance to aphids (_Aphis craccivora_ Koch) and utility of line mixtures in cowpea (_Vigna unguiculata_ L. Walp)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society.

Vellanikkara,
5th December, 1990.

SALIKUTTY JOSEPH

CERTIFICATE

Certified that this thesis entitled **"Genetics of resistance to aphid (<u>Aphis</u> <u>craccivora</u> Koch) and utility of line mixtures in cowpea (<u>Vigna</u> <u>unguiculata</u> L. Walp)"** is a record of research work done independently by **Smt.SALIKUTTY JOSEPH** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellanikkara,

5th December 1990.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Smt.SALIKUTTY JOSEPH,** a candidate for the degree of Doctor of Philosophy in Horticulture agree that the thesis entitled **"Genetics of resistance to aphids (*Aphis craccivora* Koch) and utility of line mixtures in cowpea (*Vigna unguiculata* L. Walp)"** may be submitted by Smt.Salikutty Joseph in partial fulfilment of the requirement for the degree.

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SALIKUTTY JOSEPH

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Introduction

INTRODUCTION

Interest in locating resistance of vegetable crops to insect attack has grown rapidly in recent years as a result of problems associated with the vegetable industry's dependence on a dwindling number of insecticides. This is further embellished by environmental protection groups for fear of residual toxicity and underground water pollution. Many of the currently recommended insecticide treatments lack the persistence needed for adequate control of certain pests (Ellis and Kempton, 1981). Upto the mid 1960's, the organochlorine insecticides offered such good control of many vegetable pests that no other control measures were needed. Because of their persistence (residual toxicity) and the development of insecticide-resistant strains of certain insects, the organochlorines are largely being phased out. The limitations placed on the toxicity of pesticides to man and wild life and on their persistence narrowed down the field of permissible compounds. The chemical companies quite reasonably develop pesticides primarily for the larger, profitable markets, minor requirements have therefore to be met by materials developed mainly for other purposes. Unfortunately most vegetable pest problems fall into the category of minor pesticide usage, even world-wide, so a few of the new insecticides released are ideally suitable for controlling vegetable pests also. Other control measures are needed to supplement the insecticides currently used to protect vegetable crops.

There is another very important contributory factor to the difficulties in controlling vegetable pests. Circumstantial evidences suggest that the more recently-bred cultivars of crops are more susceptible to pests than the cultivars grown by our forefathers (Russell, 1978). In the evolution of plants, the continual pressure exerted by phytophagous insects would have resulted in the natural selection of plants resistant to these pests. In the early days of organised plant breeding, this situation would still have prevailed and any pest susceptible progenies being quickly eliminated from breeding programmes. With the advent of insecticides the situation changed dramatically. Crops grown for seed purpose received blanket sprays of chemicals to protect them from insect attack throughout their growth in the field and to ensure high yields of good quality seeds. Thus, the breeders unwittingly selected for qualities such as uniformity and yield without the complication of insect attack. In a few instances this method of selection developed ultra-susceptible lines where both susceptible and resistant plants would have contributed to the breeding of new cultivars resulting in dilution of any valuable resistance. There is clearly an urgent need to evaluate plants for resistance to pests during development of new cultivars and recover the resistance that has been lost.

Host-plant resistance offers one of the most effective pest control measures and one that will fit in the best with chemical methods of control. Even partially resistant cultivars enable adequate control to be achieved with less insecticidal uses. In doing so, it helps to prolong the useful commercial life of existing insecticides by discouraging development of insecticide-resistant strains of the insect. In addition, the effectiveness of parasites and predators in controlling a pest may be improved on cultivars possessing even a low level of resistance (Van Emden, 1966).

The above being the present day situation, studies were taken up to identify source(s) of resistance, if any, in one of the most important legume vegetables, the cowpea, under Indian situations. Cowpea forms an important component in the tropical cropping systems of India, especially Kerala. It is a multiseason and multipurpose crop which can be cultivated either as monocrop or in mixed cropping situations with other crops, particularly cereals. Also it is grown as a backyard crop, near small farm houses, in a wide range of environments, often on poor soils with marginal moisture and with no fertilisation. Its importance is realised on account of its drought tolerance and adaptation to wide range of soil types. In subsistence agriculture on small farms, the nitrogen fixing ability of cowpea is of special advantage. It is grown throughout India for its long, green pods as vegetable, seeds as pulse and foliage as fodder. Cultivation is concentrated in Southern States of India. It is a major source of protein, energy, minerals, vitamins and roughage, in addition to its manifold uses in animal feed. The area under this crop is increasing in Kerala consequent on the development of short duration bushy types well adapted to the cereal farming systems of homestead conditions. It is variously named as lobia, rawan, barbatti, chaula or chowlee., black eye pea, kaffir pea, china pea, southern pea, etc. Its green tender pods, when properly cooked make a delicious dish. The green pods are variously known as asparagus bean, snake bean and yard long bean. It is considered as a counterpart to french beans. The over-riding biological constraint is the damage caused by many insect pests.

Nutritionists regard pulses as an essential means to correct malnutrition. Even in the developed countries, the trend is in favour of substituting animal protein by vegetable protein in view of the indications about the positive correlation of arteriosclerosis with diets rich in saturated fatty acids, on the one hand, and decrease in blood cholesterol level with inclusion of pulses, on the other. India has the distinction of being the world's largest producer of grain legumes (pulses) eventhough the production is not adequate to ensure a per capita availability of 80 g, which is the minimum recommended by the World Health Organisation and the Food and Agriculture Organisation. In fact, it dropped from 64 g in 1951-56 to less than 40 g in 1987-88. This is attributed to area, production and productivity stagnating over the past three decades. According to official sources, the area under pulses is around 20 to 24 million hectares, the production around 10 to 13 million tonnes and the productivity around 475 to 544 kg/ha.

Cowpea aphid (*Aphis craccivora* Koch) is a cosmopolitan species of considerable importance on cowpeas and related legumes. Its incidence on the crop is often very early. The pest build up is very fast due to parthenogenesis and telescoping of generations. Plants heavily infested at the juvenile stage soon become wilted and frequently perish while older plants are stunted in growth and display distorted leaves. Their fruit set is reduced. Aphids also affect cowpea yields indirectly by transmitting virus diseases. It is a vector of alfalfa mosaic, bean common mosaic, bean yellow mosaic, cowpea aphid-borne mosaic, cowpea banding mosaic, cowpea mild mottle, pea leaf roll and chickpea stunt. The cowpea aphid is readily controlled by application of insecticides like lindane, dimethoate, monocrotophos, menozon, phosphamidon and carbofuran. But the chemicals create hazards to human health and produce undesirable side effects on non-target insects, animals and plants. Development of pest resistant varieties is the most effective and the least expensive, desirable goal without detrimental, environmental side effects. Resistant varieties offer the best, viable long term, control option for coping with this pest, particularly, in view of the high cost and unpredictable availability of chemicals. Again in Kerala, the acreage worked by the average farmer is small and many of the farmers are not much familiar with proper use of insecticides. Unscrupulous uses of insecticides result in the death of natural enemies and consequent pest resurgence. Use of resistant varieties is the best method in the integrated control of aphids. If aphid-vector resistant cultivars would last 10 years, as has been calculated for aphid-pest resistant ones (Horber, 1972), the return would probably exceed 300:1 compared to the 5:1 return calculated by Metcalf (1971) for chemical pesticides.

Aphids feed on phloem sieve tubes. Phloem sap is under 15 to 30 atmospheres of pressure, sufficient to force sap through the extremely fine food canal in an aphid's stylets, and one could suppose that aphids feed passively (Pollard, 1973). Biology of the pest may also be directly related to quality of food material which it derives from the preferred host. Search for resistant lines can be made easier and faster by identifying possible biochemical and morphological factors, responsible for resistance. Incorporation of resistance into other widely adapted, high yielding varieties, necessitates knowledge regarding the gene system governing resistant behaviour of plant.

Relative stability of pest resistance is influenced by the host-plant specificity of the insect as well as by the genetic diversity and population density of the plant (Beck and Schoonhoven, 1979). Although insect utilization of the resistant plant might be low, through several generations the intense selective pressure would soon result in an adapted insect population. Here comes the practical application of the concept of physical mixtures. A particular non-preferred plant is not chosen as a host because of the presence of another preferred one, whereas the non-preferred plant is accepted as a host if there is no other choice. The effect, would be to manage the pest population for the purpose of avoiding build up of specific races.

The present studies were taken up with the following objectives:

1. To identify source(s) of resistance in cowpea to aphids.
2. To study morphological and biochemical bases of resistance to cowpea aphids.
3. To study genetics of resistance to aphids, and
4. To develop multilines/physical mixture to manage aphids.

Review of Literature

REVIEW OF LITERATURE

Cowpea aphid (*Aphis craccivora*) has a wide distribution across many parts of Europe, Asia, USSR, Africa, Australia, Pacific Islands, North America and West Indies (Singh and Van Emden, 1979). In India, the pest was reported in Tamil Nadu, Punjab, Maharashtra, Bihar, West Bengal, Orissa, Andhra Pradesh, Karnataka and Kerala. The host plants of cowpea aphid include lima bean, chick pea, lentil, red gram, lablab bean, alfalfa, groundnut, broadbean and peas (Fletcher, 1919; David, 1957; Anonymous, 1959).

A. Varietal reaction of cowpea to aphids

Singh (1977) at IITA Nigeria found cowpea lines TVu-408 P_2, TVu-416, TVu-2740, TVu-3417 and TVu-3509 resistant to aphids. Bell (1980) evaluated 259 cowpea lines for resistance to aphids and reported PI 476, EC 4276, V-1 and T 422/2 as resistant. Dhanorkar and Daware (1980) found that, out of 14 lines evaluated for incidence of aphids, lines PI 473 and PI 476 were completely free from aphid infestation.

Karel and Malinga (1980) evaluated 11 cowpea accessions and found that the lines TVu-408 P_2, TVu-410 and Ife brown were resistant to the aphid Acyrthosiphon gossypii. Trials conducted at IITA, Nigeria proved TVu-36 as an aphid resistant source. The lines TVu-9836, TVu-9914, TVu-9929, TVu-9930 and TVu 9944 were resistant to cowpea aphid borne mosaic virus (CAbMV) and cowpea aphids (IITA, 1982). Of several cowpea accessions evaluated for their reaction to aphids, TVu-18, TVu-36, TVu-42, TVu-109, TVu-310, TVu-801, TVu-1037, TVu-2755, TVu-2896, TVu-3000, TVu-3273, TVu-9836, TVu-9914, TVu-9929, TVu-9930 and TVu-9944 were resistant (IITA, 1982). Mcfoy and Dabrowski (1984) found that the cultivars TVu-310 and 408 P_2 were relatively resistant as compared to variety Vita I. The line IT 81D-1020 was resistant to aphids, as reported at IITA (IITA, 1985).

Messina et al. (1985) evaluated nearly 200 accessions of cowpea for resistance to cowpea aphids. The varieties reported resistant in W. Africa were highly susceptible to aphids from Southern United States. In trials at four places in Nigeria and one in Burkina Faso during 1985, IT 83 S-742-11 and IT 83-S-728-5 performed consistently well at all locations with good resistance to aphids (IITA, 1986). Pathak (1988) reported four cultivars ICV 10, ICV 11, ICV 12 and Tvu-310 resistant to aphids at Nairobi, Africa.

Ofuya (1988) evaluated 24 varieties of cowpea at Nigeria and reported that the lines EW/1, TVu-1037, TVu-2896, TVu-2994 and TVu-3000 had the lowest field infestation. Four hundred and eight accessions of cowpea were evaluated for resistance to aphids by Jayappa and Lingappa (1988). They found that the lines Mandya Local, MS 370, TVu 2740, P-912 and PI-475 had greater consistency in imparting resistance to aphids.

B. Morphological and biochemical bases of resistance

1. Physical defences of plants

The leaves and stems of many species of plants are covered with small epidermal hairs and/or hooks. The function of this pubescent cover was investigated and it was not known whether host specific aphids respond to pubescence in selecting their host plants.

Certain plants possess glandular hairs which produce exudates which trap insects and reduce damage by the pest. Hairs contribute to resistance in tomato to aphids (Mc Kinney, 1938), to whiteflies (Gentile et al., 1968) and in certain potato lines to aphids, mites, leaf hoppers and to colorado potato beetle larvae (Gibson, 1974, Tingey and Gibson, 1978). Investigations by Fluiter and Ankersmit (1948) revealed that *Aphis fabae* suffered a high mortality on bean plants, as a result of being caught on the hooks.

Hooked trichomes on french bean had profound detrimental effects on populations of Aphis craccivora (Johnson, 1953). Aphids are caught by the tarsal claw as they walk about or feed. He observed that the hairs were present on petioles, stems and undersurfaces of the leaves but were absent on uppersurfaces of leaves. They were the most dense on growing shoots and therefore the most injurious to aphids. Legs of aphids became impaled on the hooks. The results of subsequent bleeding, starvation and exhaustion decreased the longevity and reproductive rate of aphids. High nymphal mortality, increased time for nymphal development and decreased nymphal size were the consequent effects. The decreased nymphal size was associated with a reduced fecundity.

Thurston et al. (1966) reported that the alkaloids excreted by the Nicotiana trichomes were toxic to green peach aphids where a few pests were poisoned by trichome secretions and others rendered harmless by immobilisation by secretions per se. This was again observed in case of resistance to aphids in wild potatoes (Gibson, 1971) and in selected Lycopersicon and Solanum species (Gentile and Stoner, 1968).

Trichomes are unicellular or pluricellular outgrowths from the epidermis of leaves, shoots and roots (Uphof, 1962). The collective trichome cover of a plant surface is called pubescence. Levin (1973) defined the term trichome as a hair-like appendage extending from the epidermis of aerial tissues. Levin (1973) and Johnson (1975) elucidated the ecological functions of trichomes and defence mechanisms against herbivores. Insect species respond differently to presence of plant hairs. Pubescence as a resistance factor interferes with insect oviposition, attachment to the plant, feeding and ingestion. The purely mechanical effects of pubescence depend on four main characteristics of trichomes; density, erectness, length and shape. In a few cases, trichomes possess associated glands which exude secondary plant metabolites. The effect of glandular trichomes depends on nature of the exudate. It may be composed of allelochemics such as alkaloids or terpenes (Johnson, 1975). Such toxic substances may kill insects on contact or act as repellents. In some plants, sticky exudates glue the insects legs and impede locomotion. Quiros et al. (1977) reported that increase in hair density in tomato plants restricted feeding activity of potato aphid, Myzus euphorbiae under field conditions.

Bell (1980) found that the aphid resistant cowpea accession PI 476 possessed the highest number of hairs.

Ferguson et al. (1982) also opined that glandular haired alfalfa (Medicago species) were not preferred and thus resistant to spotted alfalfa aphid (Therioaphis maculata).

Lampe (1982) revealed that the pea aphids (Acyrthosiphon pisum) readily settled on sparsely haired and densely haired varieties of French bean. However, a considerable proportion of settled aphids left the plants. Aphids remaining on plants became impaled on the hooked epidermal plant hairs and died within one week, although it was shown that the French beans were physiologically suitable as a food plant. Hairs were scattered over almost the entire surface of the plants and prevented the aphids from leaving plants.

The insect's choice or rejection of a particular plant for food, oviposition or shelter is a chain linked process (Baliddawa, 1985). Insect behaviour can be discussed as response of a single insect species to a single plant or a group of plants. Four single plant resistance attributes (viz. insect repellents, plant surface texture, shape and colour) affect insect behaviour through olfactory, physical and visual stimuli. In addition to these, diversity of plant species and plant density affect insect behaviour through concentration of insect food, changing the crop microclimate and changing the background contrast against which the insects locate their host plants.

Saxena (1985) described the behavioural basis of plant resistance to insects. Various plant characters influence the behavioural responses of insects in two ways (1) by providing sensory stimuli and (2) by providing mechanical features (eg. hardiness of tissues, hairiness, etc.) which facilitate or hamper behavioural responses. The sensory stimuli from various plant characters may be perceived at a distance or by contact. The distance perceivable characters emit visual (colour, shape, etc.) hygro (water vapour) and olfactory (non-aqueous volatiles) stimuli. The contact perceivable characters provide chemical (gustatory) and physical (tactile) stimuli. To understand the mechanisms of insect resistance in plants and their characters involved, the first step is to compare the above mentioned responses of an insect species to a given set of resistant and susceptible plant species or varieties. After this, the next step in understanding the mechanisms of plant resistance to the insects would be to examine their characters which determine its responses. Sorensen et al. (1985) registered an alfalfa accession rich in glandular hairs and possessing multiple pests resistance.

Influence of trichome density on the spread of nonpersistently transmitted plant viruses by aphid vectors was studied by Gunasinghe et al. (1988). Probing activities of three important aphid vectors of soybean mosaic virus, Myzus persicae, *Rhopalosiphum maidis* and *Aphis citricola*, were affected by the density of soybean leaf trichomes. Less pubescent and glabrous isolines elicited greater probing activity than did densely pubescent isolines. Field spread of SMV was negatively correlated with density of pubescence.

On simple haired alfalfa plants, the fecundity of spotted alfalfa aphid (*Therioaphis maculata*) was considerably low (Carter *et al.*, 1988).

2. Antibiosis

The antibiosis mechanisms of resistance to aphids were investigated by several workers. Dahms and Painter (1940), Harrington (1941) and Carnahan *et al.* (1963) observed reduction in the fecundity of the pea aphid, *Acyrthosiphon pisum* reared on resistant varieties of peas. Prolonged nymphal period was observed on resistant host to the pea aphid (Harrington, 1941) and spotted alfalfa aphid (Nielson and Curie, 1959). When Painter (1958) reared *Aphis gossypii* on resistant varieties of cotton in the laboratory, he observed reduction in fecundity, early death of adults and general inability to maintain a population on the resistant host plants.

Greenhouse experiments by Auclair (1958, 1959), Cartier (1959) and Auclair and Cartier (1960a, 1960b) with pea aphids on peas showed that antibiosis was responsible for reduction in reproduction, excretion of honeydew and reduction in adult weight of individuals. Another aspect of antibiosis was related to the restlessness factor (Cartier, 1963). On resistant alfalfa plants, the spotted alfalfa aphids became restless within one to four hours and eventually died or left the plant, little or no honeydew being produced. However, on susceptible plants, honeydew was produced profusely. Mortality of aphids on highly resistant plants was caused by starvation or dessication, resulting from failure to ingest a sufficient quantity of plant sap.

Khalifa and Sharaf El-Din (1965) found that the age of the leaves of cotton and bhindi affected the development and fecundity of Aphis gossypii. Nymphs on young leaves developed the most quickly, and those on mature leaves the most slowly. Fecundity was equally high on young and old leaves, but low on matured ones. Young and old leaves provided better nutritious conditions for development and reproduction than mature ones.

Glover and Stanford (1966) and Pederson et al. (1976) also suggested antibiosis as the mechanism of resistance in alfalfa to pea aphid (Acyrthosiphon pisum). Panda and Raju (1972) found that fecundity, nymphal weight, and longevity of aphids were less on the resistant varieties than on susceptible ones. Chari et al. (1976) reported that the resistant cowpea varieties supported a lower population of aphids/plant and indicated that resistance was caused by antibiosis.

Fortedar and Kushwaha (1976) found that duration of nymphal development of Aphis craccivora on cowpea was longer on resistant than on susceptible varieties. Insect mortality is the most easily observable characteristic of antibiosis according to Singh (1977). Mortality of aphids was increased to 37.5%-62.5% in resistant lines from nil in highly susceptible ones.

Karel and Malinga (1980) attributed antibiosis as the reason for resistance observed in cowpea lines TVu 408 P_2, TVu 410 and Ife Brown to Acyrthosiphon gossypii. Bell and Chelliah (1983) evaluated 259 cowpea accessions in field and found that compared with aphids cultured on resistant accessions, those cultured on susceptible lines had a shorter nymphal period, extended reproductive period, higher fecundity and increased adult longevity. Raju and Panda (1983) reported that fecundity and adult body weight of aphids were higher, nymphal period shorter and life span longer on susceptible green gram variety Shining than on moderately resistant and tolerant lines. Jackai and Singh (1983) also attributed antibiosis as reason for resistance in a few cowpea varieties.

Atiri et al. (1984) observed that aphids were smaller and less abundant on four aphid resistant lines than on the tolerant and susceptible ones and also the aphids made more probes of shorter duration on resistant lines. Mcfoy and Dabrowski (1984) observed, based on screenhouse and laboratory studies, that feeding by Aphis craccivora was more prolonged, the number of probes/minute lesser and its population growth greater on stems of the susceptible variety, Vita 1 as compared to two resistant cultivars, TVu 310 and 408 P_2. From choice and no choice tests, there was evidence that the basis of resistance was probably antixenosis and antibiosis.

Messina et al. (1985) evaluated nearly 200 varieties of cowpea for resistance to cowpea aphids. Life table comparisons using a resistant and a susceptible variety revealed a three fold difference in the intrinsic rate of increase and more than 20 fold difference in the net reproductive rate. High nymphal mortality and low fecundity on resistant plants were largely responsible for these differences. Based on simulations, Wiktelius and Petterson (1985) suggested that any aphid resistant plant genotype should cause high nymphal mortality, prolonged development during early plant stages and a low birth rate close to ear emergence. Younis et al. (1985) opined that the rate of growth, reproduction and survival of Aphis fabae were affected by varieties. Holt and Wratten (1986) used rate of increase of aphids as a comparative measure of antibiotic resistance to Aphis fabae in faba bean.

Mechanism of resistance in cowpea lines TVu 1037, TVu 2896 and TVu 3000 included antibiosis, manifested as high mortality of nymphs, reduced life span and low fecundity of adults as reported by Ofuya (1988). Jayappa and Lingappa (1988) revealed that the biology of aphid was adversely affected when reared on resistant cowpea cultivars.

3. Biochemical mechanism of resistance

Nutritive value of the host plant plays an important role in determining plant susceptibility to insect attack.

a. Sugars

Aphids have a special feeding preference for sucrose. Sucrose is a necessary phagostimulant for Acyrthosiphon pisum (Auclair and Cartier, 1963) and Aphis gossypii (Auclair, 1967a and b) in a holidic diet. When sucrose was totally replaced by glucose or fructose, survival of Acyrthosiphon pisum and Aphis gossypii was significantly reduced. The low survival rate may be due to lack of palatability of sugars or their poor nutritive value. Wegorek and Krzymanska (1974) reported a relationship between the ratio of protein to sugar in varieties of lucerne and their susceptibility to infestation by Acyrthosiphon pisum. In greenhouse studies, the ratio was markedly higher in susceptible varieties than in resistant varieties. In field grown plants, the ratio was the lowest during early stages of plant development at whichtime the plants are highly resistant to aphid infestation. Barlow et al. (1977) observed that pea aphid, Acyrthosiphon pisum preferred mostly soluble carbohydrates and total protein. Barlow and Randolph (1978) reported that Acyrthosiphon pisum preferred the young pea plants to woody perennials because the phloem sap of young pea plants apparently had lower sugar content and higher total amino acid than woody perennials. Chhabra et al. (1986) found that the leaves of aphid resistant cultivars of blackgram had higher contents of reducing and non-reducing sugars. Mcfoy and Dabrowski (1984) found no relationship between total sugars and resistance in cowpea to aphids.

b. Nitrogen

Auclair and Maltais (1950), Maltais (1951) and Auclair et al. (1957) reported that the amount of nitrogen in pea varieties in terms of free and total amino acids contributed significantly to resistance or susceptibility of these varieties to pea aphid.

Maltais (1951) reported that nitrogen content in whole plant samples and in water extracts were higher in susceptible pea variety to Macrosiphum pisi than in the resistant ones. Maltais and Auclair (1957) reported that the varieties susceptible to pea aphid Acyrthosiphon pisum contained more nitrogen than resistant ones. Total soluble nitrogen appeared to be a generally useful indicator of susceptibility of plants to aphids (Van Emden, 1972). Mattson (1980) opined that pest infestations were affected by the nitrogen status of the host. In broad bean, the variety that was heavily infested by Aphis fabae Scopoli had a higher nitrogen content than others (Younis et al. 1985). Patriquin et al. (1988) found that the fecundity of aphids was commonly proportional to the soluble nitrogen content of phloem, and increased when plants were fertilised with nitrogen.

c. Phosphorus and potassium

Barber and Tauber (1951) reported that under field conditions, peas grown on soils severely deficient in either nitrogen, phosphorus or potassium would be damaged more heavily by Macrosiphum pisi than plants grown on soils of good fertility. Auclair (1965) reported that optimum levels of phosphorus and potassium were required for the development of aphids, lower or higher concentration being detrimental to aphids. Rahier (1978) found that high proportion of nitrogen and a low proportion of potassium in Brassica rapa are suboptimal for the plants but favoured the development of Myzus persicae.

d. Secondary plant substances

Pederson et al. (1976) reported positive correlation between high saponin concentration and resistance to pea aphids. Krzymanska (1983) confirmed that there existed a relation between level of saponins in alfalfa tops and its resistance to the pea aphid. The saponins isolated from alfalfa leaves added to the artificial diet, retarded development of the pest.

Mcfoy and Dabrowski (1984) based on chemical analysis of stems of cowpea, reported correlations of total phenols and total flavonoides with resistance to Aphis craccivora. Chhabra et al. (1986) observed that the leaves of resistant blackgram cultivars had higher contents of total phenols.

According to Maxwell and Painter (1962), susceptible plants usually contain higher amounts of free auxins than resistant plants. Pons and Moyano (1970) reported that the inhibitor and auxin-like substances in alfalfa affected degree of susceptibility, resistance or immunity to aphids.

Wegorek and Krzymanska (1968) observed that resistance in a few lupin varieties to infestation by Acyrthosiphon pisum was due to presence of alkaloids in leaves. Aphid probing and penetration can be affected by content of sinigrin (Nault and Styer, 1972).

e. Plant proteinase inhibitors

Presence of proteinase inhibitors in plants was first reported by Read and Haas (1938). Since then, inhibitors present in storage organs of Leguminosae, Graminae and Solanaceae attracted the most attention (Ryan, 1973). In addition to their presence in storage organs, proteinase inhibitors were identified in leaf extracts of a number of plant species (Chein and Mitchell, 1970; Walker-Simons and Ryan, 1977).

Plant proteinase inhibitors are considered as both regulatory and protective proteins and even as artifacts of evolutionary processes (Ryan, 1979). Activity of many plant proteinase inhibitors is usually specific for digestive proteinases, produced by animals and microorganisms (Ryan, 1973). As a result of their specificities, their presence in plant is often thought of, in terms of protecting plants by arresting the proteinases of attacking pests (Applebaum, 1964; Ryan, 1973). The active site of trypsin-like enzymes of insects was similar to that of higher animals and could be potently inhibited by natural trypsin inhibitors from plants.

Applebaum (1964) proposed that the proteinase inhibitors in legumes evolved as a defence mechanism against insects and that protein digestion in insects should be considered as a factor in host selection. The possible involvement of proteinase inhibitors in plant protection received considerable support from the finding that Colorado potato beetle infestation induced rapid accumulation of proteinase inhibitors in the leaves of potato and tomato plants (Green and Ryan, 1972).

At IITA, Ng et al. (1987) analysed the Trypsin inhibitor content in raw cowpea seeds and found that the TI units/mg protein ranged from 27 to 66 and that it was not related to resistance to bruchid pests.

4. Influence of weather factors on aphid population

The role of ecological factors on field population of aphids was reviewed by many workers. Multiplication of aphids was favoured by the moist and cloudy weather. Consequently with occurrence of favourable weather conditions for a longer period of time, a severe outbreak of aphids could be apprehended

(Singh and Sidhu, 1959, Jarvis, 1969). Higher temperature and radiation increased the aphid (Aphis fabae) population on field bean in late June and mid July or in early August (Way, 1967). Mathew et al. (1972) studied the population fluctuation of Aphis craccivora on cowpea and reported that the high and low populations occurred from September to April and from May to August, respectively. Saleh et al. (1972) revealed that the population density of Aphis craccivora reached the maximum on broad bean during March and during August on cowpea. Radke et al. (1973) reviewed the influence of relative humidity on development and reproduction of Aphis craccivora and reported that it preferred an optimal relative humidity of 65-70% for oviposition at 12.8°C and a photoperiod of 12 h induced the production of sexual forms. Of the various climatic factors, fog, frost, rain, severe cold and heat are reported important natural mortality factors for the aphids (Brar and Sandhu, 1976). Pal et al. (1978) delineated ideal conditions for the outbreak of Aphis craccivora as about 80% relative humidity, 27.5 to 28.5°C air temperature and a low number of sunshine hours. Bell (1980) found that higher maximum temperature and lower minimum temperature, relative humidity and rainfall prevailed during the period from January to May were conducive for the population build up of cowpea aphids. Sulochana (1984) reported that the aphid population got reduced considerably with increase in the number of rainy days and increase in average relative humidity. Singh et al. (1986) stated that there was no significant correlations between aphid (Myzus persicae) population and maximum, minimum temperature, wind velocity and rainfall indicating that Myzus persicae can survive and builp up at a wide range of temperatures (5-30°C). Kandaria et al. (1989) found that in Punjab, the population of Aphis gossypii decreased from mid-May to end of June, due to high temperature. Sinha et al. (1989) reported that the population builp up of aphid ceased at 50.90% humidity and below. Frequent rains during the population rise phase adversely affected aphid population build up.

C. Inheritance of resistance to aphid in cowpea

Screening work in South East India (Chari et al., 1976) and Nigeria (Singh, 1979) led to identification of several sources of resistance to Aphis craccivora. Recently, Pathak (1983) reported high levels of resistance in two cowpea cultivars, ICV 11 and ICV 12, obtained by induced mutation. An efficient breeding programme for insect resistance requires not only availability of sources of resistance but also knowledge of inheritance and genetic control systems. Not much of published works are available on inheritance of aphid resistance in cowpea. The literature pertaining to genetics of resistance to cowpea aphids, are reviewed below. International Institute of Tropical Agriculture (IITA, 1982) reported resistance as dominant to susceptibility and F_2 population segregated in a ratio of 3 resistant: 1 susceptible. The F_1, F_2, F_3 and backcross populations involving aphid resistant and susceptible parents were evaluated for their reaction to aphids (IITA, 1984). Inheritance of resistance was rather simple and the effects of individual genes were large and easily discernible. Resistance to aphids is a dominant trait and monogenically inherited as evident by 3 resistant to 1 susceptible in F_2 population and 1 resistant and 1 susceptible ratio in backcross population. Similar results were reported at the International Centre of Insect Physiology and Ecology (ICIPE) (Pathak, 1984).

Ombakho et al. (1987) studied inheritance of resistance to cowpea aphid using three resistant cultivars. In their experiments, parents, F_1 and F_2 population were artificially infested with 10 apterous adult aphids, in a screenhouse. Seedling reaction was recorded when the susceptible check was killed. The segregation data revealed that resistance is governed by single dominant gene and that resistance in ICV 10 and TVu 310 were controlled by the same dominant gene Ac_1 and that resistance in ICV 11 was controlled by another dominant gene Ac_2.

Similar, were the observations of Bata et al. (1987) and Pathak (1988). Bata et al. (1987) crossed the lines TVu 36, TVu 801 and TVu 3000, which are resistant to Aphis craccivora, with one another and with susceptible lines. The reaction of parental, F_1, F_2, F_3 and backcross generations under artificial infestation revealed that resistance was controlled by a single dominant gene in each line. Allelism tests showed that all the three resistant lines carry the same gene, designated Rac.

In a cross between susceptible and resistant cowpea lines, Pathak (1988) found that the F_1 populations were resistant, indicating the dominant nature of resistant gene(s) in those cultivars. The F_2 showed a segregation of 3 resistant: 1 susceptible seedling, indicating that resistance to the aphid in each case was governed by a single dominant gene. These conclusions were confirmed from reactions of the backcross progenies which segregated in a ratio of 1 resistant : 1 susceptible.

Works on aphid resistance in vegetables are limited. The published literature on mode of inheritance of insect resistance in certain important crops are presented in Table 1.

D. Multilines for higher yield and stability in performance

Heterogeneous populations are common in cross pollinated crops but are rare in self-pollinated crops. In self-pollinated

Table 1 Mode of inheritance of insect resistance in a few important crops

Crop	Insect pest	Inheritance	Reference
1	2	3	4
Legume and forage	Sweet clover aphid (*Therioaphis richmi*)	A single dominant gene controlled resistance. An additional complementary gene appeared to be present in some resistant clovers.	Manglitz and Gorz (1968)
	The pea aphid of alfalfa (*Macrosiphum pisi*)	One dominant gene conferred resistance	Glover and Stanford (1966)
	Spotted alfalfa aphid	1. Resistance was quantitative 2. Resistance could be both vertical and or horizontal	Glover and Melton (1966) Nielson and Kuehl (1982) Nielson and Olson (1982)
Cowpea	Weevil (*Callosobruchus maculatus*)	Resistance to cowpea weevils has additive, dominance and maternal components	Fatunla and Badaru (1983)
	Aphid (*Aphis craccivora*)	Resistance is a dominant trait and monogenically inherited	IITA (1984)
	Bruchids and thrips	Resistance was a recessive trait and digenically inherited	IITA (1984)
Vegetables	Lettuce root aphid (*Pemphigus bursarius*)	Resistance was controlled by extranuclear factor. Modifying genes might also be involved.	Dunn (1974)

Contd.

Table 1 Continued

1	2	3	4
	Lettuce leaf aphid (*Nasonovia ribisnigri*)	Resistance was due to one dominant gene	Eenink *et al*. (1982a, b)
	The melon aphid (*Aphis gossypii*)	A single dominant gene (Ag) was identified for resistance	Kishaba *et al*. (1981) Bohn *et al*. (1973)
	Striped cucumber beetle (*Acalymma vittatum*)	Resistance was governed by several genes and additive gene action was more important	Nath and Hall (1963)
	Green peach aphid (*Myzus persicae*)	Resistance appeared to be partially dominant in tuber bearing *Solanum* Genotype x environment interaction was low	Sams *et al*. (1976)
Trees and fruits	Rosy leaf curling aphid of apple (*Seppaphis devecta*)	A single dominant gene (S_2) was responsible	Alston and Briggs (1968)
	Rosy apple aphid (*Dysaphis phantaginea*)	A single dominant gene (Smh) was reported	Alston and Briggs (1970)
	The woody apple aphid (*Eriosoma lanigerum*)	A single dominant gene (Er) was responsible for resistance	Painter (1951)
	Aphid (*Amphorophora rubi*)	Immunity is governed by a single dominant gene linked to a semilethal gene	Daubeny (1966)

crops like wheat, ways of increasing and stabilising yield include development of multilineal varieties and suitable varietal blends. Superiority of multilineal varieties was reported by a number of workers. Clements et al. (1929) characterized competition among plants as a reaction-response phenomenon that gives one plant an initial advantage which is cumulative. Relation between competitive advantage and rapid early growth in mixed stands of weeds and cereals was shown by Pavlychenko (1937).

Montgomery (1912) stated "when two varieties are planted in competition, one variety is very apt to have an advantage, which, if continued, would in time cause it to practically replace the other. It appears also that the one yielding the best alone will not always be the one surviving under competition". He also noted that "for some reason, in almost every case with both wheat and oats, two varieties in competition have given a greater number of plants at harvest and a greater yield than when either variety was sown alone". This was explained by Elton (1927) on the assumption that different components of a plant community occupy different "niches" from which the competition of others is countered with their own peculiar advantages.

Considerable work was also done on effect of mixtures or varietal blends on yield. There are growing evidences that multiline mixtures of soybeans (Mumaw and Weber, 1957; Probst, 1957; Caviness, 1966) and other grain crops (Jensen, 1952; Gustafson, 1953; Simmonds, 1962; Jensen, 1965) often perform somewhat better than the means of the component lines. Probst (1957) found that 13 soybean varietal blends during 4 years yielded on an average 2.2% more than the mean of their pure lines. Frey and Maldonado (1967) showed that mixtures of oats produced higher yield and gave greater stability than pure cultivars. Brim and Schutz (1968) observed that certain combinations of soybean genotypes led to a sizable net gain in performance.

Pandey et al. (1978) reported that at all locations, differences in yield of mixtures of wheat and the average yield of their corresponding components were non-significant. However, certain composites gave higher yields upto 8.5% over average of their components. In their study, field observations indicated that, where height differences were not much, composites gave good appearance and also showed superiority in yield over the average yield of their components. But where height differences were quite marked or distinct, the plot looked very uneven and yield superiority of composites over the average of their components was very minor and in certain cases, there was a negative trend.

In addition to the beneficial effects of these synergistic interactions, the argument is often advanced that the genetic diversity of heterogeneous population should lead to stability of performance over fluctuating environments. Simmonds (1962) suggested that stability can result from "specific population adaptation", "general population adaptation" or both. He defined specific population adaptation as the aspect of stability that is attributable to interactions among components, and general population adaptation as the adaptation to varying environments of the components themselves. Allard and Bradshaw (1964) used the terms "population buffering" and "individual buffering" to describe these phenomena. Data reviewed by Simmonds (1962) and results reported by Allard (1961), Jensen (1965), Frey and Maldonado (1967) and Qualset and Granger (1970) supported the hypothesis that mixtures are more stable than their component genotypes. Data from four soybean varietiies, their six two-component mixtures and four three-component mixtures were used to study effect of intergenotypic competition on population stability by Schutz and Brim (1971). They measured stability by estimating relative contributions of purelines and mixtures to the first and second order interactions of entries, locations and years; by constructing frequency distributions of rank order, and by regression and deviations from regression of population performance on environmental productivity. Three of the six two-component mixtures exceeded their component means by a significant amount and were arbitrarily classified as over compensatory. Two component mixtures with yields similar to their component means were classified as complementary. They opined that both over compensatory and complementary competition effects appear to be essential to obtain a high degree of stability in a heterogeneous population.

Arsyad et al. (1984) reported that in twelve, 2 variety mixtures of soybean, the mixtures significantly exceeded the better component variety in yield by on an average 15% during June planting and 9% during September planting. All of the mixtures were significantly superior to the component means due to over compensation. Harrabi et al. (1986) reported that barley mixtures gave higher yields, than purestands, especially at lower yielding sites. Yield of four 50:50 blends and their eight cultivar components in wheat were measured for 3 years on a silty clay and silty loam and got a significantly higher yield, than the mean of their components, only on the loamy soil and concluded that on some soils, mixtures may be more stable than cultivars (Bacon et al., 1987).

Gubbels and Kenaschuk (1987) found that in flax, the mixture generally had stabilised production by yielding about midway between the seed yields of the 2 components grown in purestands, and thereby resulted in no advantage over growing the components in separate fields.

Dhingra et al. (1987) opined that mixed stands tended to intercept more photosynthetically active radiation than did pure stands of wheat. In barley, Gacek (1987) reported 3-15% increase in yields in mixtures compared with average of mono-cultures.

Leon and Diepenbrock (1987) found that in rapeseed, a few purestands yielded more than some mixtures, but no pure-stand outyielded the overall mean of the mixtures. Mixtures also had higher yield stability than purestands. Analysis of variance showed that lines differed in their general mixing effects and that these effects were more important than specific mixing effects in determining yield. It was concluded that it is not necessary to examine a complete diallel to find the best mixture.

a. Multilines for disease management

Hartley (1939) pointed out that genetic uniformity favoured building up of specialised strains of parasites and advocated mixtures of desirable clones of trees rather than purestands of a single clone. He also reported that in about 1914 in the

Dutch East Indies, it was proposed that a dozen or so purelines of rice be grown in mixtures to provide a single variety having greater adaptability. Hutchinson et al. (1938, 1947) dealing with sorghum and cotton stated that while much progress can be made through isolation of purelines, maintenance of variability in the total population of a crop must be given greater emphasis in future. Stevens (1939, 1942, 1948) pointed out the relationship between disease losses and pollination types in small grains and showed how plant breeding practices affect the host-suscept relations and changes in populations of pathogens. In contrast, Caffrey (1948) suggested that a mixed population of host plants might favour evolution of biological forms of plant pathogens. Stevens (1949) proposed the rotation of varieties to take advantage of the population shifts of pathogen associated with the continued growth of one variety. Rosen (1949) suggested the possibility of "utilizing mixed populations of any one cross and not breeding for uniformity" for management of pathogen.

Development of multiline varieties, originally suggested by Jensen (1952) and Borlaug (1958) aim at incorporating different genes into isogenic lines by backcrossing, mixing the lines in equal proportion, and releasing the result as a commercial multiline cultivar. If a component line of this cultivar becomes susceptible, it can be pulled out and replaced with another resistant line. The strategy was proposed as a way to control cereal rusts. Only one or a few lines of the mixture would become susceptible to the pathogen in any one season i.e. only a small proportion of the plants would be infected by the pathogen. Consequently the disease would spread more slowly than when the entire population was under a single line.

Use of multiline varieties in self-pollinating crops was advocated since the late nineteenth century (Simmonds, 1962, Browning and Frey, 1969). Programme of multiline production are based on two radically different philosophies for disease control (Marshall, 1977). In one approach, designated as the "clean crop" approach, all component lines of the mixture would be resistant to all prevalent races of the disease(s) to be controlled (Jensen, 1952; Borlaug, 1958). The aim of this scheme is to keep the crop as free of diseases as possible, and at the same time to reduce the threat of catastrophic disease losses following shifts in the racial composition of the pathogen population. In the second approach designated the "dirty crop" approach (Marshall and Pryor, 1979), each line in the mixture also carries a different single gene resistance, however, none of the lines is resistant to all known races of the pathogen. Frey <u>et al</u>. (1973, 1975) argued that such multilines should protect the crop in two ways.

The multiline varieties should stabilize the race structure of the pathogen population (Suneson, 1960; Jensen and Kent, 1963; Leonard, 1969a, b). This is based on the fact that stabilizing selection against races carrying multiple genes for virulence (Van der Plank, 1963, 1968) will ensure that simple races, carrying a single virulence gene, dominate the pathogen population. Since each component of the multiline would be attacked by only one race of the stabilised pathogen population, the remaining lines would act as spore traps, reducing rate of disease spread. In this way, multiline cultivars would have an effect similar to polygenic non-specific or horizontal resistance (Van der Plank, 1963) in delaying the intercrop build-up of the pathogen.

The "dirty crop" approach using partially resistant multi-lines, has a significant potential advantage over the "clean crop" approach, using completely resistant multilines (Marshall and Pryor, 1978). Since moderately susceptible lines are also considered, the breeder is in an advantageous position as he can exercise selection for other characters like yield, height, maturity etc. (Gill et al., 1979). It would also extend indefinitely the useful life of strong resistance genes (Van der Plank, 1963) including those which have broken down in the past. It would free the breeder from the difficult task of continually isolating and evaluating new sources of resistance. The only common point between the two approachs is the final aim to produce a variety consisting of a number (6 to 15) of phenotypically similar lines which differ only in the resistance genes, they carry.

The pre-requisites of multiline cultivar approach are, proper identification of diverse genetic sources of resistance, adequate race survey, desirable and commercially acceptable and if possible, a widely adapted recurrent parent (Rao, 1968).

A multiline concept is not restricted to a true multiline variety, based on near isogenic components carrying different race-specific resistance genes. It also comprises variety or line mixtures where the component genotypes differ for the race-specific resistant genes they contain (Parlevliet, 1979). Shorter and Frey (1979) reported the advantages of mixtures over monocultures. They are (i) more stable resistance to diseases, (ii) greater stability of performance across diverse environments and (iii) higher yield through more efficient utilization of environmental resources.

When barley varieties Hassan, Midas and Wing were grown in mixtures, the infection with Erysiphe graminis was reduced by half and the yields were upto 11% higher than the means of the component varieties grown alone (Harvey, 1978). The effect of mixtures to reduce powdery mildew was reported by

Wolfe (1977), Stolen et al. (1980), Day (1981), Stolen (1982), White (1982) and Welling et al. (1983).

Gill et al. (1981) studied progression of yellow rust in mixtures of isogenic lines of wheat in varying proportions. Of the six component lines, two were highly susceptible, two were moderately susceptible and two were highly resistant. Fifteen possible mixtures were developed in 50:50, 25:75 ratios and a race mixture was sprayed. The results indicated that the development of rust was slow in mixtures as compared to the pure cultures even when seeds of the most susceptible parents were mixed and grown. Chin and Husin (1982) reported that rice variety mixtures could effectively control Pyricularia oryzae and produce highly stable yields. Disease levels were reduced to one-third of the mean severity in purestands. This would reduce the damage to the susceptible lines as well (Singh, 1983).

In a mixture composed of 3 varieties of Barley, disease symptoms developed more slowly in mixtures than in monocultures, with infection levels in the mixtures reduced by 30.70% (Gacek, 1987). Mixtures of 3, 4, 5 and 8 components from among 13 varieties and lines of barley with known genes for resistance to Erysiphe graminis were tested during 1981-84. Incidence of E. graminis in the mixtures were intermediate between that of varieties in which resistance had broken down and that in varieties in which it was still effective (Hengstmann, 1987).

b. Multilines for insect management

In a study of relationship of pea aphids to alfalfa and to canning peas, Eichmann and Webster (1940) pointed out that severe infestations of the latter crop are derived from alfalfa. They suggested use of resistant varieties of alfalfa for control of pea aphids on peas and predicted that the control of an insect on two crops by use of resistant varieties of one may become an actuality in future. Painter (1941) added that not only may one crop and one insect be controlled but where alternate hosts are involved there is a possibility of influencing insect population level in one crop by planting resistant varieties of an alternate crop. He also opined that the question of how soon a strain of hessian fly might become adapted to a resistant wheat is dependent on the proportion of acreage of resistant to susceptible varieties in a given area.

The environmental forces acting upon a given aphid population can ultimately cause that population to change to meet the requirement of the new environment for survival and perpetuation (Neilson <u>et</u> <u>al</u>., 1970). The development of biotypes ENT-A and ENT-F of aphids appeared to have resulted directly from the influence of resistant alfalfa cultivars, probably Moapa. According to them, stability of these biotypes is a matter of concern, since it is apparent that they continue to develop and change, thus making it imperative for research workers to stockpile varied pools of resistant germplasm. Data on biological activity of these biotypes suggested that virulence was more closely related to aphid feeding and physiological mechanisms than to fecundity. Moreover, virulence appeared to be correlated to the number of parental clones, susceptible to a biotype, i.e., as biotypes become more virulent, the number of susceptible clones in a resistant cultivar increases. Thus, virulent biotypes are able to damage a wider spectrum of resistant cultivars than less virulent biotypes. According to Neilson et al. (1970) an apparent solution for control of a virulent biotype in an infested area is replacement of the cultivar with those that have a broader base of unrelated, highly resistant germplasm. These types of cultivars should decelerate development of virulent biotypes.

Some spectacular successes controlling oat rusts with multilines in Iowa (USA) (Browning, 1974) suggest that for some plant pests, this approach may block rapid population build up. Moreover, as the pest population shifts in response to selection, other component lines can be substituted. The effect, if done with finesse, would be to manage the pest population for the purpose of avoiding build up of specific races (Mac Kenzie, 1980).

Weerapat et al. (1977) reported that when seedlings of the highly susceptible variety of rice RD 7, the resistant variety RD 9 and various mixtures of the two, were infested at two leaves stage with first instar individuals of Nilaparvatha lugens RD 7, RD 9 and a 50:50 mixture of RD 7 and RD 9 showed 100%, nil and 18% damage respectively. They concluded that by planting 50% of an area with a resistant variety, the damage resulting from the attack was reduced to levels lower than those expected on the basis of the ratio of the varieties used. Gold et al. (1990) reported that varietal mixtures of cassava had no overall beneficial effect against cassava hornworm and stem borer levels as compared to purestands, in Colombia.

Multilines are mechanical mixtures of phenotypically similar component lines, each differing for specific genes for resistance to the pest population. The power of the multiline is in the blocking of infection between plants. Use of the concept of multilines in insect control has not been explored much.

E. Natural regulation of Aphis craccivora on cowpea

Like every group of animals, aphids are also attracted by natural enemies. Aphid predators represent a group of insects. Major predators of aphids are arthropods (including coccinellids), various heteroptera (especially anthocorids), syrphids, hemerobiids and chryopids, mites, earwigs, phalangids and spiders (Heathcote, 1972). Except syrphid larvae, all the predators are highly mobile.

Many natural enemies of aphids are aphidophagous at larval stage. Adults of the predators need nectar, adults of syrphids and some chryopids need pollen. Presence of flowers directly within or in the neighbourhood of a given habitat would therefore appear, likely to raise the natural enemy/aphid ratio (Stary, 1962; Van Emden, 1965; Hodek et al., 1966). Predators act depending on the density of aphid population. Efficiency of the predator is enhanced by increase in aphid population and the predator reproduces more resulting in a rapid population build up (Smith and DeBach, 1942; DeBach, 1964). Abundance of a predator remained associated with the abundance of prey (Allee et al., 1949; Saharia, 1980). Efficiency of predators is calculated on basis of ratio of mummified aphids to live aphids in a sample (DeBach, 1964).

In India Coccinellidae, Syrphidae and rarely Cecidomyiidae are the potential predators of aphids (Agarwala et al., 1987). True aphidophagous Coccinellidae in India are represented by at least 36 species. Many other records of this insect group refer to incidental predators of aphids, or are doubtful records (Agarwala and Ghosh, 1988). Coccinellids are more common predators of aphids than any other insect group (Hagen, 1962;

Hodek, 1966). Among the aphidophagous Coccinellidae, those predate on *Aphis craccivora* are listed below (Agarwala and Gosh, 1988).

Name of predators	Distribution
I. True aphidophagous Coccinellidae	
Brumoides suturalis	Oriental Region
Coccinella septempunctata	Bengla Desh, Bhutan, India, Nepal, Palaearctic Region
Coccinella transversalis	Indo-Australian Regions
Coccinella arcuata	Indo-Australian Regions
Menochilus sexmaculatus	Japan, Oriental Region
Pseudoaspidimerus circumflexus	India, Sri Lanka
Scymnus (Pullus) *pyrocheilus*	Burma, India
Scymnus (Pullus) *quadrillum*	India
Scymnus (Pullus) *xerampelinus*	India
Spitocaria bisellata	Oriental Region
II. Incidental predator or doubtful records of Coccinellidae	
1. *Chilochorus nigritus*	India
III. Unidentified species of Coccinellidae	
1. *Micraspis* sp.	–
2. *Scymnus* sp.	–

The syrphid predators on Aphis craccivora found in North East India as reported by Agarwala et al. (1987) are the following:

Allograpta javana,

Betasyrphus isaaci,

Dideopsis aegrota,

Episyrphus balteatus,

Ischiodon scutellaris,

Macrosyrphus confrator and

Paragus crenatus

They reported that larvae of all the aforesaid species exclusively feed on aphids and were the most active at the heaviest aphid infestation on trees, shrubs or herbs. Adults depend on nectar and pollen of the flowering plants and oviposit essentially in aphid colonies.

The Cecidomyiidae predating on Aphis craccivora found in India is Monobremia rishikeshensis (Agarwala et al., 1987). The larvae exclusively feed on aphids. It usually attacks its prey by piercing leg joint or some other body-joints. A toxin is injected which paralyses the aphid as aphids are rapidly immobilised, once they have been attacked. Once the prey has been seized and immobilised, the larvae settle to feed by extracting the body fluids.

Materials and Methods

MATERIALS AND METHODS

Present studies were conducted during 16 consecutive crop seasons (November 1986-January 1987, February-May 1987, June-August 1987, August-October 1987, November 1987-January 1988, January-March 1988, June-August 1988, August-October 1988, October-December 1988, December 1988-February 1989, January-March 1989, July-September 1989, October 1989-January 1990, November 1989-February 1990, January-March 1990 and June-August 1990) at the Vegetable Research Plot of Kerala Agricultural University. The plot is located at an altitude of 23 meters above mean sea level and is situated between 10° 32' N latitude and 76° 16' E longitude. Geographically, it falls in the warm humid tropical climatic zone. The weather parameters, during periods of experimentation were recorded. Soil of the experimental site is a deep, well drained and moderately acidic laterite loam fairly rich in organic matter. The studies consisted of following four main experiments.

A. Identification of source(s) of resistance to aphids in cowpea and estimation of level of resistance

B. Morphological and biochemical bases of host reaction to aphid infestation

C. Genetics of resistance to aphids (Aphis craccivora) in cowpea

D. Development of physical mixtures in cowpea to manage aphids

E. Natural predators and their identification

A. Identification of source(s) of resistance to aphids in cowpea and estimation of level of resistance

A total of 204 lines, which include both exotic and indigenous collections, were included in the preliminary field evaluations. Screening was conducted in a staggered manner over 11 seasons, and the better lines found in each stage/season of screening were further included in subsequent stages/seasons to reach the final evaluation and derive valid inferences.

Single row of seeds were sown 20 cm apart, on ridges/ furrows of 2 m length taken at a spacing of 2 m. The crop was raised following package of practices of Kerala Agricultural University (KAU, 1989). Susceptible checks (Kolencherry local and Pusa Komal) were grown all around the plots to attract aphids to the experimental plot. Development of aphids on the plants were watched at all stages of plant growth and the intensity of infestation was measured on a 0-2 scale as detailed below:

Aphid count	Class of infestation	Grade	Resistance rating
< 100 aphids	Low	0	Resistant
100 to 200 aphids	Medium	1	Moderately resistant
> 200 aphids	Heavy	2	Susceptible

(Bell and Chelliah, 1983).

Description of cowpea lines were made using the following descriptor.

A. Qualitative characters

1. Growth habit
   - a) bushy
   - b) semiviny
   - c) spreading
2. Stem and petiole colour
   - a) light green
   - b) green
   - c) light purple
   - d) purple
3. Pod colour
   - a) light green
   - b) dark green
   - c) light purple
   - d) purple

4. Seed colour

   a) light brown

   b) brown

   c) black

   d) purple

   e) cream

   f) white

B. Quantitative characters

1. Plant height (cm)
2. Branches/plant
3. Days to first flowering
4. Pod length (cm)
5. Seeds/pod
6. Pods/plant
7. Pod weight (g)
8. Pod yield/plant (g)
9. Hundred seed weight (g)

1. Estimation of level of resistance/susceptibility of selected cowpea lines, in the field - free choice test

Based on preliminary evaluations, nine promising accessions were selected. The accessions are Vs 350, Vs 438, Vs 452, Vs 306, Vs 307, Vs 147, Vs 456, Vs 457 and Vs 458. They were subjected to vigorous evaluation, along with two highly susceptible and locally adapted cowpea lines, to confirm their host response at field level. Counts of aphid population build up on the terminal shoots, terminal leaves, flowers and pods were taken from ten plants of each accession. They were further scored following above rating system.

2. In vitro evaluation of identified cowpea lines - no choice test

The identified cowpea lines were raised in 30 cm pots, thinned to one seeding/pot and each entry was grown in confinement in screenhouse (Plate I). When the first trifoliate leaf was fully expanded, (when 10-12 days old) each seedling was infested with 4 second instar nymphs and replicated 5 times. The population build up of aphids in these plants were recorded 10 and 15 days after infestation.

B. Morphological and biochemical bases of host reaction to aphid infestation

Based on intensive field evaluation and in vitro screening, three highly resistant and two highly susceptible and locally adapted lines were selected to study morphological and biochemical bases of resistance/susceptibility. The resistant lines are Vs 350, Vs 438 and Vs 452 and susceptible lines are Kanakamony and Pusa Komal. The detailed pedigree, source and mean performance of the lines are given in Table 2 and morphological description in Table 3.

1. Mechanism of preference/non-preference

a. Migratory and settling preferences

Raised circular beds of 0.8 m diameter were prepared. Seeds of susceptible line Pusa Komal were sown in the centre and all the five varieties were sown radially. The central plant was artificially infested and protected (Plate II). When the plants were 15 days old, the central plant was cut and placed in the middle point. The number of aphids migrated and colonised on the test entries were recorded the next day. Observations were made on eight plants from each line. The experiment was repeated under laboratory conditions. Shoot tip clippings of all the five varieties were taken, tagged, and kept intertwined in conical flasks filled with water (Plate III). Ten adult aphids were brought and let free onto the shoot tips randomly. The next day the shoot tips were observed for settled aphids. Experiment was repeated four times.

Plate I. Estimation of fecundity through cowpea culture in a screen house

Plate II. Migratory and settling preferences of *Aphis craccivora* in cowpea demonstrated in field

Table 2 Pedigree, source and mean performance of the cowpea lines evaluated for resistance to aphids

Accession number	Pedigree	Source	Height (cm)	Branches/ plant	Days to first flowering	Pod length (cm)	Seeds/ pod	Pods/ plant	Pod weight (g)	Pod yield/ plant (g)	Hundred seed weight (g)	Season
1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 244	3 Brown	National Bureau of Plant Genetic Resources Vellanikkara	184.0	3.0	46	15.9	14.7	16.0	3.5	56.00	11.20	November 1986 - January 1987
Vs 245	11 D B		156.0	4.0	42	20.0	17.3	13.0	2.9	37.70	10.70	
Vs 246	12 A. Black		197.0	4.0	52	15.2	14.7	17.0	3.3	56.10	10.70	
Vs 247	13 Brown		265.0	3.0	43	15.8	15.0	18.0	3.7	66.60	11.00	
Vs 248	36 Brown		146.0	3.0	53	17.2	15.5	14.0	3.8	53.20	12.04	
Vs 249	50 Black		212.0	3.0	40	14.7	13.6	13.0	4.2	54.60	9.60	
Vs 250	125 ALB		96.0	4.0	56	11.6	10.6	16.0	4.1	65.60	8.85	
Vs 251	127 APB		214.0	5.0	43	13.4	12.5	15.0	4.5	67.50	12.44	
Vs 252	144 LB		167.0	3.0	42	14.1	12.9	17.0	4.3	73.10	10.23	
Vs 253	171 Black		246.0	5.0	42	14.3	13.5	14.0	4.4	61.60	8.00	
Vs 254	177 Black		147.0	4.0	48	13.9	11.0	17.5	2.9	50.75	11.26	
Vs 255	195 Black		158.0	3.0	46	13.8	13.0	16.2	5.1	82.62	13.10	
Vs 256	201 Black		210.0	5.0	42	12.8	11.0	18.4	2.3	42.32	10.24	
Vs 257	215 Black		195.0	3.0	42	10.5	9.0	16.5	2.5	41.25	9.15	
Vs 258	224 Brown		180.0	4.0	46	13.3	12.5	18.0	3.1	55.80	10.30	
Vs 259	228 Black		210.0	5.0	51	12.9	11.5	20.0	3.0	60.00	9.83	
Vs 260	267 DB		120.0	6.0	39	18.5	17.0	31.5	5.1	160.65	12.63	

Contd.

Table .2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 261	274 Brown	National Bureau of Plant Genetic Resources Vellanikkara	52.0	6.0	40	14.5	13.5	28.4	4.5	127.80	11.40	November 1986 - January 1987
Vs 262	280 Brown		186.0	3.0	51	13.3	11.5	17.2	2.9	49.80	9.10	
Vs 263	280 ADB		126.0	3.0	44	13.5	12.6	20.0	3.2	64.00	12.30	
Vs 264	292 ADB		145.0	3.0	42	14.2	13.4	18.6	2.5	46.50	10.12	
Vs 265	310 Black		153.0	4.0	41	13.6	11.9	16.0	2.8	44.80	14.20	
Vs 266	316 RB		275.0	5.0	41	14.5	13.0	18.0	4.1	73.80	14.00	
Vs 267	316 APB		48.0	3.0	50	10.8	9.0	13.6	2.5	34.00	8.30	
Vs 268	323 Brown		180.0	3.0	42	13.5	12.0	15.5	3.5	54.25	8.68	
Vs 269	328 Brown		74.0	4.0	43	12.9	11.5	16.0	2.5	40.00	9.00	
Vs 270	416 Brown		158.0	3.0	45	10.3	8.5	14.5	4.2	60.90	11.50	
Vs 271	425 DB		174.0	2.0	42	10.4	8.5	16.5	1.5	24.75	7.60	
Vs 272	461 A Brown		145.0	2.0	53	14.1	12.5	15.4	2.5	38.50	9.10	
Vs 273	478 Brown		169.0	3.0	49	14.4	13.2	10.3	2.8	28.84	9.40	
Vs 274	486 DB		154.0	3.0	41	16.7	16.5	9.5	3.1	29.45	9.75	
Vs 275	497 ADB		138.0	3.0	40	15.6	14.5	11.5	3.5	40.25	11.54	
Vs 276	502 DB		166.0	4.0	45	14.5	13.4	13.0	3.3	42.90	13.54	
VS 277	504 Black		175.0	3.0	45	14.5	12.9	14.0	3.4	47.60	9.80	
Vs 278	510 Brown		182.0	4.0	41	13.8	13.5	15.5	3.5	54.25	50.11	
Vs 279	512 PB		190.0	4.0	46	14.8	13.8	13.5	3.6	48.60	10.10	
VS 280	516 LBB		125.0	6.0	56	12.4	12.0	17.5	3.0	52.50	9.60	
Vs 281	520 Black		156.0	4.0	48	14.0	13.2	17.0	3.3	56.10	9.70	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 282	522 Brown	National Bureau of Plant Genetic Resources Vellanikkara	178.0	3.0	48	14.0	12.8	14.4	3.3	47.52	10.60	November 1986 - January 1987
Vs 283	535 DB		245.0	5.5	57	17.9	16.0	19.4	4.9	95.06	11.20	
Vs 284	539 PB		145.0	2.0	57	14.8	11.0	15.5	3.2	49.60	10.40	
Vs 285	540 ADB		218.0	6.0	43	19.0	18.0	21.2	5.0	106.00	13.00	
Vs 286	557 APB		192.0	3.0	43	13.0	12.0	16.8	2.9	48.72	9.83	
Vs 287	570 DB		235.0	5.5	43	17.1	16.5	36.0	4.5	162.00	11.70	
Vs 288	592 RB		185.0	2.0	39	15.5	14.4	16.4	3.4	55.76	9.86	
Vs 289	594 PB		216.0	5.5	41	19.4	18.8	24.5	4.9	120.05	11.48	
Vs 290	597 DB		157.0	4.0	41	17.4	16.5	20.2	4.5	90.90	10.80	
VS 291	611 RB		145.0	3.0	41	15.7	13.0	17.5	3.6	63.00	9.62	
Vs 292	634 Brown		159.0	3.0	45	15.1	15.0	14.8	3.6	53.28	10.55	
Vs 293	644 LBB		65.0	2.0	42	13.8	13.0	13.9	3.0	41.70	10.02	
Vs 294	701 Brown		115.0	3.0	45	15.5	13.8	14.5	3.1	44.95	6.67	
Vs 295	763 Brown		176.0	3.0	45	14.8	13.2	10.5	3.6	37.80	9.30	
Vs 296	816 DB		195.0	4.0	46	14.0	12.8	16.0	3.2	51.20	10.74	
Vs 297	834 Black		164.0	2.0	44	13.0	12.0	13.5	2.9	39.15	8.90	
Vs 298	836 Brown		185.0	2.0	41	16.8	16.5	7.5	3.1	23.25	9.40	
Vs 299	930 Brown		144.0	2.0	49	12.8	10.8	11.5	2.8	32.20	6.00	
Vs 300	945 Black		139.0	2.0	44	14.2	14.0	14.4	3.2	46.08	9.90	
Vs 301	1091		156.0	3.0	49	12.5	10.0	13.6	2.3	31.28	10.10	
Vs 302	1097		165.0	2.0	50	13.8	12.2	13.0	2.9	37.70	9.45	

Contd.

Table 2. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 306	V-1	Tamil Nadu Agricultural University, Coimbatore	128.0	4.0	39	15.8	15.0	17.0	3.8	64.60	8.55	November 1986 - January 1987
Vs 307	PI-476		106.0	3.0	40	15.8	14.2	14.5	2.2	31.90	8.25	
Vs 309	MS 9369		154.0	3.0	39	17.8	14.5	17.6	3.2	56.32	9.00	
Vs 311	MS 8988		166.0	4.0	51	16.5	15.5	18.6	4.6	85.56	12.80	
Vs 312	CO-4		155.0	4.0	42	18.8	17.6	19.5	4.4	85.80	9.20	
Vs 313	C-152		105.0	3.0	42	15.8	14.9	15.6	2.9	45.24	10.15	
Vs 315	MS 9804		125.0	4.0	37	17.8	14.5	18.5	4.1	78.85	10.30	
Vs 147	TVu 1889	IITA Nigeria	110.0	4.0	45	16.1	15.0	11.0	4.4	48.40	11.10	
Vs 317	IC 26059	National Bureau of Plant Genetic Resources, New Delhi	275.0	2.0	72	14.5	13.0	17.5	3.2	56.00	8.60	June 1987 - August 1987
Vs 318	IC 20720		196.0	3.5	41	16.7	15.6	14.0	3.5	49.00	10.52	
Vs 319	IC 19707		286.0	2.0	76	13.8	12.5	12.5	3.8	47.50	9.40	
Vs 320	IC 19794		292.0	2.5	70	14.0	13.5	16.0	3.2	51.20	9.50	
Vs 321	IC 20633		216.0	3.0	53	13.5	12.5	17.0	3.6	61.20	9.40	
Vs 322	IC 20720-1		257.0	2.5	39	16.9	16.4	18.0	3.7	66.60	8.96	
Vs 323	IC 19778		240.0	2.5	46	14.0	13.0	13.5	4.0	54.00	9.70	
Vs 324	IC 20575		210.0	2.5	53	14.5	13.8	15.0	3.1	46.50	11.20	
Vs 325	IC 20617		235.0	2.5	54	14.0	13.5	12.0	3.9	46.80	10.40	
Vs 326	IC 26011		115.0	3.0	39	15.4	15.0	26.5	5.6	148.40	11.80	
Vs 327	IC 20553		208.0	2.5	42	17.0	15.5	23.0	4.9	112.70	11.50	
Vs 328	IC 20683		152.0	2.5	56	15.2	14.8	13.0	2.8	36.40	8.80	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 329	IC 24056	National Bureau of Plant Genetic Resources, New Delhi.	196.0	3.0	52	14.7	14.0	11.0	3.1	34.10	9.10	June 1987 – August 1987
Vs 330	IC 20662		170.0	3.5	52	13.5	12.0	16.0	3.2	51.20	10.70	
Vs 331	IC 20688		155.0	2.5	46	15.8	15.0	14.5	2.5	36.25	9.50	
Vs 322	IC 27500		190.0	3.0	40	17.1	15.4	13.5	2.9	39.15	8.90	
Vs 333	IC 27500		158.0	2.5	49	13.5	12.8	16.8	3.2	53.75	10.30	
Vs 334	IC 20523		145.0	3.0	47	18.0	15.4	19.0	3.7	70.30	9.00	
Vs 335	IC 19797		285.0	3.0	70	16.0	15.5	12.0	3.5	42.00	9.90	
Vs 336		Local	163.0	2.5	49	15.2	14.3	17.5	3.6	63.00	9.30	
Vs 337			185.0	5.0	40	17.2	15.4	28.0	4.3	120.40	10.07	
Vs 338			142.0	3.0	39	22.4	15.4	14.0	3.2	44.80	10.10	
Vs 339			155.0	5.0	40	13.7	12.8	32.0	4.9	156.80	8.69	
Vs 340			170.0	5.5	42	14.5	13.5	30.0	4.9	147.00	11.40	
Vs 341			140.0	4.0	38	16.8	15.9	19.0	3.3	62.70	11.00	
Vs 342			125.0	4.0	47	17.1	16.5	24.0	4.6	110.40	10.80	
Vs 343			156.0	4.0	45	16.4	14.0	19.0	4.4	83.60	12.37	
Vs 344			225.0	3.0	43	17.1	16.2	12.0	3.9	46.80	14.80	
Vs 345			236.0	3.0	43	19.1	15.5	16.0	4.1	65.60	11.20	
Vs 346			126.0	4.5	39	17.2	16.0	20.0	5.2	104.00	11.00	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 347	V-271	Assam Agricultural University, Assam	148.0	4.0	41	15.1	13.7	14.0	3.8	53.20	11.00	August 1987 – October 1987
Vs 348	V-27		165.0	3.0	43	16.0	15.1	7.0	4.6	32.20	11.70	
Vs 349	V-154		153.0	5.5	44	15.8	15.0	29.0	5.0	145.00	11.50	
Vs 350	V-16		236.0	3.5	40	14.5	12.5	22.0	2.5	55.00	11.57	
Vs 351	V-276		175.0	3.5	42	14.3	13.0	22.0	5.3	116.60	10.80	
Vs 352	KOVU-95		128.0	3.5	42	14.7	13.5	9.0	3.0	27.00	9.70	
Vs 353	KOVU-623		165.0	4.0	42	8.0	8.0	28.0	1.2	33.60	5.10	
Vs 354	RC-48		156.0	5.5	44	13.8	12.5	31.0	4.8	148.80	10.00	
Vs 355	NPRC-2		178.0	4.0	43	17.0	16.0	20.0	3.5	70.00	11.00	
Vs 357	TVu-201-1D	International Institute of Tropical Agriculture, Nigeria	140.0	3.0	46	13.5	12.0	18.5	5.2	96.20	12.90	
Vs 358	TVu-310		175.0	2.5	47	15.8	14.5	17.5	4.7	82.25	12.50	
Vs 359	TVu-801		192.0	2.5	47	18.8	17.0	14.4	3.6	51.84	12.76	
Vs 360	TVu-410		180.0	2.5	45	15.0	14.0	9.0	3.1	27.90	11.40	
Vs 361	TVu-2755		165.0	3.0	48	14.7	13.5	13.6	3.9	53.04	11.00	
Vs 362	TVu-3273		195.0	5.0	45	14.5	13.0	23.5	4.1	96.35	11.10	
Vs 363	TVu-201		148.0	4.3	46	13.8	12.0	18.0	5.2	93.60	12.80	
Vs 374	IT-81^{D}-1228-14	International Institute of Tropical Agriculture, Nigeria	65.0	3.0	40	21.0	19.0	21.0	6.1	128.10	12.20	November 1987 – January 1988
Vs 378	IT-85^{F}-2805		66.0	3.5	40	14.0	13.2	18.1	4.3	77.83	10.40	
Vs 379	IT-81^{D}-1007		47.0	4.0	41	15.5	14.4	14.6	4.0	58.40	11.00	
Vs 387	IT-85^{F}-8675		56.0	3.0	42	16.5	16.0	14.0	2.7	37.80	11.80	
Vs 393	IT 83^{S}-728-5		110.0	3.0	42	16.0	15.5	14.0	3.5	49.00	13.70	
Vs 394	IT-83^{S}-960		55.0	3.5	40	16.5	15.0	17.0	3.6	61.20	12.00	
Vs 395	IT-84^{S}-275-9		49.0	3.0	44	14.0	12.5	9.0	3.0	27.00	12.10	
Vs 396	IT-83^{S}-720-2		125.0	4.0	39	15.5	15.0	23.0	5.2	119.60	12.20	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 397	IT-85^F-2020	International Institute of Tropical Agriculture, Nigeria	140.0	3.0	45	15.5	15.0	14.0	4.1	57.40	11.70	November 1987 - January 1988
Vs 399	IT-83^S-742-2		95.0	3.5	42	16.0	15.5	16.0	4.3	68.8	11.20	
Vs 401	IT-83^D-338-1		85.0	3.0	40	13.0	7.5	13.0	2.2	28.60	9.00	
Vs 402	IT-84^D-448		60.0	3.0	41	17.0	16.0	13.0	3.7	48.10	11.40	
Vs 406	IT-81^D-1137		130.0	3.5	42	14.5	14.0	14.0	3.4	47.60	13.40	
Vs 410	IT-85^F-2829		78.0	3.0	39	16.0	14.0	9.0	3.1	27.90	13.00	
Vs 413	IT-84^D-460		60.0	3.0	42	15.8	15.0	11.5	3.9	44.85	13.00	
Vs 415	IT-81^D-1228-10		140.0	3.0	47	30.0	21.0	14.5	4.0	58.00	12.40	
Vs 417	IT-85^F-2587		135.0	3.5	43	18.5	17.5	13.5	3.9	52.65	18.10	
Vs 419	IT-83^D-3285		142.0	3.0	38	15.0	15.0	13.6	4.9	66.64	13.00	
Vs 422	IT-83^S-2085		60.0	3.0	41	17.0	16.0	20.3	4.9	99.47	12.70	
Vs 428	IT-84^S-2118		110.0	3.0	45	16.5	16.0	15.6	4.4	68.64	14.00	
Vs 371	IT-84^S-1-108	International Institute of Tropical Agriculture, Nigeria	145.0	2.5	45	14.5	13.0	11.0	4.3	47.30	12.00	January 1988 - March 1988
Vs 375	IT-85^F-1517		60.0	3.0	45	20.0	18.5	22.3	6.3	140.49	14.80	
Vs 376	IT-83^D-442		90.0	3.0	45	17.1	16.5	15.3	3.9	59.67	9.40	
Vs 377	IT-84^S-2135		56.0	4.0	40	16.4	15.5	14.7	4.2	61.74	10.20	
Vs 380	IF-E-Brown		112.0	3.5	42	14.5	14.0	14.9	3.9	58.11	9.70	
Vs 381	IT-83^S-872		55.0	4.0	41	14.5	14.0	15.5	3.5	54.25	9.70	
Vs 382	TVV-21		143.0	3.5	42	19.0	17.5	18.5	5.6	103.60	13.40	
Vs 383	IT-85^F-1380		49.0	4.0	41	18.0	17.5	12.6	4.0	50.40	10.20	
Vs 385	IT-84^E-124		15.0	2.0	39	10.5	9.0	8.0	1.7	13.60	12.40	
Vs 388	IT-83^S-990		118.0	2.5	44	17.5	16.5	13.0	3.2	41.60	13.30	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 389	IT-83^{S}-911	International Institute of Tropical Agriculture, Nigeria	60.0	4.5	42	23.5	20.0	28.0	6.2	173.60	13.50	January 1988 – March 1988
Vs 390	IT-84^{D}-660		104.0	3.0	40	17.7	17.0	17.0	3.5	59.50	14.00	
Vs 400	IT-85^{F}-2076		88.0	3.5	42	16.0	15.0	17.0	2.9	49.30	9.00	
Vs 403	IT-83^{D}-219		140.0	3.0	43	16.5	16.0	12.0	3.3	39.60	11.00	
Vs 404	IT-82^{D}-716		55.0	3.0	41	14.0	14.0	13.0	3.5	45.50	11.70	
Vs 405	IT-82^{D}-889		110.0	3.0	42	13.0	12.5	8.0	3.1	24.80	12.80	
Vs 408	IT-82^{E}-16		115.0	3.5	40	15.5	15.0	13.0	3.6	46.80	13.80	
Vs 414	IT-85^{F}-3139		110.0	4.0	43	16.2	15.5	16.3	6.4	104.32	12.20	
Vs 416	IT-85^{F}-1936		115.0	4.0	42	16.2	15.0	21.0	4.4	92.40	13.00	
Vs 420	IT-85^{D}-3577		147.0	4.0	41	16.0	13.5	19.5	5.0	97.50	12.60	
Vs 373	IT-85^{F}-898-5	International Institute of Tropical Agriculture, Nigeria	127.0	3.0	42	14.5	14.0	16.2	4.0	64.80	10.30	June 1988 – August 1988
Vs 384	IT-82^{E}-32		120.0	2.5	45	16.0	15.5	14.0	2.9	40.60	11.90	
Vs 386	IT-85^{F}-8675		50.0	2.0	41	18.0	16.5	12.0	2.4	28.80	12.80	
Vs 391	IT-84^{S}-2246-4		105.0	3.5	44	17.0	16.5	19.0	3.7	70.30	13.30	
Vs 398	IT-83^{S}-818		150.0	3.5	41	16.0	16.0	15.0	4.0	60.00	11.70	
Vs 407	IT-84^{D}-449		51.0	3.5	40	14.8	14.5	15.0	3.6	54.00	12.90	
Vs 409	IT-84^{D}-368		63.0	3.0	41	21.0	19.0	17.0	3.5	59.50	13.70	
Vs 421	IT-85^{F}-953-3		55.0	3.0	38	16.0	15.5	21.6	4.8	103.68	15.10	
Vs 424	IT-85^{F}-1380		95.0	2.5	43	14.8	13.5	8.5	4.9	41.65	12.90	
Vs 426	IT-84^{S}-2221-2		63.0	2.5	41	14.5	13.6	6.0	3.5	21.00	13.30	
Vs 427	IT-81^{D}-1137		58.0	3.0	42	14.5	14.0	12.3	5.4	66.42	14.00	
Vs 429	IT-85^{F}-2205		65.0	3.0	42	16.0	15.2	14.5	3.9	56.55	13.10	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 369	IT-83^{S}-872	International Institute of Tropical Agriculture, Nigeria	125.0	3.0	42	17.2	16.5	34.0	5.8	197.20	12.50	
Vs 370	IT-84^{S}-275-9		105.0	3.5	42	14.6	13.5	19.0	4.1	77.90	11.90	
Vs 372	IT-84^{S}-2135		80.0	3.5	40	16.0	15.0	18.5	4.2	77.70	12.70	
Vs 392	IT-84^{D}-448		65.0	3.0	42	16.0	15.0	15.0	3.9	58.50	12.90	
Vs 411	IT-84^{S}-2246-4		62.0	3.5	45	15.0	14.5	10.3	4.2	42.26	13.20	
Vs 412	IT-84^{D}-449		65.0	2.5	42	17.0	16.0	6.3	6.1	38.43	12.70	
Vs 418	IT-85$^{=}$-867		55.0	3.5	43	14.6	13.5	14.3	3.5	50.05	11.80	
Vs 423	IT-620^{D}-699		118.0	3.0	43	16.1	15.0	11.5	3.5	40.25	13.10	
Vs 425	IT-84^{S}-2246-4		60.0	2.5	42	13.5	13.0	13.0	4.3	55.90	13.20	
Vs 430	NI 989 KEN	State Faculty of Agricultural Sciences, Belgium	48.0	1.0	45	11.5	11.0	16.0	3.2	51.20	8.10	August 1988 – October 1988
Vs 431	NI 945 NER		120.0	2.0	45	9.0	9.0	15.5	2.9	44.95	7.10	
Vs 432	NI 794 NGA		32.0	1.0	46	5.0	4.0	4.5	1.0	4.50	6.00	
Vs 433	NI 910 TZA		42.0	2.0	45	8.0	8.0	9.3	1.9	17.67	7.40	
VS 434	NI 1232 BDI		110.0	2.0	46	13.5	13.0	10.5	2.4	25.20	8.00	
Vs 435	NI 973 ZIM		106.0	3.0	46	14.0	14.0	10.3	2.7	27.81	8.20	
Vs 436	NI 202 ZAR		120.0	3.0	46	13.5	13.0	11.5	2.5	28.75	8.40	
Vs 437	NI 316 TGO		135.0	3.0	45	14.0	14.0	12.0	2.9	34.80	9.00	
Vs 438	NI 778 IND		185.0	4.5	40	15.3	13.5	36.5	2.4	87.60	9.10	
Vs 439	NI 478 LAO		217.0	2.0	58	12.5	11.5	9.5	3.0	28.50	9.40	
Vs 440	NI 227 ZAR		165.0	2.0	42	11.9	11.5	10.0	3.2	32.0	9.40	
Vs 441	NI 972 ZIM		242.0	2.5	65	12.0	12.0	10.0	3.1	31.00	9.50	
Vs 442	NI 301		236.0	2.0	46	12.0	12.0	13.5	3.4	45.90	9.20	
Vs 443	NI 479 ZAR		195.0	2.5	45	12.5	12.0	7.5	3.1	23.25	9.00	

Contd.

Table 2 Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Vs 444	TVu 801	United States Vegetable Laboratory, Charleston	178.0	3.5	41	16.0	15.5	14.8	3.6	53.28	13.40	October 1988 - December 1988
Vs 445	TVu 408		196.0	3.5	42	15.0	14.0	15.0	3.5	52.50	13.80	
Vs 446	TVu 310		220.0	4.0	41	15.5	15.0	16.5	3.5	57.75	12.90	
Vs 447	TVu 76		160.0	5.0	44	16.7	16.0	21.5	5.2	111.80	14.00	
Vs 448	Local	Local	256.0	4.0	44	19.3	18.0	12.0	5.6	67.20	15.60	
Vs 449	Local	Local	289.0	4.0	44	19.8	18.1	15.5	5.9	91.45	15.30	
Vs 450	IT-839-728-5	Crops Research Institute, Ghana	118.0	3.0	42	15.8	15.5	15.0	3.5	52.50	13.80	
Vs 451	IT-839-728-13		125.0	3.0	42	15.0	15.0	18.0	3.0	54.00	13.80	
Vs 452	P 912	University of Agricultural Science, Bangalore	236.0	2.3	41	16.2	14.0	18.2	4.0	72.80	13.40	
Vs 453	Mandya Local		85.0	3.0	41	13.5	12.2	9.5	2.7	25.65	13.20	
Vs 454	MS 370		96.0	3.0	42	13.9	12.2	11.0	4.1	45.10	12.97	
Vs 455	TVu 2740		310.0	3.0	54	14.3	13.8	10.0	3.0	30.00	12.70	
Vs 456	ICV 10	International Centre for Insect Physiology and Ecology, Kenya.	154.0	5.0	41	19.0	18.0	19.0	7.9	150.10	14.60	December 1988 to March 1989
Vs 457	ICV 11		172.0	5.0	41	17.0	16.0	29.0	8.0	232.00	15.00	
Vs 458	ICV 12		167.0	5.0	41	16.0	14.0	26.0	8.0	208.00	14.63	
Vs 459	TVu 310		190.0	4.0	42	16.0	16.0	16.0	3.3	52.80	12.70	

Table 3 Morphological description of cowpea lines evaluated for resistance to aphids

Habit	SPREADING															
Stem colour	GREEN												PURPLE			
Pod colour	Light green			Green							Purple		Green		Purple	
Seed Colour	Black	Brown	Light Brown	Black	Purple	Brown	Brown	Brown	Light Brown	Cream	Brown	Cream	Black	Brown	Black	Brown
	Vs 311	Vs 275	Vs 252	Vs 246	Vs 322	Vs 244	Vs 291	Vs 345	Vs 250	Vs 318	Vs 298	Vs 373	Vs 254	Vs 271	Vs 257	Vs 270
	Vs 341	Vs 276	Vs 312	Vs 249	Vs 323	Vs 245	Vs 292	Vs 349	Vs 251	Vs 344	Vs 334	Vs 419				
	Vs 343	Vs 283	Vs 327	Vs 252	Vs 329	Vs 247	Vs 295	Vs 351	Vs 279	Vs 348	Vs 347					
	Vs 448	Vs 361	Vs 337	VS 255	Vs 332	Vs 248	Vs 296	Vs 353	Vs 284	Vs 354						
		Vs 444	Vs 359	Vs 256	Vs 333	Vs 258	Vs 299	Vs 358	Vs 286	Vs 371						
		Vs 449		Vs 259	Vs 335	Vs 260	Vs 301	Vs 360	Vs 289	Vs 382						
				Vs 265	Vs 408	Vs 262	Vs 302	Vs 362	Vs 340	Vs 398						
				Vs 277		Vs 263	Vs 309	Vs 384	Vs 357	Vs 403						
				Vs 281		Vs 264	Vs 317	Vs 388	Vs 436	Vs 415						
				Vs 297		Vs 266	Vs 319	Vs 396	Vs 437	Vs 417						
				Vs 300		Vs 268	Vs 320	Vs 397	Vs 440	Vs 420						
				Vs 336		Vs 272	Vs 321	Vs 431		Vs 423						
				Vs 342		Vs 273	Vs 324	Vs 434		Vs 441						
				Vs 346		Vs 274	Vs 325	Vs 435		Vs 442						
				Vs 443		Vs 278	Vs 328	Vs 439								
						Vs 282	Vs 330	Vs 445								
						Vs 285	Vs 331	Vs 446								
						Vs 287	Vs 335	Vs 447								
						Vs 288	Vs 338	Vs 445								
						Vs 290	Vs 339									

Table 3 Continued

Habit						BUSHY					
Stem colour	GREEN										PURPLE
Pod colour	Light green					Green				Light purple	Purple
Seed colour	Purple	Brown	Light Brown	White	Cream	Purple	Brown	Light Brown	Cream	Light Brown	Cream
	Vs 412	Vs 395	Vs 375	Vs 374	Vs 372	Vs 379	Vs 261	Vs 378	Vs 377	Vs 267	Vs 421
	Vs 422	Vs 426	Vs 385	Vs 427	Vs 389	Vs 381	Vs 293	Vs 383	Vs 394		
			Vs 413		Vs 425	Vs 411	Vs 386	Vs 402	Vs 404		
							Vs 387	Vs 407	Vs 418		
							Vs 392	Vs 409	Vs 424		
							Vs 410				
							Vs 429				
							Vs 430				
							Vs 433				

Contd.

Table 3 Continued

Habit						SEMI VINY					
Stem colour	GREEEN										PURPLE
Pod colour	Light green			Green						Purple	Purple
Seed colour	Brown	Light Brown	Cream	Black	Purple	Brown	Light Brown	White	Cream	Cream	Black
	Vs 306	Vs 400	Vs 352	Vs 147	Vs 363	Vs 269	Vs 280	Vs 315	Vs 399	Vs 401	Vs 307
	Vs 428	Vs 414	Vs 393	Vs 370	Vs 369	Vs 294	Vs 326	Vs 453	Vs 406		Vs 390
			Vs 450	Vs 452	Vs 405	Vs 313	Vs 438		Vs 416		
			Vs 451			Vs 350	Vs 458				
						Vs 376					
						Vs 380					
						Vs 391					
						Vs 432					
						Vs 454					
						Vs 456					
						Vs 457					
						Vs 459					

b. Pubescence

Shoot tips from first and second internodes and terminal leaflet of the leaf at the growing tip, were scanned under Scanning Electron Microscope to study pubescent/glabrous nature of plants in relation to host reaction. The three resistant cultivars (Vs 350, Vs 438 and Vs 452) and one susceptible cultivar (Kanakamony) were examined. Steps involved in fixation and dehydration of the biological tissue are summarised as follows:

i Preparation of buffer solution - Phosphate buffer at pH 7.2

ii Preparation of fixation solution - Gluteraldehyde 2.5%

iii Specimen preparation

iv Pre-fixation -

In 2.5% fixation solution consisting of 2.5% gluteraldehyde and phosphate buffer of pH 7.2 (1:9).

v Washing -

With phosphate buffer at pH 7.2

vi Dehydration

Steps during dehydration are as follows:

50% acetone at room temperature for 25 minutes

↓

70% acetone at room temperature for 20 minutes

↓

90% acetone at room temperature for 1 hour

↓

90% acetone at room temperature over night

↓

95% acetone at room temperature for 25 minutes

↓

95% acetone at room temperature for 25 minutes

↓

100% acetone at room temperature for 30 minutes

↓

100% acetone at room temperature for 30 minutes

↓

100% acetone at room temperature for 30 minutes

vii Critical point drying

This was done in Critical Point Dryer. Amyl acetate was substituted for dehydration.

viii Coating

Carbon was coated

ix Scanning and photographing

c. Anatomy of shoot apices from resistant/susceptible lines

Transverse sections of shoot apices from 3rd internode of the five cowpea accessions were taken, stained with safranin and temporary mounts of these were prepared. The accessions were observed for arrangement of vascular bundles as widely separated, loose, semicompact or compact. The accessions were also observed for thickness of cuticle, number of layers of cells in epidermis, hypodermis and endodermis and lignification of the schlerenchymatous pericycle.

d. Biochemical factors affecting preference

The three resistant and two susceptible lines were analysed for reducing sugar, non-reducing sugar, total sugars, protein, phosphorus and potassium content.

i. Reducing sugar

The reducing sugar content in pods was determined at three stages of maturity (5, 10, 15 DAS) following Nelson's method (Nelson, 1944).

ii. Non-reducing sugar

Non-reducing sugars present in pods at three stages of maturity (5, 10, 15 DAS) were determined by hydrolysing non-reducing sugars with sulphuric acid (Malhotra and Sarkar, 1979) to reducing sugars and then estimated by Nelson's method (Nelson, 1944).

iii. Total sugars

Sum of reducing and non-reducing sugars was taken as estimate of total sugars.

iv. Protein

Protein content of grains/leaves was calculated from the percentage of nitrogen using factor 6.25. Nitrogen content was estimated by Microkjeldahl digestion distillation method (AOAC, 1960) and expressed as (%) nitrogen in the grains/leaves on dry weight basis.

v. Phosphorus

Phosphorus was determined by vanadomolybdo-phosphoric yellow colour method (Jackson, 1958) and expressed as per cent phosphorus on dry weight basis.

vi. Potassium

Potassium in the triple acid digest of the sample was determined using EEL flame photometer (Jackson, 1958).

2. Mechanism of antibiosis

a. Rate of fecundity of aphids fed on resistant/susceptible cowpea lines

To study effects of host plants on biology of aphid, the insect was reared on five lines in the glasshouse. Single first instar nymph was released on the first trifoliate leaf of 10-12 days old potted plants of each line kept in the net house. The progenies/aphid were counted.

b. Biochemical factors inducing antibiosis

i. Total phenols

Total phenols in pods of plants were estimated by modified Folin-Denis method (Mahadevan and Sridhar, 1982).

ii. Orthodihydric phenol

Arnows method as described by Mahadevan and Sridhar (1982) was followed to estimate OD phenol in pods of cowpea.

iii. Trypsin inhibitor

Powdered seed samples from five cowpea lines were assayed for trypsin inhibiting activity by the method of Kunitz (1947) using casein as substrate and the results were expressed in terms of trypsin inhibiting units/g of dry seeds and (%) inhibition of the activity of enzymic trypsin.

Extraction

One gram of the powdered seed sample was homogenized in 10 ml of 0.1 M phosphate buffer, at pH 7.6 and was kept overnight at 4°C. Later, it was centrifuged at 15,000 rpm for 20 minutes and the supernatant solution was diluted ten fold with phosphate buffer. This diluted extract was used for estimation of antitryptic activity.

Assay

The assay system consisted of 1 ml of casein 1%, 0.1 ml diluted seed extract, 0.8 ml phosphate buffer and 0.1 ml of enzyme solution (200 mg trypsin dissolved in 100 ml of phosphate buffer). This mixture was incubated at 37°C for 30 minutes and 2 ml of TCA 5% was added to stop the reaction. The mixture was centrifuged for 5 minutes, 1 ml of supernatant was taken and the liberated phenolic aminoacids were determined using Folin-Ciocalteu method. Standard plot was prepared using the aminoacid, tyrosin. The zero time controls of all the samples were done taking the same solutions, but the enzyme was added after adding the TCA solution. To find the trypsin activity of enzyme alone, instead of 0.1 ml of pulse extract, 0.1 ml buffer was used and control for the same was also maintained by adding enzyme solution after the addition of TCA.

C. Genetics of resistance to aphids in cowpea

1. Mendelian bases of resistance

Three cowpea lines (Vs 350, Vs 438 and Vs 452) which showed consistent resistant reaction and to susceptible lines (Kanakamony and Pusa Komal) were used for the study. They were crossed in all possible combinations using suscepts as male.

F_1 plants of each cross were grown in open and the F_1s were crossed with resistant and susceptible plants to develop BC_1 and BC_2 generations. The remaining self fertilised pods on F_1 plants provided the F_2 generation seeds.

The parents, F_1s, F_2s and back cross generations of Vs 350 x Kanakamony, Vs 350 x Pusa Komal, Vs 438 x Kanakamony and Vs 438 x Pusa Komal were evaluated during July-September 1989. The number of plants evaluated in each combination are given in Table 4.

Table 4 Number of plants evaluated in each cross combination during July-September 1989

Cross combinations	Number of plants evaluated under					
	P_1	P_2	F_1	F_2	BC_1	BC_2
Vs 350 x Kanakamony	20	20	23	153	22	25
Vs 350 x Pusa Komal	20	20	38	177	18	32
Vs 438 x Kanakamony	20	20	40	140	25	41
Vs 438 x Pusa Komal	20	20	40	120	26	38

All the six generations of the crosses Vs 452 x Kanakamony and Vs 452 x Pusa Komal were evaluated during October 1989-January 1990. All the generations of the combinations, grown during July-September 1989 were again grown during October 1989-January 1990. Thirty plants each of parents, F_1 hybrids and back cross generations and 60 plants each of F_2 generation were evaluated during October 1989-January 1990. Cultural operations were done as per package of pratices (KAU, 1989). Plants were observed for incidence of aphids and aphid counts were made on 45th day after sowing. A chisquare test was used to determine goodness of fit to different genetic ratios.

2. Quantitative bases of level of resistance

The data on level of aphid resistance collected from parental lines, F_1s, F_2s, BC_1s and BC_2s were analysed as per Mather and Jinks (1971).

Scaling tests

Presence of non-allelic interaction was detected by scaling tests (Mather, 1949). Estimates of additive (D) and dominance (H) components of genetic variance were made using the mean and variance of six generations - P_1, P_2, F_1, F_2, BC_1 and BC_2

$$A = 2\bar{B}_1 - \bar{P}_1 - \bar{F}_1$$
$$V(A) = 4V(\bar{B}_1) + V(\bar{P}_1) + V(\bar{F}_1)$$
$$B = 2\bar{B}_2 - \bar{P}_2 - \bar{F}_1$$
$$V(B) = 4V(\bar{B}_2) + V(\bar{P}_2) + V(\bar{F}_1)$$
$$C = 4\bar{F}_2 - 2\bar{F}_1 - \bar{P}_1 - \bar{P}_2$$
$$V(C) = 16V(\bar{F}_2) + 4V(\bar{F}_1) + V(\bar{P}_1) + V(\bar{P}_2)$$

Adequacy of the scale satisfied two conditions namely, additivity of gene effects and independence of heritable components from non-heritable ones.

Generation mean analysis

Three parameter model as suggested by Jinks and Jones (1958) was used in the absence of non-allelic interaction.

$$m = \frac{1}{2}\bar{P}_1 + \frac{1}{2}\bar{P}_2 + 4\bar{F}_2 - 2\bar{B}_1 - 2\bar{B}_2$$

$$V(m) = \frac{1}{2}V(\bar{P}_1) + \frac{1}{2}V(\bar{P}_2) + 16V(\bar{F}_2) + 4V(\bar{B}_1) + 4V(\bar{B}_2)$$

$$d = \frac{1}{2}\bar{P}_1 - \frac{1}{2}\bar{P}_2$$

$$V(d) = \frac{1}{2}V(\bar{P}_1) + \frac{1}{2}V(\bar{P}_2)$$

$$h = 6\bar{B}_1 + 6\bar{B}_2 - 8\bar{F}_2 - \bar{F}_1 - 3/2\,\bar{P}_1 - 3/2\,\bar{P}_2$$

$$V(h) = 36V(\bar{B}_1) + 36V(\bar{B}_2) + 64V(\bar{F}_2) + V(\bar{F}_1) - 9/4V(\bar{P}_1) + 9/4\,V(\bar{P}_2)$$

In the presence of non-allelic interaction, six parameter model was used (Hayman, 1958).

$$m = \bar{F}_2$$

$$v(m) = V(\bar{F}_2)$$

$$d = \bar{B}_1 - \bar{B}_2$$

$$V(d) = V\,\bar{B}_1 + V\,\bar{B}_2$$

$$h = \bar{F}_1 - 4\bar{F}_2 + \frac{1}{2}\bar{P}_1 - \frac{1}{2}\bar{P}_2 + 2\bar{B}_1 + 2\bar{B}_2$$

$$V(h) = V(\bar{F}_1) + 16V(\bar{F}_2) + \frac{1}{4}V(\bar{P}_1) + \frac{1}{4}V(\bar{P}_2) + 4V(\bar{B}_1) + 4V(\bar{B}_2)$$

$$i = 2\bar{B}_1 + 2\bar{B}_2 - \bar{F}_2$$

$$V(i) = 4V(\bar{B}_1) + 4V(\bar{B}_2) + 16V(\bar{F}_2)$$

$$j = \bar{B}_1 - \frac{1}{2}\bar{P}_1 - \bar{B}_2 + \frac{1}{2}\bar{P}_2$$

$$V(j) = V(\bar{B}_1) + \frac{1}{4}V(\bar{P}_1) + V(\bar{B}_2) + \frac{1}{4}V(\bar{P}_2)$$

$$l = \bar{P}_1 + \bar{P}_2 + 2\,\bar{F}_1 - 4\,\bar{F}_2 - 4\,\bar{B}_1 - 4\,\bar{B}_2$$

$$V(l) = V(\bar{P}_1) + V(\bar{P}_2) + 4\,V(\bar{F}_1) + 16\,V(\bar{F}_2) + 16\,V(\bar{B}_1) + 16\,V(\bar{B}_2)$$

where m = mean

d = additive effect

h = dominance effect

i = additive × additive interaction

j = additive × dominance interaction

l = dominance × dominance interaction

The above genetic parameters were tested for significance using 't' test.

Degree of dominance

Following equations were solved to calculate the proportion between dominance and additive variance

$$V(F_2) = \tfrac{1}{2}\,D + \tfrac{1}{4}\,H + E$$

$$V(B_1) + V(B_2) = \tfrac{1}{2}\,D + \tfrac{1}{2}\,H + E$$

where $E = \dfrac{V(P_1) + V(P_2) + V(F_1)}{3}$

Degree of dominance $\sqrt{H/D}$

Effective factors

Using the following formulae the number of effective factors were calculated.

$$K_1 = \frac{(\bar{P}_1 - \bar{P}_2/2)^2}{D}$$

$$K_2 = \frac{[\bar{F}_1 - (\bar{P}_1 + \bar{P}_2)/2]^2}{H}$$

D. Development of physical mixtures in cowpea to manage aphids (*Aphis craccivora*)

a. Materials

Three cowpea lines - Vs 452 (R_1), Vs 350 (R_2) and Vs 438 (R_3) - resistant to aphids and two locally adapted susceptible lines - Kanakamony (S_1) and Pusa Komal (S_2) - were used to develop physical mixtures of different composition. A total of 19 treatments comprising five purelines, six 2 component mixtures, six 3 component mixtures and two 4 component mixtures were developed.

Obstructions created to incidence of aphids by the components in 19 treatments ranged from 0 in suscepts (S_1, S_2) to 100 in resistant lines (R_1, R_2, R_3). A two component mixture has an obstruction of 50%.

The detailed treatments were as follows:

Treatments	Components of mixtures	Total plants/ plot (6mx3m)	Number of plants from each line/plot					Obstruction created (%)
			R_1	R_2	R_3	S_1	S_2	
Pureline	R_1	80	80	-	-	-	-	100
	R_2	80	-	80	-	-	-	100
	R_3	80	-	-	80	-	-	100
	S_1	80	-	-	-	80	-	0
	S_2	80	-	-	-	-	80	0
2 component mixtures	R_1S_1	80	40	-	-	40	-	50
	R_1S_2	80	40	-	-	-	40	50
	R_2S_1	80	-	40	-	40	-	50
	R_2S_2	80	-	40	-	-	40	50
	R_3S_1	80	-	-	40	40	-	50
	R_3S_2	80	-	-	40	-	40	50
3 component mixtures	$R_1R_2S_1$	80	27	-	27	26	-	66.66
	$R_1R_2S_2$	80	27	27	-	-	26	66.66
	$R_2R_3S_1$	80	-	27	27	26	-	66.66
	$R_2R_3S_2$	80	-	27	27	-	26	66.66
	$R_1R_3S_1$	80	27	-	27	26	-	66.66
	$R_1R_3S_2$	80	27	-	27	-	26	66.66
4 component mixtures	$R_1R_2R_3S_1$	80	20	20	20	20	-	75.00
	$R_1R_2R_3S_2$	80	20	20	20	-	20	75.00

R_1 - Vs 452

R_2 - Vs 350

R_3 - Vs 438

S_1 - Kanakamony

S_2 - Pusa Komal

b. Lay out and experimental design

The experiments were conducted during three seasons August-October 1989 (Season I), November 1989-February 1990 (Season II), June-August 1990 (Season III), in a uniformly fertile soil at the Vegetable Research Plot of Kerala Agricultural University. The five purelines and 14 physical mixtures were grown in two replications and treatments were allotted randomly. The net plot size was 6 m x 3 m with 8 ridges/channels, taken at a spacing of 75 cm and seeds sown 30 cm apart. There were 80 plants/ treatment and the fixed proportions of every line in mixtures were maintained in each treatment by careful dibbling. Cultural practices were followed as per Kerala Agricultural University (1989).

The plants were observed for incidence of aphids in each treatment. The pods/plot and yield/plot were recorded during each harvest and cumulated at the end. In physical mixtures, data from component lines were carefully collected separately and then plot totals were derived at.

c. Statistical analyses of data

i. Analysis of variance

The data were subjected to analyses of variance as described by Ostle (1966) for a randomised block design. The variance due to 19 treatments was further partitioned. The actual break up of the total variance into different components is indicated in Table 5.

Table 5 General analysis of variance for purelines and physical mixtures

Sources of variation*	df				MS
Replications	1				R_1
Treatments	18				T_1
Purelines		4			T_2
Physical mixtures		13			T_3
2 way mixtures			5		T_4
Resistant lines within 2 way mixtures				2	T_5
Suscepts within 2 way mixtures				1	T_6
Resistant lines x suscepts				2	T_7
3 way mixtures			5		T_8
4 way mixtures			1		T_9
3 way mixtures vs 4 way mixtures			1		T_{10}
2 way mixtures vs 3 and 4 way mixtures			1		T_{11}
Purelines vs physical mixtures		1			T_{12}
Error	18				E
CD (P=0.05)					

* Significance of variances due to treatments and their components were tested using F test using E as denominator

ii. Associative ability analysis

Data from purelines and 2 component mixtures were analysed to find out general associative ability of purelines and specific associative ability of physical mixtures.

Associative ability analysis was done as in a line x tester analysis. The 2 component mixtures were formed by 50:50 mixing as in a format for a line x tester hybrid programme. Resistant lines (R_1, R_2, R_3) were considered as lines and two suscepts (S_1, S_2) as testers. The line x tester hybrids would be 6 in number (3 x 2) and the present 2 component mixtures were analogous to the hybrids except for hybridisation but for physical mixing.

The statistical model is

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

where

Y_{ijk} = mean of i^{th} + j^{th} physical mixture at k^{th} replication

μ = grand mean

g_i = general associative ability effect (gaa) of j^{th} resistant lines

g_j = general associative ability effect (gaa) of j^{th} susceptible line

s_{ij} = specific associative ability effect (saa) of $(i+j)^{th}$ physical mixture

e_{ijk} = Error associated with $(i+j)^{th}$ physical mixture at k^{th} replication

$$g_1 = \frac{g_{12} + g_{13} + g_{14} + g_{15}}{4} - g_{11}$$

$$g_2 = \frac{g_{21} + g_{23} + g_{24} + g_{25}}{4} - g_{22}$$

$$s_{ij} = s_{12} - \frac{s_{11} + s_{22}}{2}$$

iii. General coexistence ability index (GCoA)

The general coexistence ability index of a genotype refers to the ratio of its average performance in physical mixtures to its performance in purestand.

$$GCoA(i) = \frac{\bar{M}_i}{\bar{M}_{ip}}$$

where GCoA(i) = the general coexistence ability of i^{th} genotype in various physical mixtures

$\bar{M}_{ip}$ = Mean performance of the i^{th} genotype in purestand

$\bar{M}_i$ = Mean performance of the i^{th} genotype in various physical mixtures

If GCoA(i) is

a) $<$ I, the pureline is a poor competitor

b) equal to I, the pureline isunaffected by other varieties

c) $>$ I, the pureline competes favourably with other varieties and therefore, a better competitor.

iv. Correlation between obstruction created (%) and level of resistance to aphids

Simple correlation was worked out between obstruction created (%) (x) and level of resistance to aphids (y).

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

v. Pooled analysis of variance

Analyses of variance of the data pooled over three seasons were done for pods/plot, yield/plot and level of aphid resistance as per Panse and Sukhatme (1978) (Table 6). Homogeneity of error variances in separate seasons was tested using Bartlett's test (1937).

Table 6 Pooled analyses of variance

Sources	df	MS
Total	113	
Seasons	2	M_1
Treatments	18	M_2
Seasons x treatments	36	M_3
Pooled error	54	M_4

Variance due to seasons x treatments interaction was tested as M_3/M_4. Once M_3 was significant, M_1 and M_2 were tested against M_3.

vi. Phenotypic stability analysis

The phenotypic stability analyses for pods/plot, yield/plot and level of aphid resistance were conducted as suggested by Eberhart and Russel (1966). Parameters of phenotypic stability were estimated. The parameters are (i) regression of individual mean performance over environmental index and (ii) deviation from regression. Mean performance of treatments were also considered along with the above two parameters to locate stable treatments.

The environmental index is the average performance of all varieties in a season minus grand mean over all seasons. The statistical model used is

$$Y_{ij} = \mu + b_i I_j + \delta_{ij}$$

$i = 1, 2 \ldots\ldots\ldots\ldots\ldots 19$

$j = 1 \ldots 3$

where

Y_{ij} = Mean performance of i^{th} treatment in j^{th} season

μ = Mean of all the treatments over all seasons

b_i = Regression coefficient of i^{th} treatment on the environmental index which measures response of the treatment to different seasons

I_j = The season index which is defined as the deviation of the mean of all the treatments at a given season from the overall mean

δ_{ij} = The deviation from regression of i^{th} treatment at the j^{th} season

The season index is expressed as $I_j = (\sum_i Y_{ij}/19) - (\sum_i \sum_j Y_{ij}/114)$; with

$$\Sigma_j I_j = 0$$

The stability parameter (b_i) was estimated using the formula

$$b_i = \Sigma_j Y_{ij} I_j / \Sigma_j I_j^2$$

The second stability parameter S^2di was estimated using the formula

$$S^2di = \Sigma_j \delta_{ij}^2 / 1 - S^2e/r$$

where S^2e/r is the estimate of the pooled error and

$$\Sigma_j \delta_{ij}^2 = (\Sigma_j Y_{ij}^2 - Y_i^2/3) - (\Sigma_j Y_{ij} I_j)^2 / \Sigma_j I_j^2$$

where $Y_i = \sum_{j=1}^{3} Y_{ij}$

The average of error mean squares over all seasons was taken as the estimate of pooled error variance. The detailed analysis of variance for estimation of stability parameters is given in Table 7.

Table 7 Analysis of variance for phenotypic stability

Sources	df	SS	MS
Total	38	$\Sigma_i \Sigma_j Y_{ij}^2 - CF = TSS$	
Treatments (G)	18	$\Sigma_i Y_i^2/3 - CF = GSS$	MS_1
Seasons	2	$\Sigma_j Y_j^2/19 - CF = SSS$	
Treatments x Seasons	36	TSS-GSS-SSS	MS_2
Seasons + (Treatment x seasons)	38	$\Sigma_i \Sigma_j Y_{ij}^2 - \Sigma_i Y_i^2/3$	
Season (linear)	1	$1/19(\Sigma_j Y_j I_j)^2/\Sigma_j I_j^2 = SSE$	
Treatment x Season (linear)	18	$\Sigma_i \left[(\Sigma_j Y_{ij} I_j)^2/\Sigma_j I_j^2 \right] - SSE$	MS_3
Pooled deviation	19	$\Sigma_i (\Sigma_j \delta i^2 j)$	MS_4
Treatment 1	1	$\Sigma_j Y^2{}_{1j} - \frac{(Y1)^2}{3} - (\Sigma_j Y_{ij} I_j)^2/\Sigma_j I^2{}_j$	
⋮		⋮	
Treatment 19	1	$\Sigma_j Y^2{}_{19j} - \frac{Y^2{}_{19}}{3} - (\Sigma_j Y_{19j} I_j)^2/\Sigma_j I^2{}_j$	
Pooled error	54		MS_5

i) The significance of the difference among treatment means was tested using 'F' ratio

$$F = \frac{MS_1}{MS_4} = \frac{\text{Mean square for treatments}}{\text{Pooled deviation mean square}}$$

ii) The significance of treatment x environment interaction was tested using 'F' ratio

$$F = \frac{MS_2}{MS_5} = \frac{\text{Mean square for treatment x seasons}}{\text{Pooled error mean squares}}$$

iii) Differences among treatments for their regression on the environmental index were tested using 'F' test.

$$F = \frac{MS_3}{MS_4} = \frac{\text{Mean square for T x S (linear)}}{\text{Pooled deviation mean square}}$$

iv) Deviation from regression for each treatment was tested using 'F' ratio

$$F = \frac{(\Sigma_j \delta_{ij}^2)/1}{MS_5}$$

v) The significance of the difference between a regression coefficient and unity was tested using the 't' test

$$t = \frac{bi-1}{\sqrt{MS_4/I^2 j^2}}$$

The relation between performance and stability (bi) of 19 treatments were diagramatically represented.

E. Natural predators and their identification

Throughout the courses of field experiments, aphidophagous insects were seen in cowpea plots. The most prevalent predators were collected, specimens prepared and sent to Zoological Survey of India, Calcutta for identification.

Results

RESULTS

A. Identification of source(s) of resistance to aphids in cowpea and estimation of level of resistance

1. Evaluation of indigenous and exotic collections of cowpea under natural field conditions

Preliminary evaluations of cowpea lines were done under field conditions as and when indigenous and exotic lines were assembled (Table 8). A total of 204 lines consisting grain, forage and vegetable types were evaluated for host reponse to aphids during 11 seasons from November 1986 to March 1989 (Flow chart 1). Observations were made on number of aphids on the plant at all stages of plant growth. Intensity of infestation was graded into three - low, medium and high. There was overlapping of different generations of the pest, which helped in the build up of sufficiently high pest population, ideal for assessing host response with a high degree of reliability under natural field conditions.

In the first trial, during November 1986-January 1987, 67 lines were evaluated for host response. Among them, 14 had low infestation, three medium and 50 had high infestation. The low and medium infested group together (17 accessions) were further evaluated for 3 more seasons (February-May 1987, June-

Table 8 Preliminary evaluation of cowpea lines

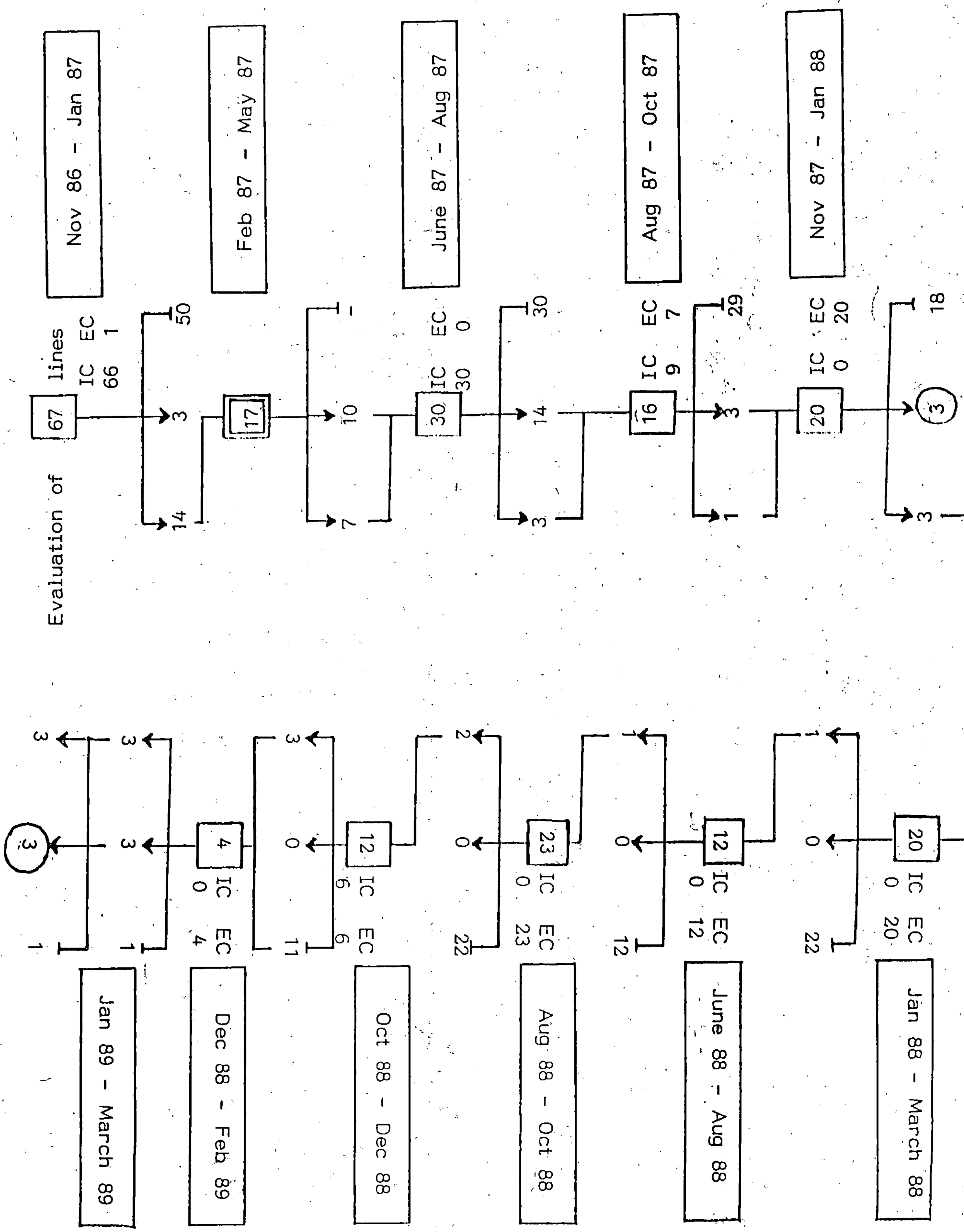
Seasons	Total cowpea lines evaluated		Remarks
	IC lines	EC lines	
1	2	3	4
November 1986-January 1987	66	1	Fourteen lines were resistant (scale 0) and three lines moderately resistant (scale 1)
February-May 1987	-	-	Seventeen lines, promising during the previous season were tested. Seven lines were resistant (scale 0) and ten lines moderately resistant (scale 1)
June-August 1987	30	-	Along with 30 new entries, the 17 promising entries were tested. All the 30 new entries were highly susceptible. Out of the 17 lines, 3 were resistant (scale 0) and 14 moderately resistant (scale 1)
August-October 1987	9	7	Sixteen new entries and the 17 promising entries were tested. One line was resistant (scale 0), three moderately resistant (scale 1) and 29 were highly susceptible (scale 2)

Contd.

Table 8 Continued

1	2	3	4
November 1987-January 1988		20	Twenty new entries and four promising entries were tested. Three were resistant (scale 0) and three were moderately resistant (scale 1). Eighteen were susceptible (scale 2).
January-March 1988	-	20	Twenty new entries along with three resistant lines were tested. One was resistant (scale 0) and 22 were susceptible (scale 2).
June-August 1988	-	12	Twelve new lines and one resistant line obtained previously were tested. One was resistant (scale 0) and 12 were susceptible (scale 2).
August-October 1988	-	23	The resistant line and 23 new lines were tested. Two were resistant (scale 0) and 22 susceptible (scale 2).
October-December 1988	6	6	Two resistant lines and 12 new entries were tested. Three were resistant (scale 0) and 11 were susceptible (scale 2).
December 1988-February 1989	-	4	Three resistant lines and 4 new lines were tested. Three were resistant (scale 0), three moderately resistant (scale 1) and one was susceptible (scale 2).
January-March 1989	-	-	The above seven lines were once again tested. Three confirmed their resistance (scale 0), three moderately resistant (scale 1) and one was susceptible (scale 2).

Flowchart depicting cowpea accessions evaluated for resistance to aphids over eleven seasons



August 1987 and August-October 1987). It was observed that out of 17 accessions evaluated, 14 had medium and three had low infestation. During the fourth season (August-October 1987), the three low infested accessions (Vs 306, Vs 307 and Vs 147) fell into the medium infested grade and the remaining 14 fell into the high infested grade.

During third season (June-August 1987) 30 new lines were evaluated and all the 30 were severaly infested. During the 4th season (August-October 1987) 16 new lines were further tested among which one (Vs 350) had only very low infestation. Low infestation was recorded in Vs 350 consecutively during subsequent five seasons.

During the fifth season (November 1987-January 1988), 20 new accessions were evaluated, out of which two had only low infestation and 18 had high infestation. During the sixth season (January-March 1988), the two low infested lines also got severely infested. During sixth (January-March 1988), seventh (June-August 1988) and eighth (August-October 1988) seasons, 20, 12 and 23 new accessions respectively were evaluated. All were highly susceptible except Vs 438 among the 23 accessions grown during the eighth (August-October 1988) season. During ninth season, two resistant lines (Vs 350, Vs 438) and 12 new lines were further evaluated. The two resistant lines exhibited consistent resistant reaction and Vs 452 among the 12 new entries also fell into the low infestation group. The three resistant accessions and four new accessions were further grown during tenth (December 1988-February 1989) season. The resistant accessions continued to be resistant and three among the new accessions were infested only medium and one was highly infested.

All the accessions grown during tenth season were again grown during 11th season (January-March 1989). The three resistant lines (Vs 350, Vs 438 and Vs 452) confirmed resistance. As in the previous seasons, the other three lines (Vs 456, Vs 457 and Vs 458) were medium infested and one (Vs 459) was severely infested.

All the cowpea lines evaluated for reaction to aphids were observed for vegetative and productive characters and their components (Table 2 and 3).

There was great variability among cowpea lines evaluated, for vegetative and productive characters. Out of 204 accessions evaluated for resistance, 39 lines were bushy, 30 were semiviny and 135 were spreading. The accession Vs 432 was the dwarfest (32 cm). Branches/plant ranged from 1 to 6. Thirtytwo accessions flowered in less than 40 days. The accession Vs 315 took only 37 days for flowering and Vs 419 only 38 days. One hundred and fortyeight lines flowered within 40 to 50 days, and 20 lines within 50 to 60 days. Four accessions (Vs 317, Vs 319, Vs 320 and Vs 335) were very late and took more than 70 days for flowering. The line Vs 432 had the shortest (5.0 cm) and the lightest (1.0 g/pod) pod. The accession Vs 415 had the longest pod (30 cm). The lines Vs 457 and Vs 458 had the heaviest pods (8.0 g/pod) and the pod yield/plant was the highest in Vs 457 (232.0 g). Pod yield was only 4.50 g in Vs 432.

2. Weather parameters and aphid population

The weather parameters - mean maximum temperature, mean minimum temperature, mean relative humidity, rainfall and number of rainy days are given in Tables 9 to 12.

Aphid population was the lowest during March, April and May in 1987, 1988 and 1990. During 1990 (Table 12), low aphid infestation was observed during June and July, also. During 1987, the highest mean maximum temperature (36.4°C, 36.2°C, 36.1°C) was recorded during March, April and May compared to other months of the year (Fig. 1a). Mean relative humidity was the lowest during March, April and May (55%, 64% and 66%, respectively) except for 52% in January and February. The rainfall was nil, 13.3 mm and 95 mm during March, April and May and number of rainy days were 0, 1 and 3 respectively.

Table 9 Weather parameters and aphid population rating (year 1987)

Weather parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	33.2	35.0	36.4	36.2	36.1	30.7	30.3	29.6	31.5	31.9	31.6	31.6
Mean minimum temperature (°C)	22.7	22.4	22.2	25.3	24.7	23.7	23.5	23.5	23.9	23.9	22.8	23.3
Mean relative humidity (%)	52	52	55	64	66	83	84	87	79	79	77	70
Rainfall (mm)	0	0	0	13.3	95.0	837.7	336.5	388.4	174.0	280.4	224.4	64.6
Number of rainy days	0	0	0	1	3	21	17	22	8	16	6	6
Aphid population rating	H	H	M	M	M	H	H	H	H	H	H	H

H = Heavy; M = Medium; L = Low

Table 10 Weather parameters and aphid population rating (year 1988)

Weather parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	32.4	35.8	35.7	35.1	33.7	30.0	29.0	29.2	29.9	31.7	32.6	32.6
Mean minimum temperature (°C)	22.0	23.1	24.4	24.8	25.4	23.7	23.2	24.3	23.2	23.3	22.9	22.3
Mean relative humidity (%)	56	56	67	70	76	86	88	86	85	78	68	57
Rainfall (mm)	0	7.8	87.9	135.4	242.6	632.1	545.0	507.8	700.0	116.6	11.0	14.9
Number of rainy days	0	1	1	8	6	25	26	25	24	9	1	2
Aphid population	H	H	M	L	L	H	H	H	H	H	H	H

H = Heavy; M = Medium; L = Low

Table 11 Weather parameters and aphid population rating (year 1989)

Weather parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	33.4	36.3	36.5	35.3	33.7	29.4	29.1	29.5	29.9	31.0	32.5	32.7
Mean minimum temperature (°C)	22.2	21.2	23.2	25.1	24.5	22.7	23.3	23.1	23.1	23.0	22.7	23.2
Mean relative humidity (%)	54	45	58	69	74	86	86	83	82	80	63	60
Rainfall (mm)	0	0	31.3	52.6	115.8	784.6	562.0	319.9	180.1	351.3	8.1	0
Number of rainy days	0	0	2	4	7	27	17	19	15	16	2	0
Aphid population	H	H	M	L	L	H	H	H	H	H	H	H

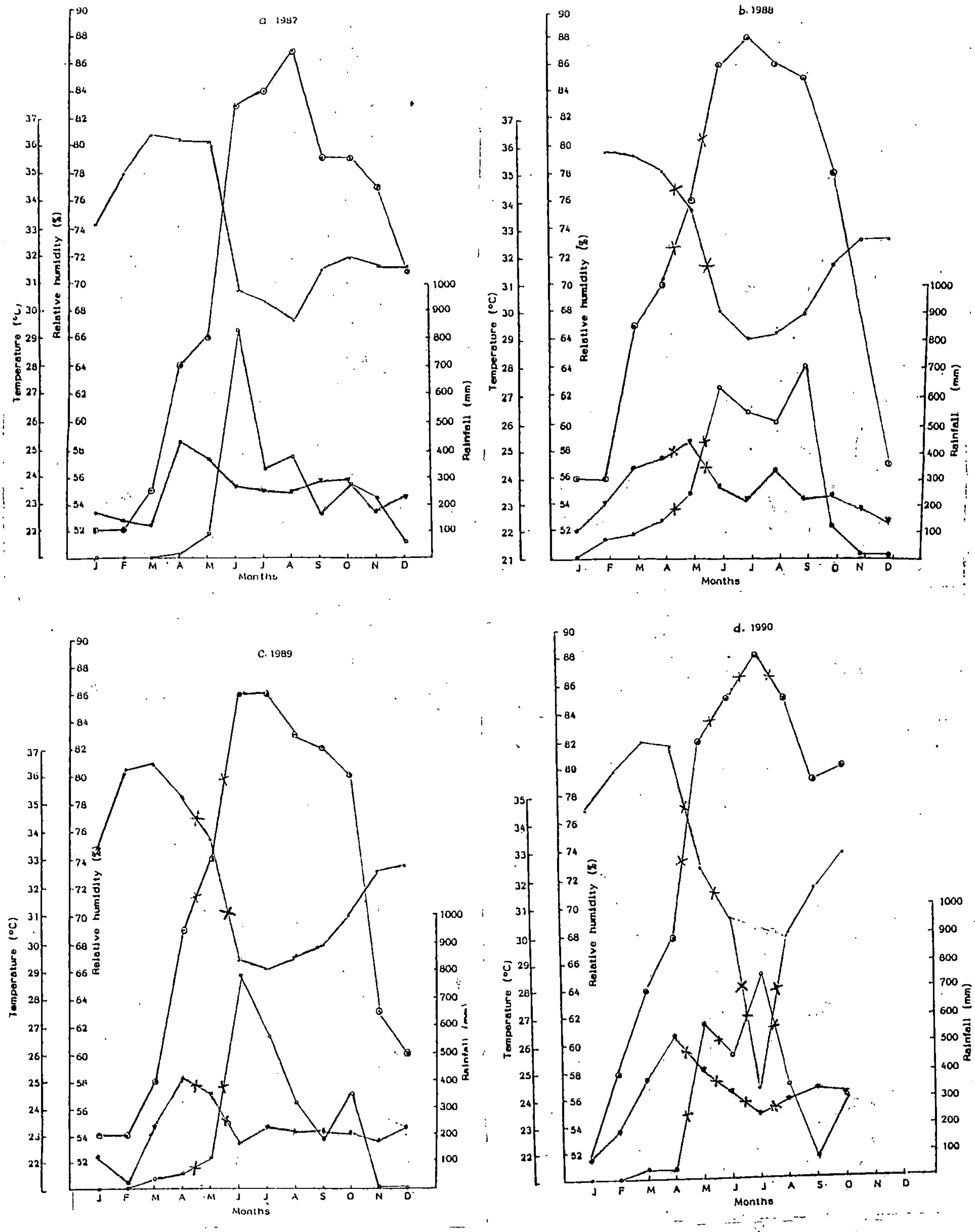
H = Heavy; M = Medium; L = Low

Table 12 Weather parameters and aphid population rating (year 1990)

Weather parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	33.5	34.9	36.0	35.8	31.5	29.7	23.4	29.0	30.7	31.9		
Mean minimum temperature (°C)	20.8	21.9	23.8	25.4	24.1	23.3	22.5	23.0	23.4	23.2		
Mean relative humidity (%)	50	58	64	68	82	85	88	85	79	80		
Rainfall (mm)	3.5	0	4.4	38.8	583.9	467.3	759.3	356.4	87.5	318.3		
Number of rainy days	0	0	1	2	18	25	28	22	8	12		
Aphid population	H	H	M	L	L	L	L	H	H	H		

H = Heavy; M = Medium; L = Low

Fig. 1. Weather parameters for the years
a. 1987 b. 1988 c. 1989 d. 1990



x Low aphid population

Maximum temperature
Minimum temperature
Relative humidity
Rainfall

During 1988, the highest mean maximum temperature was recorded during February (35.8°C) followed by March (35.7°C), April (35.1°C) and May (33.7°C) (Table 10, Fig. Ib). The mean minimum temperature was the highest during March (24.4°C), April (24.3°C) and May (25.4°C), when compared to other months. Number of rainy days were only 1, 8 and 6 with a total rainfall of 37.9 mm, 145.4 mm and 242.6 mm during March, April and May respectively. The period of lowest incidence of aphids coincided with dry months of March, April and May. There was heavy incidence during all other months.

During 1989, the mean maximum temperature was the highest during February, March, April and May with 36.3°C, 36.5°C, 35.3°C and 33.7°C respectively (Table 11, Fig. Ic). The relative humidity was also low during February (45%), March (58%), April (69%) and May (74%). The rainfall was low with zero mm (February), 31.3 mm (March), 52.6 mm (April) and 115.8 mm (May) with 0, 2, 4 and 7 rainy days. During 1989 also, the lowest incidence of aphids was noted during March, April, May months characterized by the highest maximum temperature, low relative humidity and low rainfall. The incidence was heavy during all other months.

During 1990 also, the highest maximum temperature was recorded during March (36.0°C) and April (35.8°C). The mean minimum temperature recorded was also the highest, 23.8°C and 25.4°C during March and April respectively (Table 12, Fig.1d). The mean relative humidity was 64% and 68% during March and April. Number of rainy days were only one and two during March and April respectively with 4.4 mm and 38.8 mm rainfall. Immediately after the severe dry months of March and April 1990, there was heavy rainfall during May 1990 with 18 rainy days and 583.9 mm rainfall (in contrast to the light rains during 1987, 1988 and 1989 towards May end). This was followed by heavy rains during June and July and the aphid population was low during June and July 1990.

3. *In vitro* evaluation of identified cowpea lines

Based on results obtained from the preliminary observations in the field, an *in vitro* evaluation was taken up using nine selected lines Vs 350, Vs 438, Vs 452, Vs 306, Vs 307, Vs 147, Vs 456, Vs 457 and Vs 458 and two susceptible lines Kanakamony and Pusa Komal. The lines were tested for their suitability for feeding and breeding by the aphids through pot culture studies in screen houses when the seedlings were 10-12 days old. Each seedling was infested with 4 first instar nymphs of aphids. The average number of aphids/plant at 10 and 15 days after infestation (DAI) was recorded. There was significant difference among all varieties belonging to all the three groups (Table 13) for number of aphids they sustained on 10 and 15 DAI. The aphid population increased at different rates among test cowpea accessions (Table 14). The three groups differed significantly for number of aphids, they maintained at 10 and 15 DAI. The aphid multiplication ranged from 34.8 (Vs 438) to 52.6 (Vs 452) by 10 DAI and 86.4 (Vs 438) to 143.2 (Vs 452) by 15 DAI in the resistant group. In the moderately resistant group, the multiplication ranged from 56.2 (Vs 307) to 84.0 (Vs 456) by 10 DAI and 176.2 (Vs 307) to 292.6 (Vs 456) by 15 DAI. Rate of multiplication was maximum in the susceptible group and was 208.0 and 714.6 in Kanakamony and 187.6 and 627.6 in Pusa Komal by 10 DAI and 15 DAI respectively.

Table 13 Analysis of variance for performance of selected cowpea line artificially infested with 4 nymphs of aphids at seedling stage in the screen house

Sources	df	MS
Lines (L)	10	175866.785**
DAI	1	987816.238*
L x DAI interaction	10	55631.523**
Error	88	795.920

**P = 0.01

Table 14 Performance of selected cowpea accessions artificially infested with 4 nymphs of aphids at seedling stage in the screenhouse

Lines	Average number of aphids	
	10 DAI	15 DAI
Vs 438	34.8 ± 1.85	86.4 ± 2.22
Vs 350	35.2 ± 1.58	90.4 ± 2.46
Vs 452	52.6 ± 2.59	143.2 ± 4.28
Vs 306	82.6 ± 2.51	270.0 ± 4.27
Vs 307	56.2 ± 2.42	176.2 ± 3.12
VS 147	61.8 ± 1.69	192.4 ± 3.00
Vs 456	84.0 ± 3.42	292.6 ± 12.33
Vs 457	59.6 ± 2.46	198.8 ± 8.14
Vs 458	76.6 ± 2.54	231.6 ± 5.15
Kanakamony	208.0 ± 2.90	714.6 ± 16.29
Pusa Komal	187.6 ± 3.88	627.6 ± 14.95
Sem±	12.62	12.62
CD (P=0.05 to compare lines (L)	25.06	
DAI	10.68	
L x DAI	35.44	

DAI = Days after infestation

4. Estimation of level of resistance in resistant cowpea lines and extent of susceptibility in susceptible lines

Three resistant cowpea lines (Vs 350, Vs 438 and Vs 452), six moderately resistant lines (Vs 306, Vs 307, Vs 147, Vs 456, Vs 457 and Vs 458) and two highly susceptible lines (Kanakamony and Pusa Komal) were subjected to rigorous evaluation to confirm their host response.

Counts of aphid population build up on the terminal shoots, terminal leaves, flowers and pods were taken (Table 15). Population build up was observed on all lines and they were rated into 3 groups - low, medium and high. In the group rated as resistant, the number of aphids on terminal shoots ranged from 20.3 (Vs 452) to 22.7 (Vs 350), in the moderately resistant group it ranged from 33.4 (Vs 307) to 86.3 (Vs 456) and in the susceptible group 504.6 (Pusa Komal) to 596.5 (Kanakamony). On terminal leaves, the ranges were 10.2 (Vs 350) to 26.6 (Vs 452) in resistant group, 39.8 (Vs 458) to 76.7 (Vs 457) in moderately resistant group and in the susceptible group the range was from 820.5 (Pusa Komal) to 912.7 (Kanakamony). On the flowers, the ranges were 6.9 (Vs 438) to 28.5 (Vs 452), 12.1 (Vs 457) to 35.1 (Vs 306) and 96.1 (Pusa Komal) to 108.2 (Kanakamony) in the resistant, moderately resistant and susceptible groups, respectively. Ranges on pods were 10.4 (Vs 438) to 19.9 (Vs 452), 22.0 (Vs 147)

Table 15 Reaction of selected cowpea lines to aphids in the field

Lines	Average number of aphids on				Resistance rating	
	Terminal shoot	Terminal leaves	Flower	Pod		
Vs 438	20.5	16.5	6.9	10.4	0	R
Vs 350	22.7	10.2	20.2	16.5	0	R
Vs 452	20.3	26.6	28.5	19.9	0	R
Vs 306	51.8	58.6	35.1	46.2	1	MR
Vs 307	33.4	45.9	32.1	77.6	1	MR
Vs 147	67.5	43.1	24.8	22.0	1	MR
Vs 456	86.3	63.0	16.4	32.5	1	MR
VS 457	54.2	76.7	12.1	33.7	1	MR
Vs 458	70.5	39.8	27.4	60.5	1	MR
Kanakamony	596.5	912.7	108.2	910.0	2	S
Pusa Komal	504.6	820.5	96.1	842.0	2	S

to 77.6 (Vs 307) and 842 (Pusa Komal) to 910 (Kanakamony) aphids on resistant, moderately resistant and susceptible groups respectively.

B. Morphological and biochemical bases of host reaction to aphid infestation

The mechanism of resistance to aphids was studied in three resistant and two susceptible accessions.

1. Mechanism of preference/non-preference

a Migratory and settling preferences

The experiment was conducted to study differences in preference of aphids to selected resistant and susceptible lines. Number of aphids migrated and settled on five lines in field and on shoot tip clippings kept in the conical flask in laboratory were counted.

Under free choice conditions, aphids migrated in all directions. However, they showed a clearcut preference for migration and colonization both in field experiment and in laboratory (Fig. 2). Differences in number of aphids migrated and colonized on the five cowpea lines were highly significant, within one day (Table 16). It was noted that Vs 350 (resistant) recorded zero number of aphids/plant followed by the remaining two resistant

Fig. 2. Difference in preference for settling of aphids among selected cowpea lines

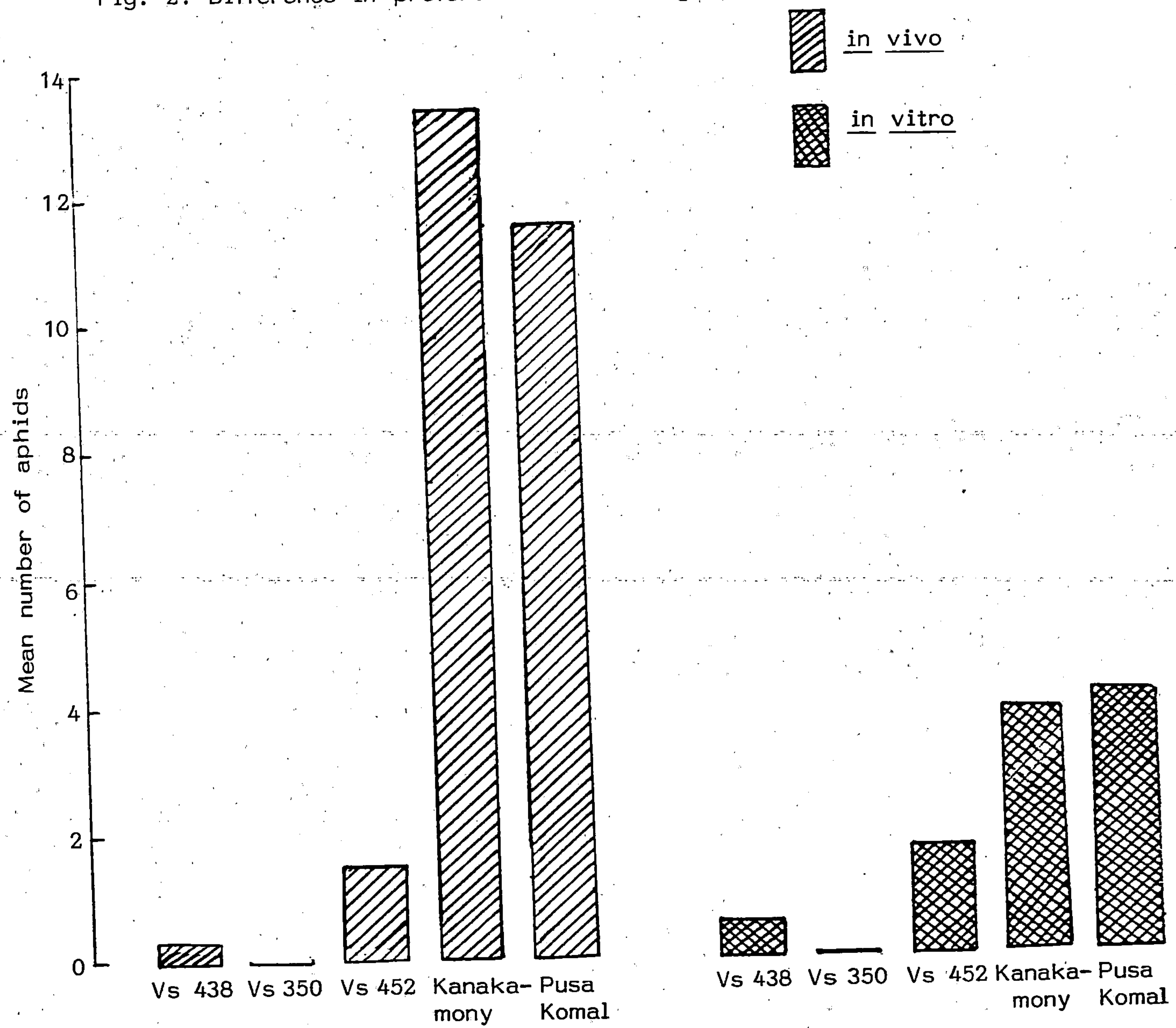


Table 16 Analysis of variance for preferences for settling of aphids among selected accessions in field and in laboratory

Sources	df	Mean squares	
		In field	In laboratory
Lines	4	275.65**	13.38**
Error	35	3.44	0.43

** P = 0.01

accessions Vs 438 (0.25, 0.50) and Vs 452 (1.50, 1.75) in field and in laboratory respectively. As evidenced from the high number of aphids (Table 17) observed on susceptible lines (Kanakamony - 13.25, 3.75 and Pusa Komal - 8.25, 4.0) in field and laboratory conditions respectively, susceptible lines were more preferred by aphids.

Table 17 Difference in preference for settling of aphids among selected cowpea lines

Lines	Mean number of aphids settled	
	In vivo	In vitro
Vs 438	0.25	0.50
Vs 350	0.00	0.00
Vs 452	1.50	1.75
Kanakamony	13.25	3.75
Pusa Komal	8.25	4.00
Sem±	0.65	0.32
CD (p = 0.05)	1.88	0.99

b Pubescence

i) Trichomes on leaves

Four lines (Vs 452, Vs 438, Vs 350 and Kanakamony) differed considerably in density, size and form of trichomes. The line Vs 452 has a dense covering and profuse growth of trichomes (Plate IV). Long, medium long and short trichomes were seen mixed. They were prostrate, but straight with tips pointed. The angle of insertion departed from 90°. Line Vs 438 also had profuse trichome cover consisting of long and short types mixed together (Plate V). They were prostrate, curved back, inserted at angles, but straight with tips pointed. Vs 350 was less densely pubescent, when compared to Vs 452 and Vs 438 (Plate VI). Both long and short trichomes were mixed and were positioned at different angles. They were straight with tips pointed.

Kanakamony was sparsely pubescent with very short trichomes (Plate VII). They were of uniform size without any long or medium long ones.

ii) Trichomes on shoot tips

Trichomes on stems were bold and stout, but lesser in density when compared to leaves. The stem tip of Vs 452 was the most densely pubescent (Plate VIII). They were seated very

Plate III. Migratory and settling preferences of *Aphis craccivora* in cowpea demonstrated through shoot tip clippings

Plate IV. Scanning electron micrograph showing trichome coverage on leaves of Vs 452 (100x)

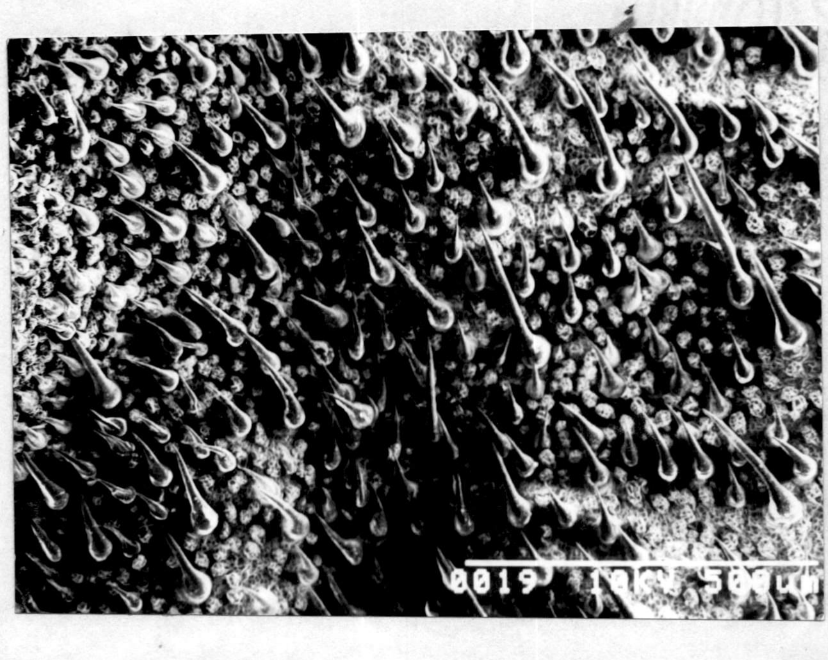

0019 10KV 500um

Plate V. Scanning electron micrograph showing trichome coverage on leaves of Vs 438 (100x)

Plate VI. Scanning electron micrograph showing trichome coverage on leaves of Vs 350 (150x)


0015

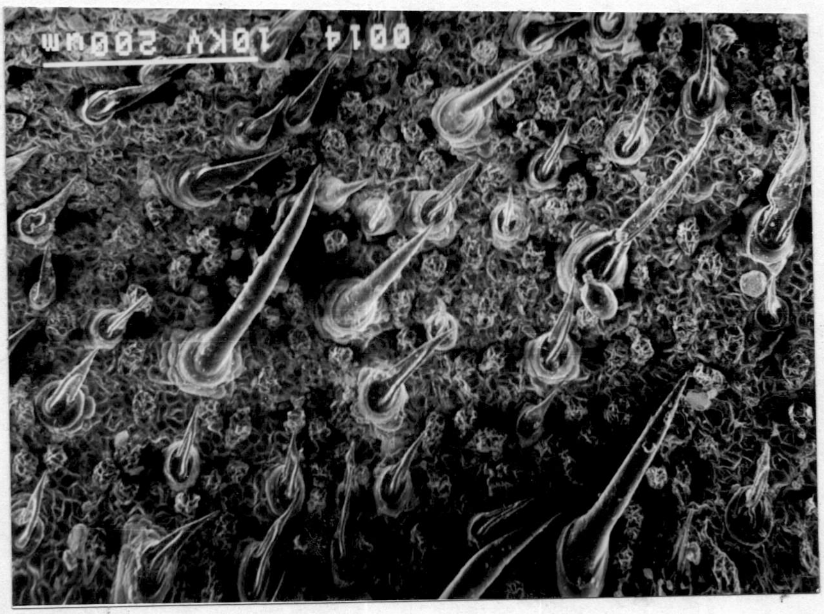

0014 10KV 200μm

Plate VII. Scanning electron micrograph showing trichome coverage on leaves of Kanakamony (100x)

Plate VIII. Scanning electron micrograph showing trichome coverage on first internode of Vs 452 (150x)

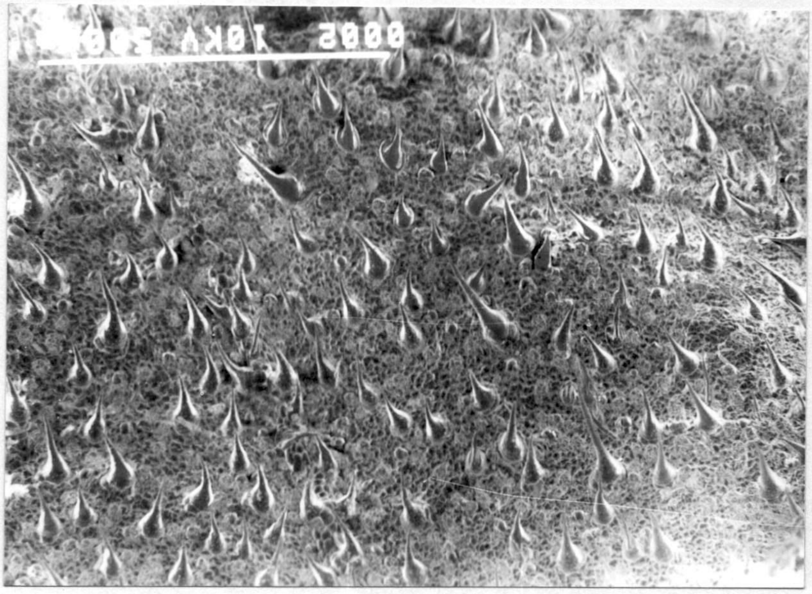
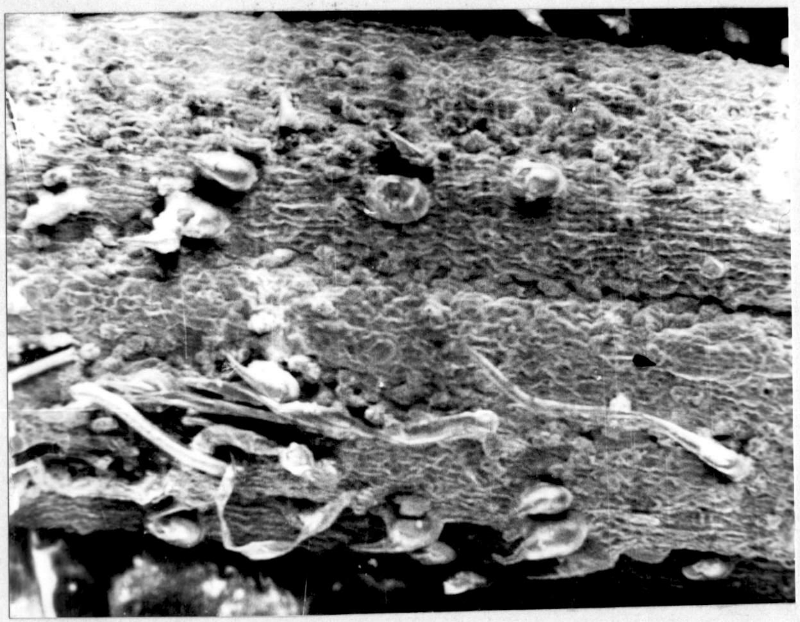


Plate IX. Scanning electron micrograph showing trichome coverage on first internode of Vs 438 (60x)

Plate X. Scanning electron micrograph showing trichome coverage on first internode of Vs 350 (60x)



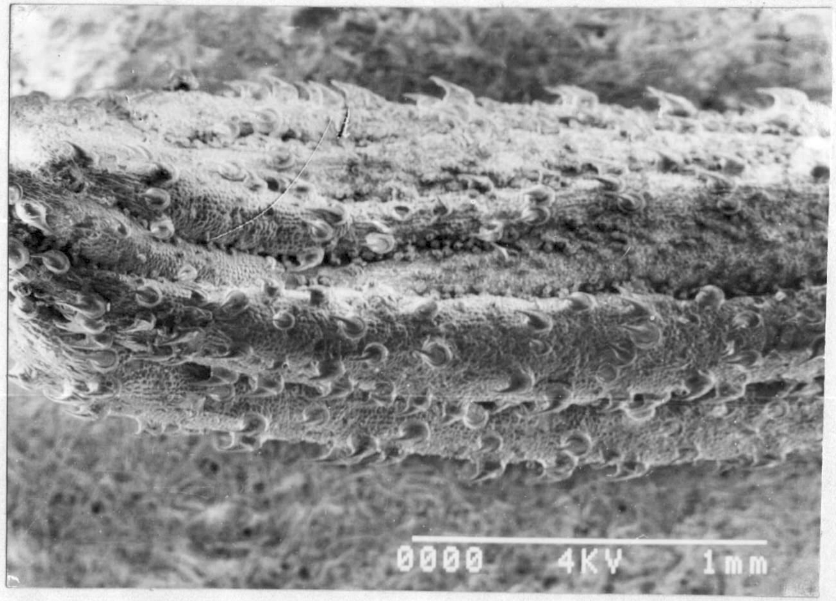

0000 4KV 1mm

Plate XI. Scanning electron micrograph showing trichome coverage on first internode of Kanakamony (60x)

Plate XII. Grub of *Coccinella arcuata*

closely. Long and short trichomes were mixed together. They were not straight but with bend tips. The line Vs 438 also had a dense coverage (Plate IX) of trichomes similar to Vs 452. But they were smaller in size. Vs 350 was less pubescent with small trichomes (Plate X). It was 'curly pubescent' with very long slender trichomes. Early deciduous hair stubs were noted. Kanakamony was sparsely pubescent with very small trichomes (Plate XI). The top most one centimeter shoot tips from second internode of all the four lines were sparsely pubescent.

c Anatomy of shoot apices

Transverse sections of shoot apices from 3rd internode of all cowpea accessions were observed for arrangement of vascular bundles as widely separated, loose, semicompact or compact. Lines Vs 438, Vs 350 and Kanakamony had 14 vascular bundles and Vs 452 and Pusa Komal had 15 vascular bundles. No distinction was observed in their arrangement. The above classification based on arrangement is not useful in the present study. The resistant accession Vs 438 had a slightly thick cuticle while the other two resistant lines and two susceptible lines were characterized by thin and uniform cuticle.

There was only slight difference in the number of layers of cells in the hypodermal collenchyma and chlorenchyma (Table 18). Two resistant accessions (Vs 438, Vs 452) had 3 layers of

Table 18 Description of anatomy of shoot apices

Lines	Number of vascular bundles	Nature of cuticle	Number of layers of cells in					Lignification of schlerenchyma
			Epidermis	Collenchyma	Chlorenchyma	Endodermis	Schleren chymatous pericycle	
Vs 438	14	Slightly thick	1	3	3	1	4	Not lignified
Vs 350	14	Thin	1	2	3	1	3	Not lignified
Vs 452	15	Thin	1	3	3	1	4	Slightly lignified
Kanakamony	14	Thin	1	2	2	1	5	Highly lignified
Pusa Komal	15	Thin	1	3	3	1	4	Highly lignified

collenchymatous cells and one resistant line (Vs 350) and one susceptible line (Kanakamony) had 2 layers of collenchymatous cells each. All the lines except Kanakamony had three layers each of chlorenchymatous cells and Kanakamony had only two layers.

The lowest number of schlerenchymatous layers (3) was observed in the resistant line Vs 350. Two resistant lines (Vs 438 and Vs 452) and the susceptible line Pusa Komal had four layers and the other susceptible line Kanakamony had five layers.

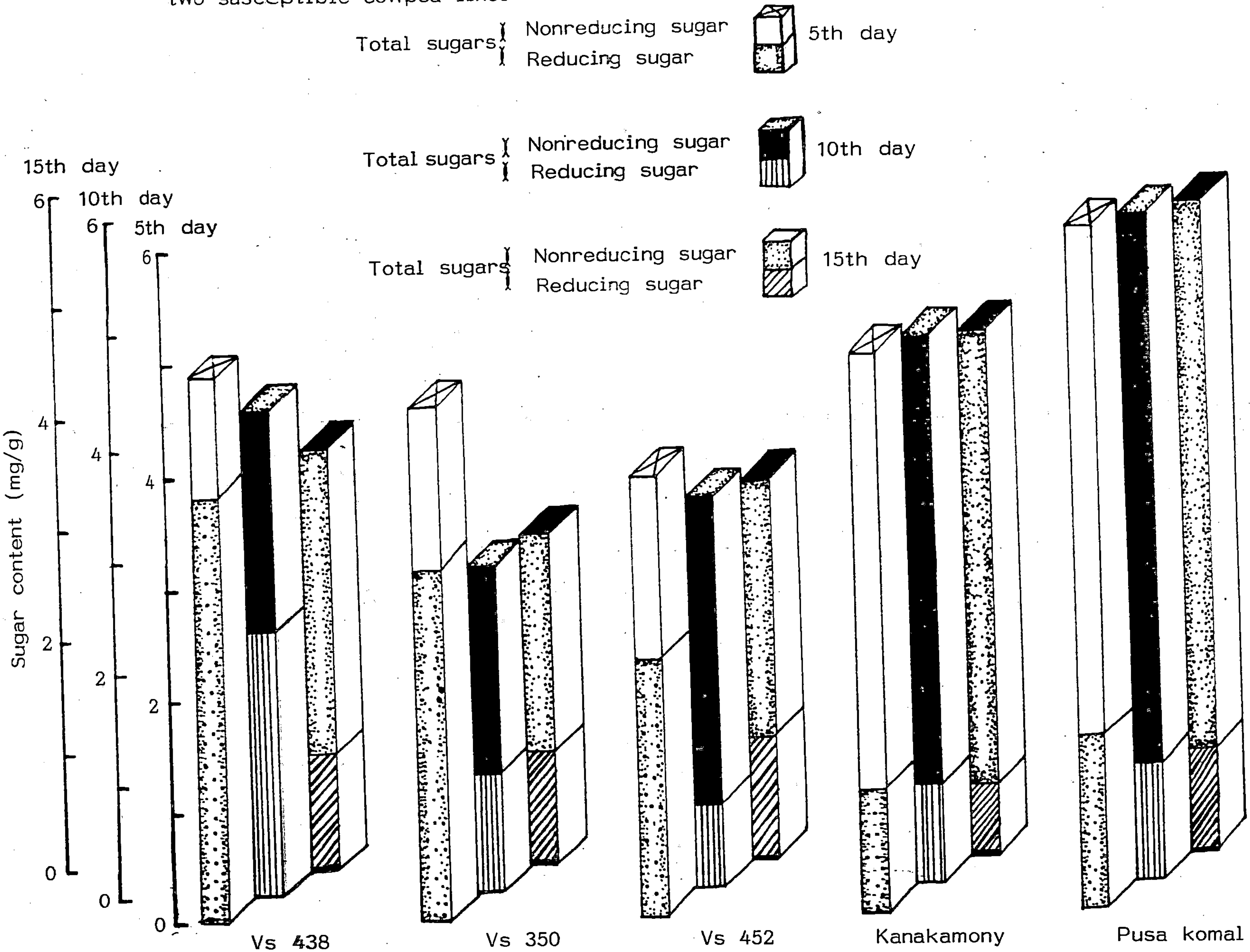
Higher lignification of the schlerenchymatous pericycle was noted in the susceptible lines Kanakamony and Pusa Komal. The resistant lines Vs 438 and Vs 350 were not at all lignified and Vs 452 was only slightly lignified.

d Biochemical factors affecting preference

i) Reducing sugar

Reducing sugar content in pods decreased continuously with passage of time in all the varieties, resistant or susceptible. The resistant lines possessed more reducing sugars than the susceptible lines (Fig. 3). The resistant line Vs 438 had the highest reducing sugar content during all the three stages (3.80, 2.40 and 1.12 mg/g, respectively). Even the resistant lines differed significantly among themselves for reducing sugars, though

Fig. 3. Reducing sugar, nonreducing sugar and total sugar content (mg/g) in pods of three resistant and two susceptible cowpea lines



they possessed more reducing sugars at all stages than the susceptible lines (Table 19). The line Vs 350 contained 2.68, 1.14 and 1.08 mg/g of reducing sugar at 5, 10 and 15 days of maturity respectively. Vs 452 had higher reducing sugar content than Vs 350 at 10 days (1.28 mg/g) and 15 days (1.10 mg/g) of maturity. Among the susceptible lines, Pusa Komal had more reducing sugars (1.62, 1.14 and 0.90 mg/g) than Kanakamony (1.10, 0.92 and 0.65 mg/g) at 5, 10 and 15 days of maturity respectively (Table 20).

Table 19 Analysis of variance for reducing sugar, non-reducing sugar and total sugar contents in cowpea pods at three stages of maturity

Sources	df	Mean squares		
		Reducing sugar	Non-reducing sugar	Total sugar
Lines (L)	4	3.02**	17.55**	10.08**
Stages (S)	2	6.97**	1.54*	2.08*
L x S	8	0.68**	0.22**	0.19
Error	30	0.04	0.03	0.07

* P = 0.05
** P = 0.01

ii) Non-reducing sugar

Non-reducing sugar contents increased continuously for 15 days in all the varieties (Table 20). In general, the lines differed

Table 20 Reducing sugar, non-reducing sugar and total sugar content in pods of three resistant and two susceptible cowpea lines, mg/g

Lines	Reducing sugar			Non-reducing sugar			Total sugar		
	Maturity of pods in days								
	5	10	15	5	10	15	5	10	15
Vs 438	3.80	2.40	1.12	1.10	1.95	2.63	4.90	4.35	3.75
Vs 350	2.68	1.14	1.08	1.46	1.85	1.91	4.14	2.99	2.99
Vs 452	2.30	1.28	1.10	1.66	2.17	2.30	3.96	3.45	3.40
Kanakamony	1.10	0.92	0.65	3.95	4.01	4.07	5.05	4.93	4.72
Pusa Komal	1.62	1.14	0.90	4.53	4.82	4.94	6.15	5.96	5.84
Sem	0.46	0.26	0.09	0.70	0.61	0.57	0.39	0.53	0.51
CD (P=0.05) to compare Lines (L)		0.19			0.16			0.26	
Stage of maturity (S)		0.15			0.12			0.20	
L x S		0.33			0.27			0.45	

significantly for the non-reducing sugar contents among themselves at all stages and the difference between stages was also significant. The line Vs 438 contained the lowest on 5th day (1.10 mg/g) when compared to other resistant lines Vs 350 (1.46 mg/g) and Vs 452 (1.66 mg/g) (Fig. 3). On 10th day, the non-reducing sugar content increased to 1.95 mg/g in the line Vs 438, 1.85 mg/g in Vs 350 and 2.17 mg/g in Vs 452. On 15th day, the line Vs 438 had the maximum (2.63 mg/g) and Vs 350 had the minimum reducing sugar content (1.91 mg/g). The line Vs 452 was intermediate with 2.30 mg/g. The non-reducing sugar contents in susceptible lines were very high with 3.95, 4.01 and 4.07 mg/g in Kanakamony and 4.53, 4.82 and 4.94 mg/g in Pusa Komal on 5th, 10th and 15th days respectively.

iii) Total sugar

The total sugar content decreased with maturity of pods in all the resistant and susceptible lines (Table 20). The resistant lines possessed less total sugar when compared to susceptible lines (Fig. 3). All the varieties differed significantly in total sugar content. Among the resistant lines, Vs 452 had the lowest total sugars on 5th day (3.96 mg/g). The decrease was not steep and had 3.45 mg/g on 10th and 3.40 mg/g on 15th day respectively. The line Vs 350 had 4.14 mg/g on 5th day and a sharp decrease was observed on 10th day (2.99 mg/g) and had 2.90 mg/g on 15th day. The line Vs 438 had the highest total sugar content among the resistant lines. It had a total sugar content of 4.90, 4.35 and 3.75 mg/g on 5th, 10th and 15th day respectively. Among the susceptible lines, Kanakamony had the lowest total sugar content. It had 5.05, 4.90 and 4.72 mg/g on 5th, 10th and 15th day respectively. The line Pusa Komal had a total sugar content of 6.15 mg/g on 5th day, 5.96 mg/g on 10th day and 5.84 mg/g on 15th day.

iv) Protein

The protein content (Table 21) was the lowest in the resistant line Vs 438 (19.75%) and the highest in the susceptible line Pusa Komal (24.35%). The resistant line Vs 350 had more protein (23.05%) than the other two resistant lines and one susceptible line Kanakamony (21.85%).

Table 21 Protein content of cowpea seeds, per cent

Lines	Protein content (%)
Vs 438	19.75
Vs 350	23.50
Vs 452	20.20
Kanakamony	21.85
Pusa Komal	24.35

v) Nitrogen

Total nitrogen content varied only slightly among the lines (Table 22). The line Vs 350 had the highest nitrogen content (3.93%) among the resistant lines followed by Vs 452 (3.86%) and Vs 438 had the lowest (3.80%). The susceptible line Pusa Komal had the highest nitrogen content (4.08%) among all the lines and Kanakamony had 3.88%.

Table 22 Total nitrogen, phosphorus and potassium contents in cowpea lines at 30th DAS, per cent

Lines	Total nitrogen	Phosphorus	Potassium
Vs 438	3.80	0.33	1.85
Vs 350	3.93	0.31	2.07
Vs 452	3.86	0.30	1.98
Kanakamony	3.88	0.34	1.98
Pusa Komal	4.08	0.30	2.13

DAS - Days after sowing

vi) Phosphorus

The phosphorus content (Table 22) also did not vary among the lines. The susceptible line Kanakamony had 0.34% and Pusa Komal had 0.30% of phosphorus content. The resistant line Vs 452 had 0.30%, Vs 350 had 0.31% and Vs 438 had 0.33% of phosphorus content.

vii) Potassium

The potassium content also was not different among the lines (Table 22). It was the highest in the susceptible line Pusa Komal (2.13%) followed by the resistant line Vs 350 (2.07%) and was the lowest in the resistant line Vs 438 (1.85%). Both Kanakamony and Vs 452 had 1.98% potassium.

2. Mechanism of antibiosis

Possible mechanism of antibiosis in resistant accessions, on biology of Aphis craccivora, in terms of fecundity was studied. The chemical constituents which may cause antibiosis were also estimated.

a. Rate of fecundity in aphids fed on resistant/susceptible cowpea lines

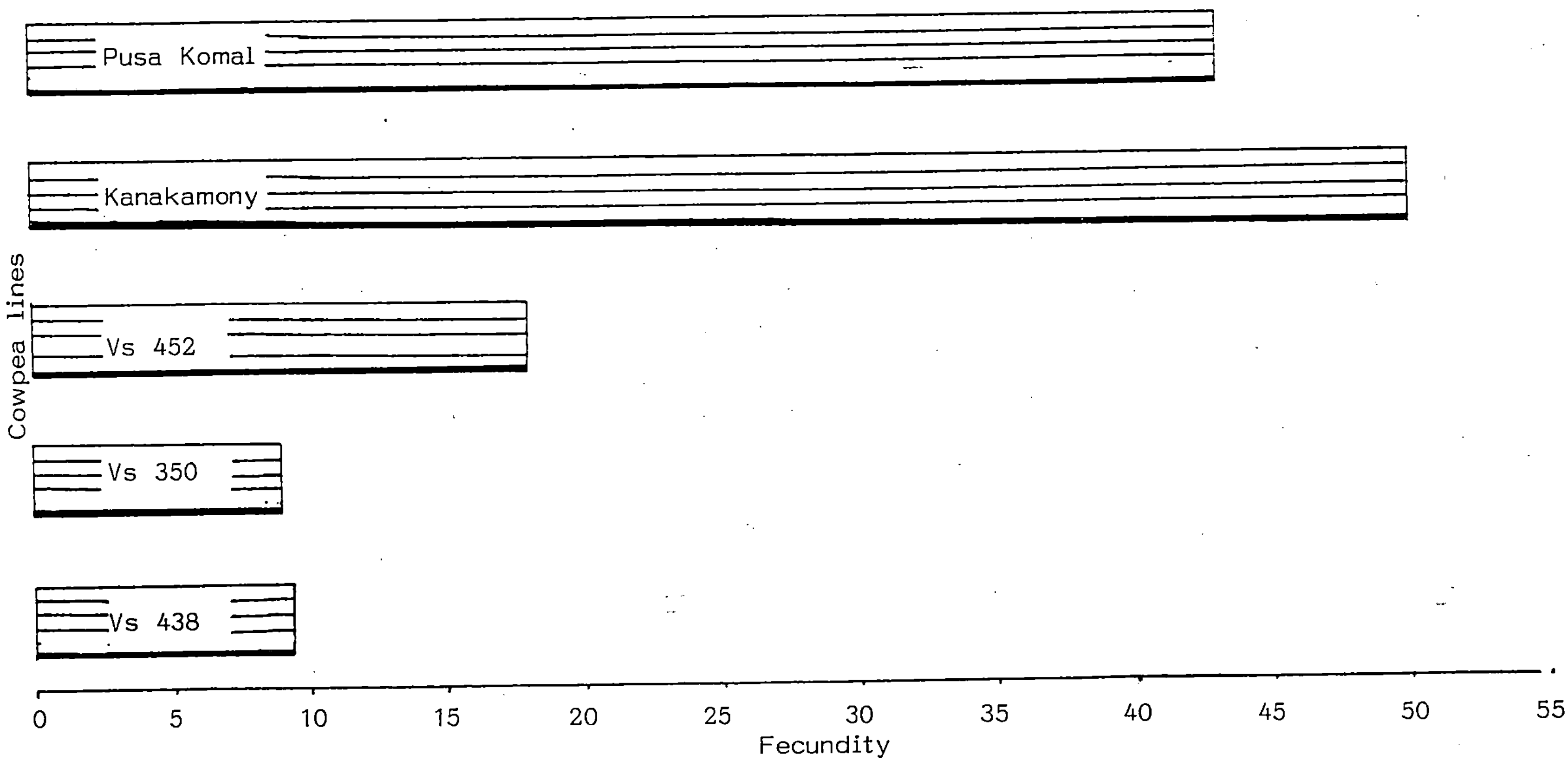
As a consequence of feeding by aphids on test plants, the rate of reproduction was affected considerably. The mean number of progenies/aphid on resistant cowpea lines, ranging from 9.0 to 17.6 were significantly lower than on susceptible lines (43.2 to 50.80) (Table 23). The line Vs 350 restricted the rate of

Table 23 Analysis of variance for fecundity of aphids on selected cowpea lines

Sources	df	MSS
Lines	4	1944.94
Error	20	54.26

**P = 0.01

Fig. 4. Fecundity of aphids on selected cowpea lines



reproduction to a minimum (9.0) while Vs 452 allowed maximum (17.6) among the resistant entries (Table 24) (Fig. 4). The susceptible lines did not restrict the reproductive potential of the pest and Kanakamony recorded a progeny number of 50.8 and Pusa Komal 43.2.

Table 24 Fecundity of aphids on selected cowpea lines

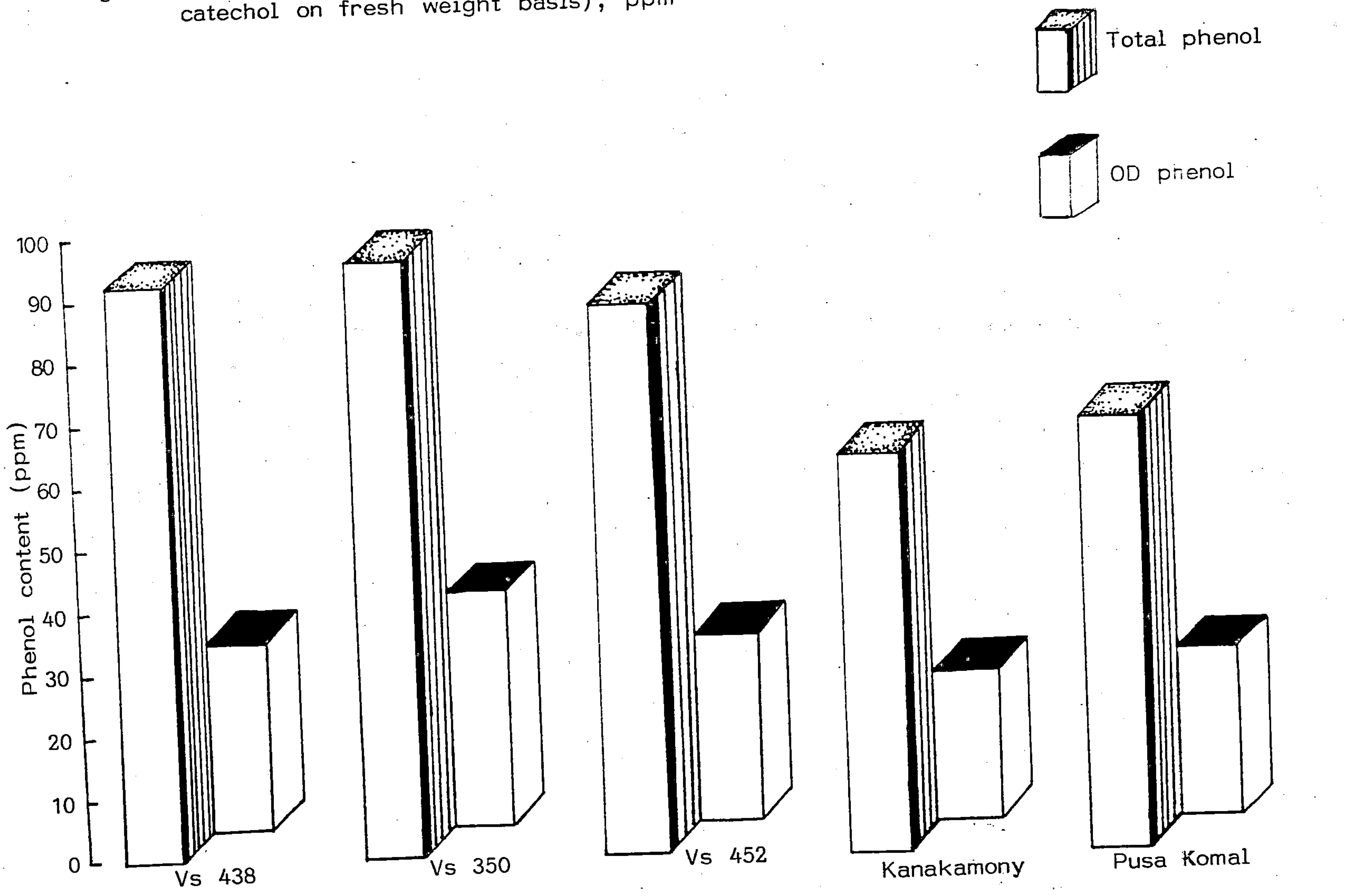
Lines	Fecundity
Vs 438	9.4 ± 0.51
Vs 350	9.0 ± 0.40
Vs 452	17.6 ± 2.38
Kanakamony	50.8 ± 2.38
Pusa Komal	43.2 ± 2.85
Sem±	0.65
CD (P = 0.05)	9.72

b. Biochemical factors inducing antibiosis

i) Phenol and OD phenol

The total phenol and orthodihydric phenol content expressed as catechol in fresh seeds are presented in Table 25. The total phenol content was high in resistant lines and low in susceptible lines. Among the resistant lines, Vs 350 had the maximum (96 ppm) followed by Vs 438 (92 ppm) and Vs 452 (88 ppm) (Fig. 5).

Fig. 5. Total phenol and orthodihydric phenol content in matured pods of cowpea (expressed as catechol on fresh weight basis), ppm



The lowest total phenol content was observed in Kanakamony (64 ppm). Pusa Komal had 69 ppm total phenol.

Table 25 Total phenol and orthodihydric phenol content in matured pods of cowpea (expressed as catechol on fresh weight basis), ppm

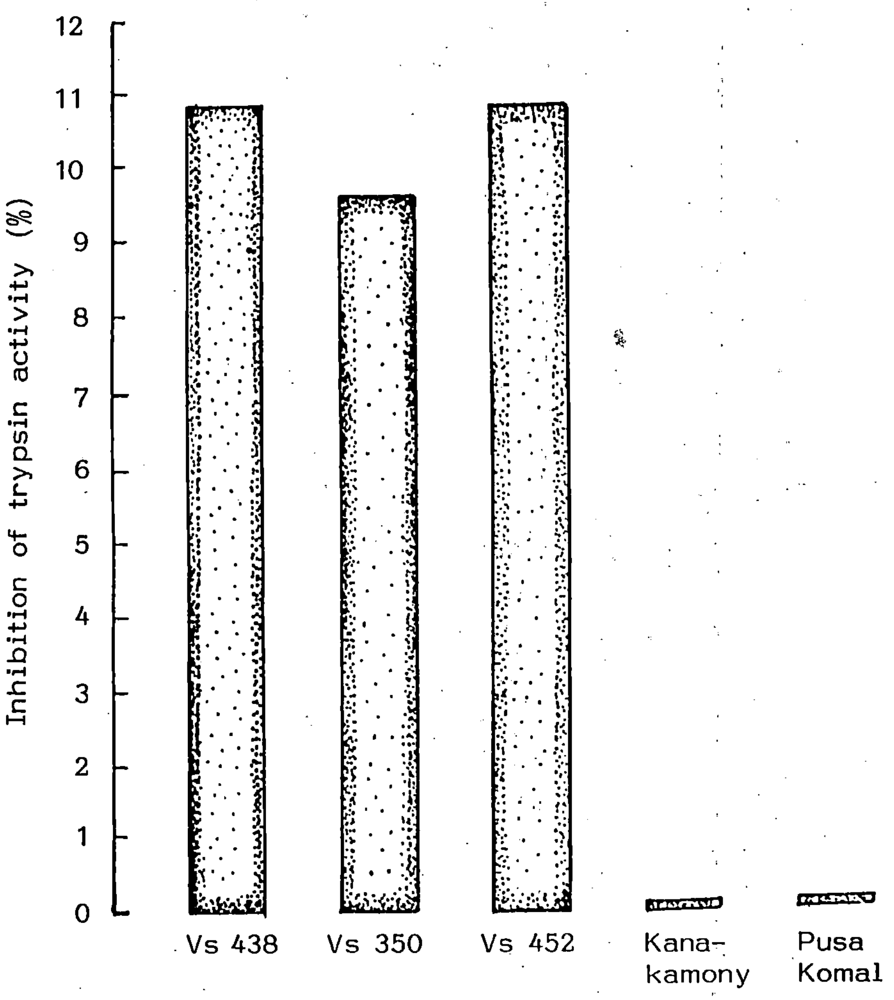
Lines	Total phenol	OD phenol
Vs 438	92	30
Vs 350	96	38
Vs 452	88	29
Kanakamony	64	23
Pusa Komal	69	27

The highest OD phenol content was also estimated in the resistant accessions (Table 25, Fig. 5). The line Vs 350 had 38 ppm followed by Vs 438 with 30 ppm and Vs 452 with 29 ppm. The OD phenol content was the lowest in Kanakamony (23 ppm) and Pusa Komal had 27 ppm.

b. Trypsin inhibitor

The trypsin inhibitor contents present in the lines were estimated (Table 26). The resistant lines Vs 438 and Vs 452 had 1.50 T.I. units/g of the seeds (Fig. 6). The line Vs 350 had 1.33 T.I. units/g of seed. Both the susceptible lines had no

Fig. 6. Inhibition of trypsin activity (%) in dry cowpea seeds



inhibitor present in their seeds. The inhibition of trypsin activity was 10.85% in the case of Vs 438 and Vs 452. The line Vs 350 inhibited the activity by 9.62%.

Table 26 Inhibition of trypsin activity (%) and trypsin inhibitor units/g of seed in dry cowpea seeds

Lines	Inhibition of trypsin activity (%)	Trypsin inhibitor units/g of seed
Vs 438	10.85	1.50
Vs 350	9.62	1.33
Vs 452	10.85	1.50
Kanakamony	0.00	0.00
Pusa Komal	0.00	0.00

C. Genetics of resistance to aphids in cowpea

1. Mendelian bases of resistance

The parents, F_1, F_2, BC_1 and BC_2 generations of crosses involving three resistant lines (Vs 350, Vs 438 and Vs 452) and two susceptible lines (Kanakamony, Pusa Komal) were evaluated to study inheritance of aphid resistance. Aphid counts were taken and rated as resistant and susceptible.

All the F_1 plants from the resistant x susceptible crosses were completely resistant (Table 27). In the six crosses studied,

Table 27 Reaction of parents and F_1s to cowpea aphid

Purelines and hybrids	Number of plants	
	Resistant	Susceptible
Vs 350	50	0
Vs 438	50	0
Vs 452	50	0
Kanakamony	50	50
Pusa Komal	50	50
Vs 350 x Kanakamony	53	0
Vs 350 x Pusa Komal	68	0
Vs 438 x Kanakamony	70	0
Vs 438 x Pusa Komal	70	0
Vs 452 x Kanakamony	30	0
Vs 452 x Pusa Komal	30	0

the F_2 populations showed a good fit to a 3 resistant: 1 susceptible ratio. Pooled over all the six crosses, there were 682 resistant plants and 248 susceptible plants which also fitted very closely to a 3:1 ratio (Table 28).

Table 28 Reaction of F_2 populations of cowpea to aphids

F_2 progenies	Number of F_2 plants		χ^2 3 : 1	Probability
	Resistant	Susceptible		
Vs 350 x Kanakamony	167	43	0.040	0.80-0.90
Vs 350 x Pusa Komal	185	52	0.041	0.80-0.90
Vs 438 x Kanakamony	133	67	0.113	0.70-0.80
Vs 438 x Pusa Komal	130	50	0.037	0.80-0.90
Vs 452 x Kanakamony	43	17	0.133	0.70-0.80
Vs 452 x Pusa Komal	41	19	0.266	0.50-0.70
Total	682	248	0.630	0.99
Deviation χ^2			0.022	0.80-0.90
Heterogeneity χ^2			0.608	0.98-0.99

The segregation pattern in the back cross populations further supported the F_2 data. The monogenic dominant inheritance of aphid resistance was confirmed in back cross generation analysis also. All the back cross progenies involving resistant parents (BC_1) were resistant. The BC_2 generation segregated into 137 resistant and 179 susceptible plants fitting a 1:1 ratio (Table 29). The test for heterogeneity was non-significant indicating a similar segregation pattern in all the back cross populations involving susceptible parents.

Table 29 Reaction of back cross populations of cowpea for aphid resistance

Back cross progenies	Number of back cross progenies					
	BC_1		BC_2		χ^2 1 : 1	Probability
	Resistant	Susceptible	Resistant	Susceptible		
(Vs 350 x Kanakamony) x Vs 350	52	0	-	-	-	-
(Vs 350 x Kanakamony) x Kanakamony	-	-	24	31	0.127	0.70- 0.80
(Vs 350 x Pusa Komal) x Vs 350	48	0	-	-	-	-
(Vs 350 x Pusa Komal) x Pusa Komal	-	-	26	36	0.161	0.50-0.70
(Vs 438 x Kanakamony) x Vs 438	55	0	-	-	-	-
(Vs 438 x Kanakamony) x Kanakamony	-	-	32	39	0.099	0.70-0.80
(Vs 438 x Pusa Komal) x Vs 438	56	0	-	-	-	-
(Vs 438 x Pusa Komal) x Pusa Komal	-	-	30	38	0.118	0.70-0.80
(Vs 452 x Kanakamony) x Vs 452	30	0	-	-	-	-
(Vs 452 x Kanakamony) x Kanakamony	-	-	12	18	0.200	0.50-0.70
(Vs 452 x Pusa Komal) x Vs 452	30	0	-	-	-	-
(Vs 452 x Pusa Komal) x Pusa Komal	-	-	13	17	0.133	0.70-0.80
Total	271	0	137	179	0.838	0.98-0.99
Deviation χ^2					0.133	0.70-0.80
Heterogeneity χ^2					0.705	0.98-0.90

2. Quantitative bases of level of resistance

Five parental lines Vs 452, Vs 350, Vs 438, Kanakamony and Pusa Komal with varying levels of resistance to aphids were used to study quantitative bases of inheritance. Mean number of aphids on the parental lines, F_1s, F_2s and backcross generations are given in Table 30.

Presence/absence of non-allelic interactions were determined by A, B, C scaling tests (Table 31). The null hypotheses underlying the scaling tests that A = 0, B = 0, C = 0, D = 0 were rejected in combination Vs 350 x Kanakamony and Vs 350 x Pusa Komal indicating presence of non-allelic interactions. The scaling tests were not significant in crosses Vs 438 x Kanakamony, Vs 438 x Pusa Komal, Vs 452 x Kanakamony and Vs 452 x Pusa Komal.

Generation means were partitioned into different components like mean effect (m), additive effect (d), dominance effect (h), additive x additive effect (i), additive x dominance effect (j) and dominance x dominance effect (l) in cases where scaling tests were significant (Table 32).

Additive effects (d) were significant in all the six crosses and were negative (Tables 32 and 33). Dominance effects (h) were significant only in Vs 350 x Kanakamony and Vs 350 x Pusa Komal

Table 30 Generation means for level of resistance to aphids in cowpea, per cent

Generations	P_1S_1	P_1S_2	P_2S_1	P_2S_2	P_3S_1	P_3S_2
P_1	42.26 ±3.844	42.27±3.844	52.37±4.21	52.37±4.21	65.30±3.74	65.30±3.74
P_2	472.90 ±19.79	463.63±26.71	472.90±19.79	461.68±26.72	472.90±19.79	461.63±26.74
F_1	48.17±3.69	39.57±3.40	44.03±3.55	45.10±4.30	43.50±3.44	51.60±4.21
F_2	145.18±19.45	153.33±21.69	144.12±19.12	144.43±20.36	152.38±23.00	149.25±21.05
B_1	58.83±3.68	53.13±3.19	55.03±3.95	50.00±3.91	57.70±3.65	52.43±4.03
B_2	203.57±28.67	242.57±32.36	271.67±31.47	260.67±34.86	269.23±36.25	244.50±32.67

P_1 = Vs 350; P_2 = Vs 438; P_3 = Vs 452; S_1 = Kanakamony; S_2 = Pusa Komal

Table 31 Scaling tests for non-allelic interactions for level of resistance to aphids in cowpea

Scales	Crosses					
	P_1S_1	P_1S_2	P_2S_1	P_2S_2	P_3S_1	P_3S_2
A	27.23±2.99**	24.43±8.19*	13.67±9.63	2.53 ±9.86	6.60±8.89	-12.03±9.83
B	-113.76±60.78	-16.07±70.11	26.40 ±66.07	14.60±74.79	22.07±75.23	-24.23±70.71
C	-30.97±0.38	30.30±91.13	-36.87±79.43	-26.47±86.25	-15.67±94.45	-33.13±88.84

**P = 0.01; *P = 0.05; P_1 = Vs 350; P_2 = Vs 438; P_3 = Vs 452; S_1 = Kanakamony; S_2 = Pusa Komal

Table 32 Components of total genetic effect for level of resistance to aphids in cowpea

Crosses	Genetic parameters					
	m	d	h	i	j	l
P_1S_1	145.13±19.45**	-144.83±28.91**	-264.95±97.54**	-55.53±96.94	70.48±30.62**	142.03±141.02
P_1S_2	153.33±21.69**	-189.4 ±32.52**	-234.32±109.33**	-21.93±108.44	20.25±35.21	13.57±158.82
P_2S_1	144.11 ±19.12	-216.63±31.72	-141.67±99.94	76.93±99.37	-6.37±33.29	-117.00±149.69
P_2S_2	144.43±20.36	-210.67±35.08	-168.3 ±108.43	43.60±107.50	-6.03±37.60	-60.73±164.71
P_3S_1	152.38±23	-211.53±36.43	-181.26±117.86	44.30±117.38	-7.70±37.80	-73.00±173.67
P_3S_2	149.25±21.06	-192.07±32.92	-215.00±107.83	-3.00±106.90	6.10±35.57	39.40±158.83

**P = 0.01; *P = 0.05; P_1 = Vs 350; P_2 = Vs 438; P_3 = Vs 452; S_1 = Kanakamony; S_2 = Pusa Komal

Table 33 Components of total genetic effects for level of resistance to aphids in cowpea

Genetic parameters	Crosses					
	P_1S_1	P_1S_2	P_2S_1	P_2S_2	P_3S_1	P_3S_2
m	313.12±97.47	273.88±109.28	185.70±99.88	213.40±108.35*	244.77±117.81	266.60±107.74
d	-215.32±10.07	-209.68±13.50	-210.27±10.12**	-204.63±13.52**	-203.80±10.07**	-198.17±13.49**
h	-406.98±235.02	-247.88±264.27	-24.67±246.07	-107.57±269.26	-108.27±287.37	-254.40±262.74

**P = 0.01; *P = 0.05; P_1 = Vs 350; P_2 = Vs 438; P_3 = Vs 452; S_1 = Kanakamony; S_2 = Pusa Komal

Table 34 Components of genetic variance, degree of dominance, heritability estimates and number of effective factors for level of aphid resistance

Cross	D	H	Degree of dominance $\sqrt{H/D}$	$h^2(n)$	$h^2(b)$	K_1	K_2
P_1S_1	-4729.48	83486.00	-4.20	-0.05	0.95	-9.80	0.53
P_1S_2	-6981.31	97302.82	-3.73	-0.07	0.92	-6.3	0.47
P_2S_1	-16504.8	103865.61	-2.51	-0.18	0.95	-2.68	0.46
P_2S_2	-24085.56	117679.5	-2.21	-0.24	0.92	-1.74	0.38
P_3S_1	-16144.762	142598.95	-2.97	-0.12	0.97	-2.57	0.36
P_3S_2	-11810.348	100198.293	-2.91	-0.12	0.92	-3.33	0.45

P_1 = Vs 350; P_2 = Vs 438; P_3 = Vs 452; S_1 = Kanakamony; S_2 = Pusa Komal but were negative. The interaction was additive x dominance (j) type in Vs 350 x Kanakamony.

Components of genetic variance, degree of dominance, heritability estimates and number of effective factors were worked out and are presented in Table 34.

Estimates of heritability in narrow sense $h^2(n)$ were low in all cases. Heritability in broad sense was high in all cases (0.92-0.97). The estimates of K_2 ranged from 0.36 in Vs 452 x Kanakamony to 0.53 in Vs 350 x Kanakamony.

D. Development of physical mixtures in cowpea to manage aphids

i) Analyses of variance for pods/plot, yield/plot and level of aphid resistance

Multilines generated through physical mixing of seeds from three resistant cowpea lines (Vs 452, Vs 350 and Vs 438) and two suscepts (Kanakamony and Pusa Komal) in two, three and four ways were evaluated during August-October 1989 (Season I), November 1989-February 1990 (Season II) and June-August 1990 (Season III).

Data were collected on pods/plot, yield/plot and level of aphid resistance. The treatments, consisting of five purelines and 14 physical mixtures, were significantly different for the above characters during all the three seasons (Table 35). The purelines consisting of three resistant and two suscepts also differed significantly for pods/plot, pod yield/plot and level of aphid resistance during all the seasons. The 14 physical mixtures also differed significantly for the above three characters during the three seasons. When purelines as a whole were compared with physical mixtures, the difference was significant only for level of aphid resistance during all the three seasons. Significant difference was observed between purelines and physical mixtures for pods/plot only during first season. No significant difference was observed when purelines were compared as a whole with physical mixtures for yield/plot. The three resistant lines differed significantly for yield/plot during second and third seasons, for pods/plot during second and third seasons and for level of aphid resistance during second and third seasons. The two suscepts differed significantly for pods/plot during first season, for yield/plot during second and third seasons and for level of aphid resistance during second and third seasons. The three way physical mixtures differed significantly among themselves, for pods/plot during all the seasons, for yield/plot during first and third seasons and did not differ for level of aphid resistance. The two, four way mixtures did not differ for their level of

Table 35 Analysis of variance for pods/plot, yield/plot and level of aphid resistance in a set of purelines and physical mixtures of cowpea

Sources	df	Mean squares								
		Pods/plot			Yield/plot			Level of aphid resistance		
		Season I	Season II	Season III	Season I	Season II	Season III	Season I	Season II	Season III
Replications	1	2232.00	728.00	33487.99	0.18	0.04	0.03	32.14	42.09	21.38
Treatments	18	124121.32**	92755.56**	84267.99**	0.40**	0.62**	0.44**	451.28**	75.37**	23.29**
Purelines	4	227192.50**	218108.51**	171766.99**	0.76**	1.74**	1.10**	1604.92**	236.09**	80.31**
Physical mixtures	13	142839.68**	61248.62**	63748.92**	0.32**	0.31**	0.28**	95.56**	21.69*	3.92
2 way mixtures	5	171003.60**	9790.80**	89461.60**	0.23*	0.46*	0.33**	14.90	7.71	0.82
Resistant lines within 2 way mixtures	2	167537.99	18493.00	221827.00	0.13	1.08**	0.78**	7.94	14.58**	1.65**
Suscepts within 2 way mixtures	1	357766.01*	4372.00	2324.00	0.28	0.11**	0.08**	2.09	8.33**	0.63*
Resistant lines x suscepts	2	31087.99*	3798.00	665.00	0.33**	0.01	0.00	28.25	0.52	0.08
3 way mixtures	5	169797.60**	36551.60**	73560.40**	0.40**	0.11	0.15**	50.97	6.88	2.19
4 way mixtures	1	107583.99**	10303.00	10000.00	0.10	0.07	0.39**	6.25	0.39	0.00
3 way vs 4 way mixtures	1	35751.99	166616.00**	2704.00	0.02	0.38*	0.04	152.36*	35.45*	10.55
2 way mixtures vs 3 and 4 way mixtures	1	9576.00	387600.02**	920.00	0.88**	0.88**	0.84**	754.31**	173.23**	26.03*
Purelines vs physical mixtures	1	14849.01**	928.00	1024.00	0.01	0.14	0.00	461.06**	130.31**	46.38*
Error	18	9755.56	4591.11	4911.11	0.05	0.05	0.03	22.51	6.43	3.60
CD (P = 0.05)		207.52	142.36	147.24	0.46	0.46	0.34	9.97	5.33	3.99

* P = 0.05
** P = 0.01

aphid resistance during three seasons. The two way mixtures when compared with three or four way mixtures, significant differences were observed as a whole for yield/plot during all seasons, pods/plot during second season and level of aphid resistance during all the three seasons.

ii) Observed and expected performance of purelines and two, three and four component mixtures

Pods/plot

Pods/plot ranged from 1197.5 (R_2) to 2178.5 (R_3) in purelines (Table 36). In mixtures, the range was from 991 pods/plot in $R_2R_3S_2$ to 1885 in R_3S_1 during first season. The two way mixture R_3S_1 deviated to an extent of 7.47% over the expected values, had they been grown as monocultures During second season, the 4 way mixture $R_1R_2R_3S_1$ deviated by an extent of 21.76% over the expected values. The pods/plot decreased in 8 out of 14 mixtures. During third season, the purelines ranged in pods/plot from 1213.5 in R_2 to 1965.5 in R_3. The mixtures ranged from 1225.5 pods/plot ($R_1R_2S_1$) to 1756 pods/plot (R_3S_2). During third season, six physical mixtures had lower number of pods/plot compared to the expectations, had they been grown in purestand.

Yield/plot (kg)

In purelines, yield/plot ranged from 3.085 kg (R_2) to 4.593 kg (S_2) during first season (Table 37). In mixtures, the range

Table 36 Observed and expected performance of purelines and two, three and four component mixtures in cowpea for pods/plot

Treatments	Season I (August-October 1989)				Season II (November 89-February 90)				Season III (June-August 1990)			
	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)
R_1	1277.50				1549.00				1299.00			
R_2	1197.50				1178.50				1213.50			
R_3	2178.50				2087.00				1965.50			
S_1	1329.50				1598.00				1416.50			
S_2	1322.50				1756.50				1459.00			
R_1S_1	1346.00	1303.50	42.50	3.26	1469.50	1573.50	-104.00	-6.61	1479.00	1357.75	121.25	8.93
R_1S_2	1003.50	1300.00	-296.50	-22.80	1544.00	1652.75	-108.75	-6.58	1482.00	1379.00	103.00	7.47
R_2S_1	1308.50	1263.50	45.00	3.56	1374.50	1388.25	-13.75	-0.99	1245.00	1315.00	-70.00	-5.32
R_2S_2	1246.50	1260.00	-13.50	-1.07	1447.50	1467.50	-20.00	-1.36	1271.00	1336.85	-65.25	-4.88
R_3S_1	1885.00	1754.00	131.00	7.47	1559.00	1842.50	-283.50	-15.39	1701.50	1691.00	10.50	0.62
R_3S_2	1253.50	1750.50	-497.00	-28.39	1526.00	1921.75	-395.75	-20.59	1756.00	1712.25	43.75	2.56
$R_1R_2S_1$	1320.00	1268.17	51.80	4.09	1654.50	1441.83	212.67	14.75	1225.50	1309.67	-84.17	-6.43
$R_1R_2S_2$	897.00	1265.83	-368.80	-29.14	1401.00	1494.67	-93.67	-6.27	1285.00	1323.83	-38.83	-2.93
$R_1R_3S_1$	1570.50	1595.16	-24.66	-1.55	1769.00	1744.67	24.33	1.39	1708.50	1560.33	148.17	9.50
$R_1R_3S_2$	991.00	1592.83	-601.80	-37.78	1732.00	1797.50	-65.50	-3.64	1588.50	1574.50	14.00	0.89
$R_2R_3S_1$	1609.00	1568.50	40.50	2.58	1735.00	1621.17	113.83	7.02	1603.50	1531.83	71.67	4.68
$R_2R_3S_2$	1267.50	1566.16	-298.67	-19.07	1702.00	1674.00	28.00	1.67	1502.00	1546.00	-44.00	-2.85
$R_1R_2R_3S_1$	1549.00	1495.75	53.25	3.56	1952.00	1603.13	348.87	21.76	1504.50	1473.63	30.87	2.09
$R_1R_2R_3S_2$	1221.00	1494.00	-273.00	-18.27	1850.50	1642.75	207.75	12.65	1405.00	1484.25	-79.25	-5.34
SEm±	69.84				47.52				49.54			
CD (P = 0.05)	207.52				142.36				147.24			

R_1 = Vs 452; R_2 = Vs 350; R_3 = Vs 438

Table 37. Observed and expected performance of purelines and two, three and four component mixtures in cowpea for yield/plot(kg).

Treatments	Season I (August–October 1989)				Season II (November '89–February '90)				Season III (June–August 1990)			
	Observed mean (O)	Expected mean (E)	O–E	Deviation (%)	Observed mean (O)	Expected mean (E)	O–E	Deviation (%)	Observed mean (O)	Expected mean (E)	O–E	Deviation (%)
R_1	3.615				4.045				3.963			
R_2	3.085				2.425				2.775			
R_3	3.290				4.136				3.750			
S_1	4.138				4.425				4.413			
S_2	4.593				4.895				4.715			
R_1S_1	4.098	3.877	0.221	5.700	4.059	4.235	-0.176	-4.160	4.265	4.188	0.077	1.840
R_1S_2	3.603	4.104	-0.501	-12.210	4.364	4.470	-0.106	-2.370	4.388	4.339	0.049	1.120
R_2S_1	3.500	3.612	-0.112	-3.100	3.413	3.425	-0.012	-0.350	3.505	3.594	-0.089	-2.480
R_2S_2	3.925	3.839	0.086	2.240	3.498	3.660	-0.162	-4.430	3.680	3.745	-0.065	-1.740
R_3S_1	4.483	3.714	0.769	20.710	4.359	4.281	0.078	1.820	4.285	4.082	0.203	4.970
R_3S_2	3.723	3.942	-0.219	-5.560	4.546	4.516	0.030	0.660	4.475	4.233	0.242	5.717
$R_1R_2S_1$	4.058	3.613	0.445	12.320	3.558	3.632	-0.074	-2.040	3.625	3.717	-0.092	-2.480
$R_1R_2S_2$	3.282	3.764	-0.482	-12.810	3.560	3.788	-0.228	-5.020	3.447	3.818	-0.371	-9.720
$R_1R_3S_1$	3.920	3.681	0.239	0.649	4.013	4.202	-0.189	-4.500	4.155	4.042	0.113	2.800
$R_1R_3S_2$	3.138	3.833	-0.695	-18.130	4.104	4.359	-0.255	-5.850	4.072	4.143	-0.070	-1.710
$R_2R_3S_1$	3.760	3.504	0.256	7.310	3.680	3.662	0.018	0.490	3.713	3.646	0.070	1.840
$R_2R_3S_2$	2.990	3.656	-9.666	-18.220	3.821	3.819	0.002	0.050	3.665	3.747	-0.080	-2.190
$R_1R_2R_3S_1$	3.765	3.532	0.233	6.590	3.302	3.758	-0.456	-12.130	3.965	3.725	0.240	6.440
$R_1R_2R_3S_2$	3.455	3.646	-0.191	-5.240	3.568	3.875	-0.307	-7.920	3.350	3.801	-0.450	-11.870
SEm±	0.157				0.157				0.115			
CD (P = 0.05)	0.465				0.465				0.345			

R_1 = Vs 452; R_2 = Vs 350; R_3 = Vs 438

was from 2.990 kg ($R_2R_3S_2$) to 4.483 kg (R_3S_1). The two way mixture R_3S_1 deviated by an extent of 20.71% over the expected values, had they been grown as monocultures. During second season, the yield/plot ranged from 2.425 kg (R_2) to 4.895 kg (S_2) in purelines and from 3.302 kg ($R_1R_2R_3S_1$) to 4.546 kg (R_3S_2) in mixtures. Yield/plot decreased in 10 out of 14 mixtures. During third season, the purelines yielded 2.775 kg (R_2) to 4.715 kg (S_2) and mixtures yielded 3.350 kg ($R_1R_2R_3S_2$) to 4.475 kg (R_3S_2). The 4 way mixture $R_1R_2R_3S_1$ deviated by 6.44% over the expected values and 8 out of 14 mixtures deviated in positive direction, from the expected values.

Level of aphid resistance

Level of aphid resistance ranged from 76.88% (R_1) to 95% (R_3) in resistant purelines and 31.88% (S_2) to 40% (S_1) in susceptible purelines (Table 38). Among the mixtures, the level of resistance ranged from 64.38% (R_1S_1) to 85% ($R_1R_2R_3S_2$) during first season. All the physical mixtures deviated in a positive direction from the expected values. The two way mixture ((R_1S_2) deviated by an extent of 26.43% from the expected values. The three way mixture ($R_2R_3S_2$) deviated by 15.84% and four way mixture ($R_1R_2R_3S_2$) deviated by 17.24% during first season. Level of aphid resistance ranged from 86.25% (R_1) to 94.38% (R_2) among the resistant purelines and the level of resistance was 72.5%

Table 38 Observed and expected performance of purelines and two, three and four component mixtures in cowpea for level of aphid resistance

Treatments	Season I (August-October 1989)				Season II (November '89-February '90)				Season III (June-August 1990)			
	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)	Observed mean (O)	Expected mean (E)	O-E	Deviation (%)
R_1	76.88				86.25				97.50			
R_2	86.25				94.38				100.00			
R_3	95.00				93.75				100.00			
S_1	40.00				72.50				88.75			
S_2	31.88				72.50				86.88			
R_1S_1	64.38	58.44	5.94	10.16	81.87	79.38	2.49	3.14	95.63	93.13	2.50	2.68
R_1S_2	68.75	54.38	14.37	26.43	84.38	79.38	5.00	6.30	95.00	92.19	2.81	3.05
R_2S_1	72.50	63.13	9.37	14.84	86.25	83.44	2.81	3.37	96.88	94.38	2.50	2.67
R_2S_2	66.25	59.07	7.19	12.17	87.50	83.44	4.06	4.87	96.25	93.44	2.81	3.01
R_3S_1	68.13	67.50	0.62	0.92	85.00	83.13	1.87	2.25	96.25	94.38	1.87	1.98
R_3S_2	67.50	63.44	4.06	6.40	86.25	83.13	3.12	3.75	98.13	93.44	4.69	5.02
$R_1R_2S_1$	72.22	67.71	4.51	6.66	90.00	84.38	5.62	8.66	96.13	95.42	0.71	0.74
$R_1R_2S_2$	69.68	65.00	4.68	7.20	90.00	84.38	5.62	8.66	97.50	94.79	2.71	2.86
$R_1R_3S_1$	79.17	70.63	8.54	12.09	88.13	84.17	3.96	4.70	96.53	95.42	1.21	1.27
$R_1R_3S_2$	75.35	67.92	7.44	10.95	86.25	84.17	2.08	2.47	97.50	94.79	2.71	2.86
$R_2R_3S_1$	81.34	73.75	7.59	10.29	91.25	86.88	4.37	5.03	97.50	96.25	0.80	0.83
$R_2R_3S_2$	82.29	71.04	11.25	15.84	90.63	86.88	3.75	4.32	98.75	95.63	3.12	3.26
$R_1R_2R_3S_1$	82.50	74.53	7.97	10.69	93.13	86.72	6.41	7.39	99.38	96.56	2.82	2.92
$R_1R_2R_3S_2$	85.00	72.50	12.50	17.24	92.50	86.72	5.78	6.67	99.38	96.10	3.28	3.41
SEm±	3.37				1.79				1.34			
CD (P = 0.05)	9.97				5.33				3.99			

R_1 = Vs 452; R_2 = Vs 350; R_3 = 438 in both the susceptible purelines during second season. The two component mixture (R_1S_2) deviated by an extent of 6.3%, the three component mixtures ($R_1R_2S_1$ and $R_1R_2S_2$) deviated by 8.66% and four component mixture ($R_1R_2R_3S_1$) by 7.39%. During third season, the two component mixture (R_3S_2) deviated by an extent of 5.02%, the three component mixture ($R_2R_3S_2$) deviated by an extent of 3.26% and four component mixtures ($R_1R_2R_3S_2$) by 3.41%. All the physical mixtures had better advantages over monocultures for level of aphid resistance during all the three seasons.

iii) Associative ability analysis in a set of 50:50 physical mixtures (two component mixtures) of cowpea

Data from monocultures and physical mixtures were analysed to find out general associative ability and specific associative ability effects.

Pods/plot

The highest associative ability (gaa) was recorded in R_3 during all the three seasons (228.75, 55.75 and 239.67) (Table 39). The lowest gaa value was recorded by R_1 (-165.75) during first and R_2 during second (-75.75) and third (-231.08) seasons. Among the two susceptible lines, S_1 had higher gaa effect during first season (172.67) and S_2 during second (19.08) and third (13.92) seasons.

Table 39 Estimates of general associative ability (gaa) effects of resistants and suscepts

	Pods/plot			Yield/plot			Level of aphid resistance		
	Season I	Season II	Season III	Season I	Season II	Season III	Season I	Season II	Season III
Resistants									
R_1	-165.75	20.00	-8.58	-0.053	0.172	0.227	-1.354	-2.083	-0.708
R_2	-63.00	-75.75	-231.08	-0.146	-0.584	-0.507	1.458	1.667	0.542
R_3	228.75	55.75	239.67	0.199	0.412	0.280	-0.104	0.417	0.167
SE (gi)	103.76	71.18	73.62	0.233	0.233	0.170	4.98	2.66	1.99
SE (gi-gj)	146.74	100.66	104.11	0.330	0.330	0.242	7.05	3.77	2.82
Suscepts									
S_1	172.67	-19.08	-13.92	0.153	-0.096	-0.081	0.42	-0.83	0.23
S_2	-172.67	19.08	13.92	-0.153	0.096	0.081	-0.42	0.83	-0.23
SE (gi)	177.99	58.12	60.11	0.189	0.191	0.132	4.07	2.18	1.63
SE (gi-gj)	119.81	82.19	85.01	0.269	0.269	0.198	5.76	3.08	2.30

The highest saa effect was manifested by R_3S_1 during first (143.08) and second (35.58) seasons and by R_3S_2 during third season (13.33) (Table 40). The lowest saa was recorded by R_3S_2 during first (-143.08) and second (-35.58) seasons and by R_3S_1 during third season (-13.33).

Pod yield/plot

Consistently high gaa effect was manifested by R_3 during all the three seasons (0.199, 0.412 and 0.280) (Table 39). The lowest gaa effect was manifested consistently by R_2 during all the three seasons (-0.146, -0.584 and -0.507). Among the two susceptible lines S_1 possessed the higher gaa (0.153) during first season and S_2 had the higher gaa during second (0.096) and third seasons (0.081).

The saa effect was maximum in R_2S_2 (0.32) during first season, in R_1S_2 (0.06) during second season and in R_1S_1 (0.02) during third season (Table 40). R_2S_1 had the minimum saa effect during first season (-0.32), R_1S_1 during second season (-0.06) and R_1S_2 (-0.02) during third season.

Level of aphid resistance

During all the three seasons, the line R_2 had the highest values of gaa effect (1.458, 1.667 and 0.542) (Table 39). The

Table 40 Estimates of specific associative ability (saa) effects

	Pods/plot			Yield/plot			Level of aphid resistance		
	Season I	Season II	Season III	Season I	Season II	Season III	Season I	Season II	Season III
R_1S_1	-1.42	-18.17	12.42	0.09	-0.06	0.02	-2.60	-0.42	0.08
R_1S_2	1.42	18.17	-12.42	-0.09	0.06	-0.02	2.60	0.42	-0.08
R_2S_1	-141.67	-17.42	0.92	-0.32	0.05	-0.01	2.71	0.21	0.08
R_2S_2	141.67	17.42	-0.92	0.32	0.05	0.01	-2.71	-0.21	-0.08
R_3S_1	143.08	35.58	-13.33	0.23	0.00	-0.01	-0.10	0.21	-0.17
R_3S_2	-143.08	-35.58	13.33	-0.23	0.00	0.01	0.10	-0.21	0.17
SE (Sij)	146.74	100.66	104.10	0.33	0.33	0.24	7.05	3.77	2.82
SE (Sij-Ski)	207.52	142.24	147.24	0.47	0.47	0.34	9.97	5.33	3.99

lowest gaa effect was recorded consistently by R_1 during all the three seasons (-1.354, -2.083, -0.708). S_1 had a high gaa effect during first (0.42) and third (0.23) seasons and S_2 (0.83) during second season, among the susceptible lines.

The mixtures R_2S_1 (2.71), R_1S_2 (0.42) and R_3S_2 (0.17) possessed high saa effects during first, second and third seasons respectively (Table 40). The low saa effects were manifested by R_2S_2 (-2.71), R_1S_1 (-0.42) and R_3S_1 (-0.17) during first, second and third seasons respectively.

iv) General coexistence ability and mean performance of three resistant and two susceptible cowpea lines in purestand and in mixtures

The general coexistence ability of three resistant (R_1, R_2 and R_3) and two susceptible (S_1 and S_2) cowpea lines for pods/plant, yield/plant and level of aphid resistance were calculated and are presented in Tables 41, 42, 43.

Pods/plant

The GCoA estimates of all the purelines except S_1 (1.02) were below one during first season (Table 41). During second season, the GCoA estimates of R_1 (1.08), R_2 (1.19) and R_3 (1.03) were greater than one and that of S_1 (0.98) and S_2 (0.84) less

Table 41 Mean performance and general coexistence ability (GCoA) estimates of different genotypes in pure stands and in mixtures for pods/plant

Genotypes	Stand	Mean performance			General coexistence ability			
		Season I	Season II	Season III	Season I	Season II	Season III	Mean
Vs 452 (R_1)	Mixture	15.36	20.94	16.05	0.96	1.08	0.99	1.01
	Pure	15.97	19.37	16.24				
Vs 350 (R_2)	Mixture	14.81	17.54	15.28	0.99	1.19	1.01	1.06
	Pure	14.97	14.74	15.17				
Vs 438 (R_3)	Mixture	24.23	26.82	25.24	0.89	1.03	0.99	0.97
	Pure	27.24	26.09	24.57				
Kanakamony (S_1)	Mixture	16.93	19.53	17.32	1.02	0.98	0.98	0.99
	Pure	16.62	19.98	17.71				
Pusa Komal (S_2)	Mixture	9.61	18.43	17.12	0.58	0.84	0.94	0.79
	Pure	16.53	21.96	18.24				

Table 42 Mean performance and general coexistence ability (GCoA) estimates of different genotypes in pure stands and in mixtures for yield/plant

Genotypes	Stand	Mean performance			General coexistence ability			
		Season I	Season II	Season III	Season I	Season II	Season III	Mean
Vs 452 (R_1)	Mixture	52.27	50.51	48.54	1.16	1.00	0.98	1.05
	Pure	45.19	50.57	49.54				
Vs 350 (R_2)	Mixture	40.49	29.79	31.06	1.05	0.98	0.90	0.98
	Pure	38.57	30.32	34.69				
Vs 438 (R_3)	Mixture	52.02	53.38	52.37	1.27	1.03	1.12	1.14
	Pure	40.94	51.70	46.88				
Kanakamony (S_1)	Mixture	51.25	53.87	55.91	0.99	0.97	1.01	0.99
	Pure	51.72	55.32	55.16				
Pusa Komal (S_2)	Mixture	31.63	55.01	55.45	0.55	0.90	0.94	0.80
	Pure	57.41	61.19	58.94				

Table 43 Mean performance and general coexistence ability (GCoA) estimates of different genotypes in pure stands and in mixtures for level of aphid resistance

Genotypes	Stand	Mean performance			General coexistence ability			Mean
		Season I	Season II	Season III	Season I	Season II	Season III	
Vs 452 (R_1)	Mixture	82.54	89.44	97.26	1.09	1.04	1.00	1.04
	Pure	76.88	86.25	97.50				
Vs 350 (R_2)	Mixture	88.98	95.58	99.77	1.03	1.01	1.00	1.01
	Pure	86.28	94.38	100.00				
Vs 438 (R_3)	Mixture	93.11	96.04	99.77	0.98	1.02	1.00	1.00
	Pure	95.00	93.75	100.00				
Kanakamony (S_1)	Mixture	54.30	78.00	95.03	1.35	1.08	1.07	1.17
	Pure	40.00	72.50	88.75				
Pusa Komal (S_2)	Mixture	52.46	81.58	94.32	1.65	1.13	1.09	1.29
	Pure	31.88	72.50	86.88				

than unity. During third season, the GCoA of the line R_2 only was greater than unity (1.01). Considering all the seasons together the GCoA of S_1 was 0.99 the GCoA of R_3 was 0.97, and that of R_1 was 1.01. The GCoA of R_2 was 1.06 and that of S_2 was below unity (0.79).

Yield/plant

For yield/plant, R_1 (1.16), R_2 (1.05) and R_3 (1.27) had the GCoA estimates greater than one, S_1 had 0.99 and S_2 had less than one (0.55) during first season (Table 42). During second season, the GCoA was 1.0, 0.98, 1.03, 0.97 and 0.90 and during third season the GCoA was 0.98, 0.90, 1.12, 1.01 and 0.94 respectively for R_1, R_2, R_3, S_1 and S_2. However, considering the mean GCoA over all the seasons, S_1 had a GCoA of 0.99, R_2 0.98, R_1 1.05 and R_3 1.14. The GCoA of S_2 (0.80) was less than unity.

Level of aphid resistance

For level of aphid resistance, all the lines except R_3 (0.98) had a GCoA greater than unity during first season (Table 43). During second season, all the lines had a GCoA greater than unity. During third season the GCoA of all the resistant lines were equal to one and that of S_1 (1.07) and S_2 (1.09) were greater than unity. Considering all the seasons together the GCoA of R_3 was unity and that of both susceptible lines were greater than unity.

v) Correlation between obstruction created (%) and level of resistance to aphids

The level of aphid resistance during three seasons were subjected to correlation analysis with the obstruction (%) created due to blending of resistant and susceptible components. The correlation coefficients (r values) are presented in Table 44. There is a significant and positive correlation between the obstruction given and the resistance during all the three seasons. The advantage of mixing, increased with increasing level of obstruction created. In mixtures, the level of resistance was higher than the mean level of susceptible components grown in purestands. During first season 81% of the variation in the level of resistance is explained by the obstruction given. During second and third seasons 70% and 69% of the variations respectively were explained by the obstruction given.

Table 44 Mean obstruction (%), mean level of aphid resistance (%) and correlation between them over three seasons

Seasons	Mean obstruction (%)	Mean level of resistance (%)	Coefficient of correlations	Coefficient of determination (R^2) (%)
Season I	60.52	71.83	0.89**	81
Season II	60.52	86.97	0.84**	70
Season III	60.52	96.47	0.83**	69

vi) Pooled analysis of variance for pods/plot, yield/plot and level of aphid resistance in a set of purelines and mixtures

The data collected during the three seasons (August-October 1989, November 1989-February 1990 and June-August 1990 were pooled and analysed to study extent of variations due to treatments, seasons and treatments x seasons interactions (Table 45). The treatments were significantly different (p = 0.01) for pods/plot, yield/plot and level of aphid resistance. The treatments x seasons interactions were highly significant (p = 0.01) for pods/plot and yield/plot and were not significant for level of aphid resistance.

The mean performance of 19 treatments during the three seasons for pods/plot, yield/plot and level of aphid resistance are given in Tables 46, 47 and 48 respectively.

Pods/plot

Among the purelines, pods/plot ranged from 1197.5 in R_2 to 2176.5 in R_3 during first season (Table 46). Among the mixtures, two component mixtures R_1S_2 had 1003.5 pods/plot and R_3S_1 had 1885 pods/plot. Among the 3 component mixtures, $R_1R_2S_2$ had the lowest (897) and $R_1R_3S_1$ had the highest (1570.5) pods/plot during the first season. During second and third seasons also, R_2 had the lowest (1178.5, 1213.5) and R_3 had the highest

Table 45 Pooled analyses of variance for pods/plot, yield/plot and level of aphid resistance

Sources	df	Mean squares		
		Pods/plot	Yield/plot	Level of aphid resistance
Treatments	18	258708.43**	1.16**	391.79**
Seasons	2	691911.98	0.43	5863.25*
Treatments x Seasons	36	51122.67**	0.15**	79.39
Pooled error	54	6393.48	0.04	10.90

**P = 0.01; *P = 0.05

Table 46 Mean performance of purelines and mixtures for pods/plot

Treatments	Season I	Season II	Season III	Mean performance over three seasons
R_1	1277.50	1549.00	1299.00	1375.17
R_2	1197.50	1178.50	1213.50	1196.50
R_3	2178.50	2087.00	1965.50	2077.00
S_1	1329.50	1598.00	1416.50	1448.00
S_2	1322.50	1756.50	1459.00	1512.67
R_1S_1	1346.00	1469.50	1479.00	1431.50
R_1S_2	1003.50	1544.00	1482.00	1343.17
R_2S_1	1308.50	1374.50	1245.00	1309.33
R_2S_2	1246.50	1447.50	1271.00	1321.67
R_3S_1	1885.00	1559.00	1701.50	1715.17
R_3S_2	1253.50	1526.00	1756.00	1514.83
$R_1R_2S_1$	1320.00	1654.50	1225.50	1399.00
$R_1R_2S_2$	897.00	1401.00	1285.00	1194.33
$R_1R_3S_1$	1570.50	1769.00	1708.50	1682.67
$R_1R_3S_2$	991.00	1732.00	1588.50	1437.17
$R_2R_3S_1$	1609.00	1735.00	1603.50	1649.17
$R_2R_3S_2$	1267.50	1702.00	1502.00	1490.50
$R_1R_2R_3S_1$	1549.00	1952.00	1504.50	1668.50
$R_1R_2R_3S_2$	1221.00	1850.50	1405.00	1492.17
SEm±	69.84	47.52	49.54	92.31
CD (P = 0.05)	207.52	142.36	147.24	264.74

R_1 = Vs 452; R_2 = Vs 350; R_3 = Vs 438

Table 47 Mean performance of purelines and mixtures for yield/ plot (kg)

Treatments	Season I	Season II	Season III	Mean performance over three seasons
R_1	3.615	4.045	3.963	3.87
R_2	3.085	2.425	2.775	2.76
R_3	3.290	4.136	3.750	3.73
S_1	4.138	4.425	4.413	4.33
S_2	4.593	4.895	4.715	4.73
R_1S_1	4.098	4.059	4.265	4.14
R_1S_2	3.603	4.364	4.388	4.12
R_2S_1	3.500	3.413	3.505	3.47
R_2S_2	3.925	3.498	3.680	3.70
R_3S_1	4.483	4.359	4.285	4.44
R_3S_2	3.723	4.546	4.475	4.25
$R_1R_2S_1$	4.058	3.558	3.625	3.75
$R_1R_2S_2$	3.282	3.560	3.447	3.43
$R_1R_3S_1$	3.920	4.013	4.155	4.02
$R_1R_3S_2$	3.138	4.104	4.072	3.77
$R_2R_3S_1$	3.760	3.680	3.713	3.72
$R_2R_3S_2$	2.990	3.821	3.665	3.49
$R_1R_2R_3S_1$	3.765	3.302	3.965	3.68
$R_1R_2R_3S_2$	3.455	3.568	3.350	3.46
SEm±	0.157	0.157	0.115	0.16
CD (P = 0.05)	0.465	0.465	0.345	0.46

R_1 = Vs 452; R_2 = Vs 350; R_3 = Vs 438

Table 48 Mean performance of purelines and mixtures for level of aphid resistance (%)

Treatments	Season I	Season II	Season III	Mean performance over three seasons
R_1	76.88	86.25	97.50	86.88
R_2	86.25	94.38	100.00	93.54
R_3	95.00	93.75	100.00	96.25
S_1	40.00	72.50	88.75	67.08
S_2	31.88	72.50	86.88	63.75
R_1S_1	64.38	81.87	95.63	80.63
R_1S_2	68.75	84.38	95.00	82.71
R_2S_1	72.50	86.25	96.88	85.21
R_2S_2	66.25	87.50	96.25	83.33
R_3S_1	68.13	85.00	96.25	83.13
R_3S_2	67.50	86.25	98.13	83.29
$R_1R_2S_1$	72.22	90.00	96.13	86.78
$R_1R_2S_2$	69.68	90.00	97.50	85.73
$R_1R_3S_1$	79.17	88.13	96.63	87.64
$R_1R_3S_2$	75.35	86.25	97.50	86.37
$R_2R_3S_1$	81.34	91.25	97.50	90.03
$R_2R_3S_2$	89.29	90.63	98.75	90.55
$R_1R_2R_3S_1$	82.50	93.13	99.38	91.67
$R_1R_2R_3S_2$	85.00	92.50	99.38	92.29
SEm±	3.37	1.79	1.34	3.64
CD (P=0.05)	9.97	5.33	3.99	10.43

R_1 = Vs 452; R_2 = Vs 350; R_3 = Vs 438

(2087, 1965.5) pods/plot respectively. During second season among the mixtures, the highest pods/plot (1952) was recorded by $R_1R_2R_3S_1$ and the lowest number (1374.5) was recorded by R_2S_1. During third season, the highest pods/plot (1756) was recorded by R_3S_2 and the lowest (1245) by R_2S_1. Considering all the seasons together, the mean pods/plot was the highest (1715.17) in R_3S_1 and the lowest in R_2S_1 (1309.33) among the mixtures.

Yield/plot

Among the purelines, the highest yield/plot was recorded by S_2 (5.593 kg, 4.895 kg, 4.715 kg) during all the three seasons, respectively (Table 47). Among the mixtures, the highest yield/plot was recorded by R_3S_1 (4.483 kg) during first season, R_3S_2 during second (4.546 kg) and third seasons (4.475 kg). The lowest was recorded by $R_2R_3S_2$ (2.990 kg) during first, $R_1R_2R_3S_1$ (3.302 kg) during second and $R_1R_2R_3S_2$ (3.350 kg) during third season. Among purelines, the mean yield was the highest (4.73 kg) in S_2. Among the mixtures, R_3S_1 (4.44 kg) had the highest mean yield and $R_1R_2R_3S_2$ (3.46 kg) had the lowest mean yield.

Level of aphid resistance

The highest level of aphid resistance was recorded by R_3 (95.0%) during first season and R_2 (94.38%) during second season (Table 48). Both R_2 and R_3 recorded 100% resistance during third season. Among the mixtures, the four component mixtures were the highest in the level of resistance during all the three seasons. The mixture $R_1R_2R_3S_2$ had the highest level of aphid resistance (85.0%) during first season, the mixture $R_1R_2R_3S_1$ had the highest (93.13%) during second season and both $R_1R_2R_3S_1$ and $R_1R_2R_3S_2$ had 99.38% resistance during third season.

vii) Phenotypic stability analyses for pods/plot, yield/plot and level of aphid resistance

Phenotypic stability analyses as suggested by Eberhart and Russel (1966) were conducted to estimate parameters of stability for each of the 19 treatments for pods/plot, yield/plot and level of aphid resistance (Table 49). Treatments were significantly different for yield/plot over the three seasons ($p = 0.01$). Seasons were not significantly different to create variations for pods/plot and yield/plot. Seasons were significantly different for level of aphid resistance ($p = 0.05$). The treatments x seasons interactions were highly significant for pods/plot and yield/plot ($p = 0.01$). The significance of difference of regression coefficient from unity was tested and was significant in treatments $R_1R_3S_2$ and R_3S_1 for pods/plot (Table 50). The deviation from regression (S^2di) of each of the treatment was tested from zero and was observed significant in $R_1R_3S_2$ and R_3S_1. The two dimensional

Table 49 Analysis of variance for phenotypic stability

Sources	df	Mean squares: Pod/plot	Yield/plot	Level of aphid resistance
Treatments	18	258708.43**	1.16**	391.79**
Seasons	2	691911.98	0.43	5863.25*
Treatments × Seasons	36	51122.67**	0.15**	79.39
Season + (Treatment × Season)	38	84848.42	0.17	383.81
Season (linear)	1	1383872.80	0.86	11726.58
Treatments × Season (linear)	18	66415.08	0.24**	149.70**
Pooled deviation	19	33940.08	0.06	8.60
R_1	1	6950.43	0.01	7.11
R_2	1	404.89	0.08	0.07
R_3	1	19511.69	0.11	12.24
S_1	1	831.86	0.01	4.27
S_2	1	2497.56	0.02	30.65
R_1S_1	1	3913.18	0.02	1.89
R_1S_2	1	35836.52	0.003	0.16
R_2S_1	1	5822.73	0.006	0.98
R_2S_2	1	2994.01	0.02	5.22
R_3S_1	1	811.61	0.01	0.11
R_3S_2	1	93107.49	0.01	0.89
$R_1R_2S_1$	1	41542.50	0.01	2.29
$R_1R_2S_2$	1	16659.46	0.01	6.85
$R_1R_3S_1$	1	1502.36	0.01	0.87
$R_1R_3S_2$	1	44869.81	0.01	4.80
$R_2R_3S_1$	1	2632.95	0.01	0.003
$R_2R_3S_2$	1	883.61	0.03	2.06
$R_1R_2R_3S_1$	1	34617.84	0.23	0.04
$R_1R_2R_3S_2$	1	7040.22	0.02	1.16
Pooled error	54	6393.48	0.04	10.90

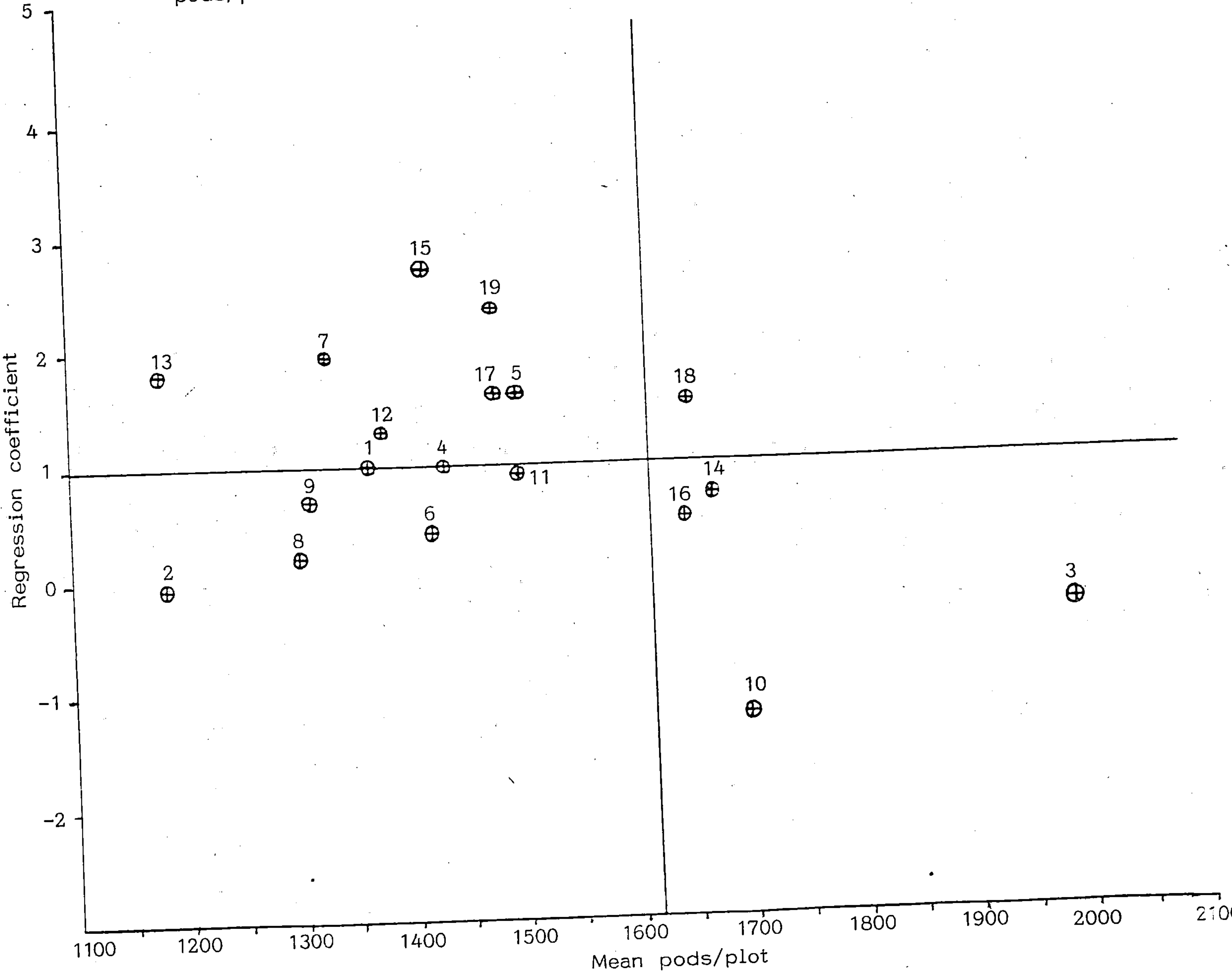
*P = 0.05; **P = 0.01

Table 50 Mean and stability parameters (bi, S^2di) for pods/plot

Treatments	Mean	Stability parameters	
		bi	S^2di
R_1	1375.17	1.03	556.95
R_2	1196.50	-0.08	-5988.59
R_3	2077.00	-0.30	13118.21
S_1	1448.00	1.00	-5561.62
S_2	1512.67	1.62	-3895.91
R_1S_1	1431.50	0.44	-2480.31
R_1S_2	1343.17	1.95	29443.03**
R_2S_1	1309.33	0.26	-570.76
R_2S_2	1321.67	0.76	-3399.47
R_3S_1	1715.17	-1.20*	-5581.88
R_3S_2	1514.83	0.96	86714.00
$R_1R_2S_1$	1399.00	1.30	35149.02**
$R_1R_2S_2$	1194.33	1.84	10265.98*
$R_1R_3S_1$	1682.67	0.73	-4891.12
$R_1R_3S_2$	1437.17	2.69*	38476.33**
$R_2R_3S_1$	1649.17	0.48	-3760.53
$R_2R_3S_2$	1490.50	1.60	-5509.87
$R_1R_2R_3S_1$	1668.50	1.55	28224.36**
$R_1R_2R_3S_2$	1492.17	2.36	646.74
SEm±	92.31		
CD (P = 0.01)	355.07		

*P = 0.05; **P = 0.01

Fig. 7. Scatter diagram indicating mean performance (μ) and regression coefficient (bi) for pods/plot



scatter diagram (Fig. 7) indicates that the resistant pureline R_3 has the highest overall mean for pods/plot (2077), and regression tending to zero (-0.30). Among the two way mixtures, R_3S_1 gave the highest pods/plot (1715.17) and deviation from regression (S^2di) nonsignificant. The regression (bi) was however significant. Among the three way mixtures, $R_1R_3S_1$ was the most promising average stable treatment.

Yield/plot

Treatments were significantly different for yield/plot (Table 49). Among purelines, S_2 yielded the highest over the seasons (4.73 kg/plot) (Table 51). Among resistant lines, R_1 yielded the highest (3.87 kg/plot). The treatment R_3S_1 yielded 4.44 kg/plot, the highest among the physical mixtures. Its regression (bi) deviated significantly from unity, though S^2di was non-significant. Among three way mixtures, $R_1R_3S_1$ was the promising with an overall mean of 4.02 kg/plot, regression non-significant from unity and deviation from regression non-significant. The scatter diagram (Fig. 8) indicated that R_1 is an average stable pureline with regression tending to one and deviation from regression non-significant. Its yield was 3.87 kg/plot.

Level of aphid resistance

The 19 treatments were significantly different for level

Fig. 8. Scatter diagram indicating mean performance (μ) and regression coefficient (bi) for mean yield

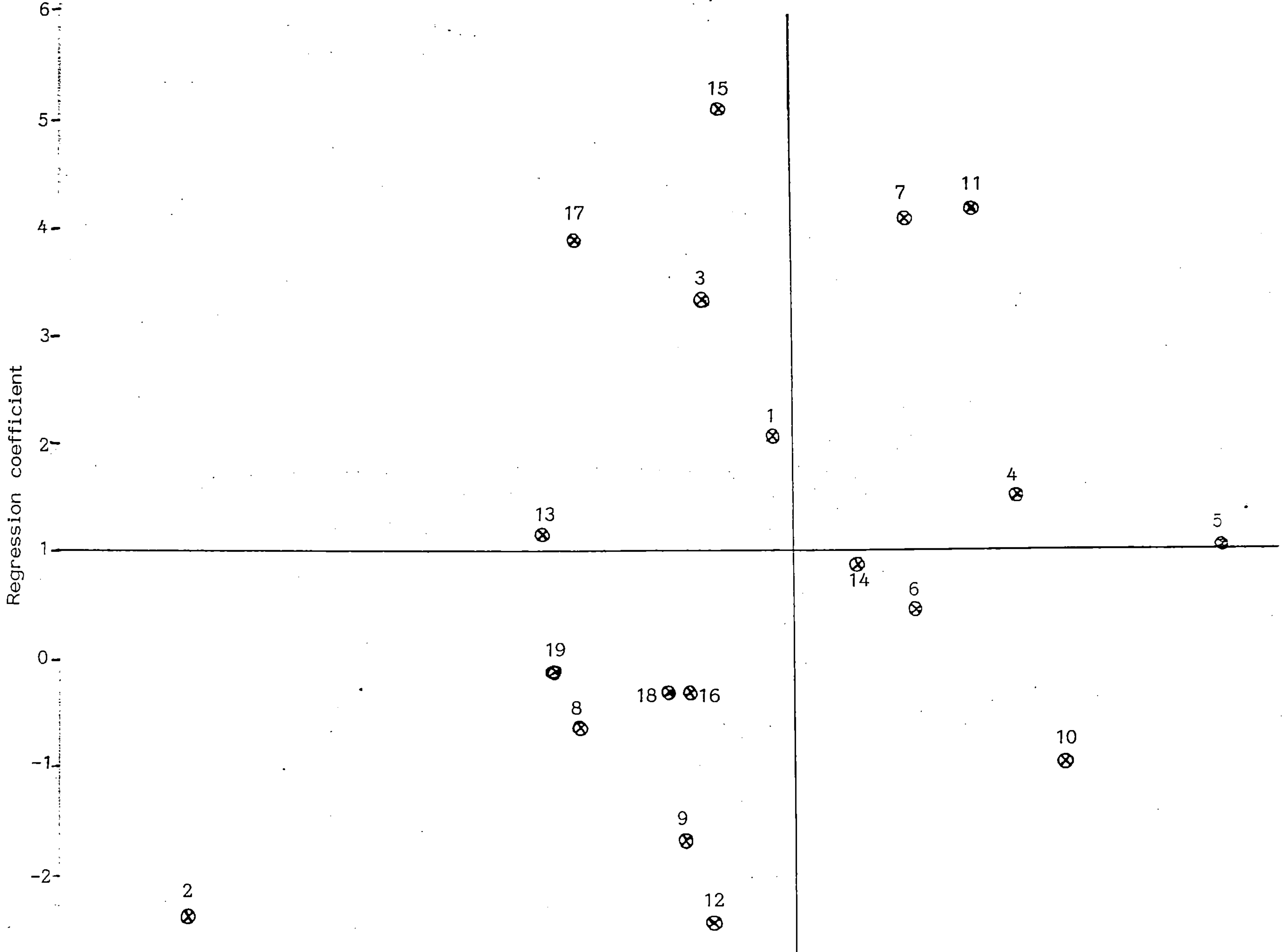


Fig. 9. Scatter diagram indicating mean performance (μ) and regression coefficient (bi) for aphid resistance (%)

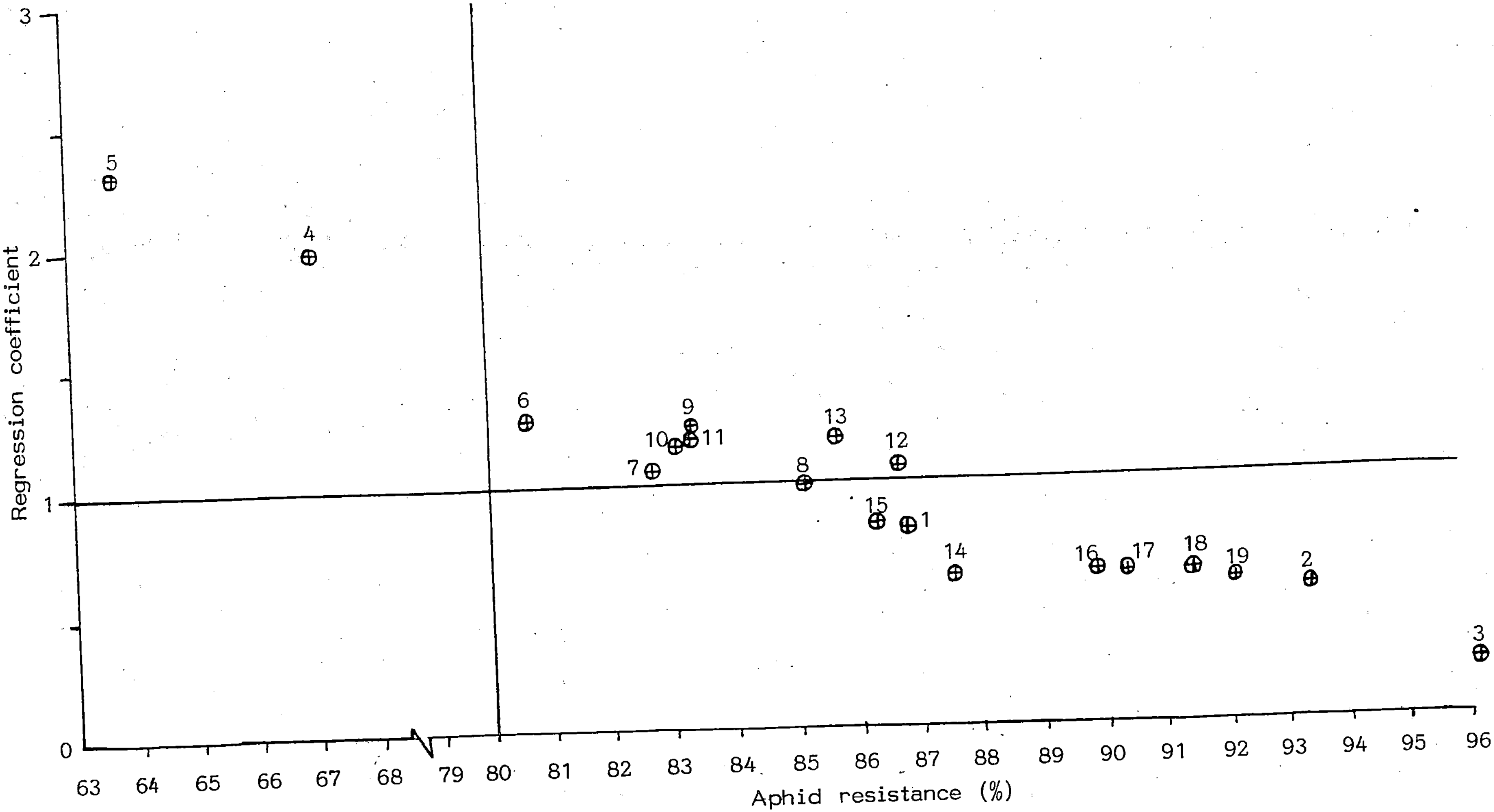


Table 51 Mean and stability parameters (bi, S^2di) for yield/plot

Treatments	Mean (kg)	Stability parameters	
		bi	S^2di
R_1	3.87	2.06	-0.03
R_2	2.76	-2.44**	0.04
R_3	3.73	3.33	0.07*
S_1	4.33	1.51	-0.04
S_2	4.73	1.05	-0.02
R_1S_1	4.14	0.45	-0.02
R_1S_2	4.12	4.18	-0.04
R_2S_1	3.47	-0.66	-0.04
R_2S_2	3.70	-1.72*	-0.02
R_3S_1	4.44	-0.90	-0.04
R_3S_2	4.25	4.22*	-0.03
$R_1R_2S_1$	3.75	-2.48**	-0.03
$R_1R_2S_2$	3.43	1.14	-0.03
$R_1R_3S_1$	4.02	0.96	-0.03
$R_1R_3S_2$	3.77	5.12**	-0.03
$R_2R_3S_1$	3.72	-0.33	-0.04
$R_2R_3S_2$	3.49	3.99*	-0.01
$R_1R_2R_3S_1$	3.68	-0.37	0.19**
$R_1R_2R_3S_2$	3.46	-0.09	-0.02
SEm±	0.16		
CD (P = 0.01)	0.62		

*P = 0.05; **P = 0.01

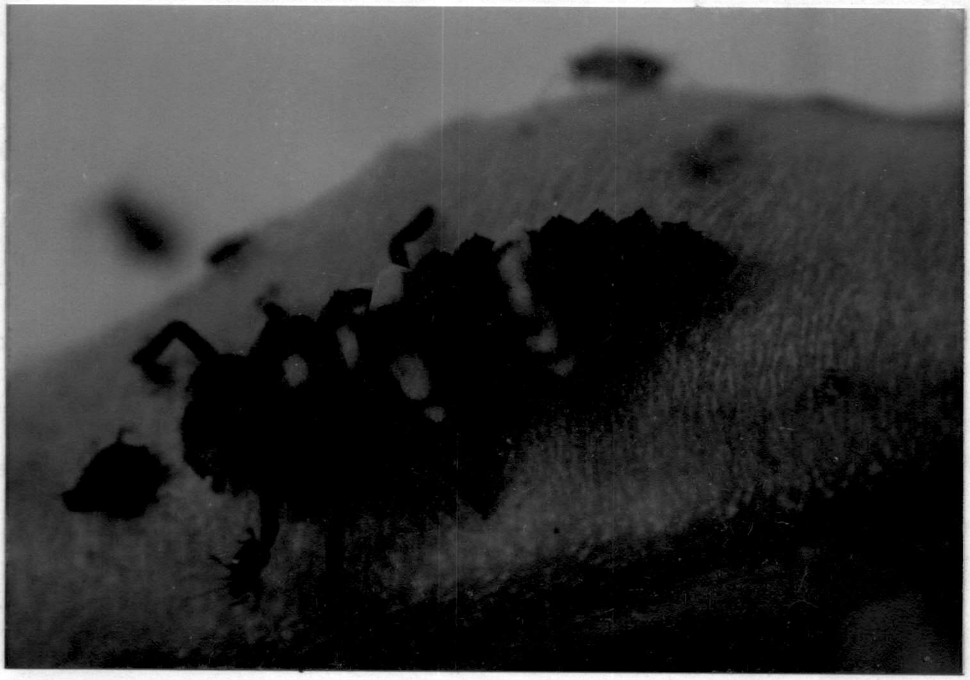
Table 52. Mean and stability parameters (bi, S^2di) for level of aphid resistance

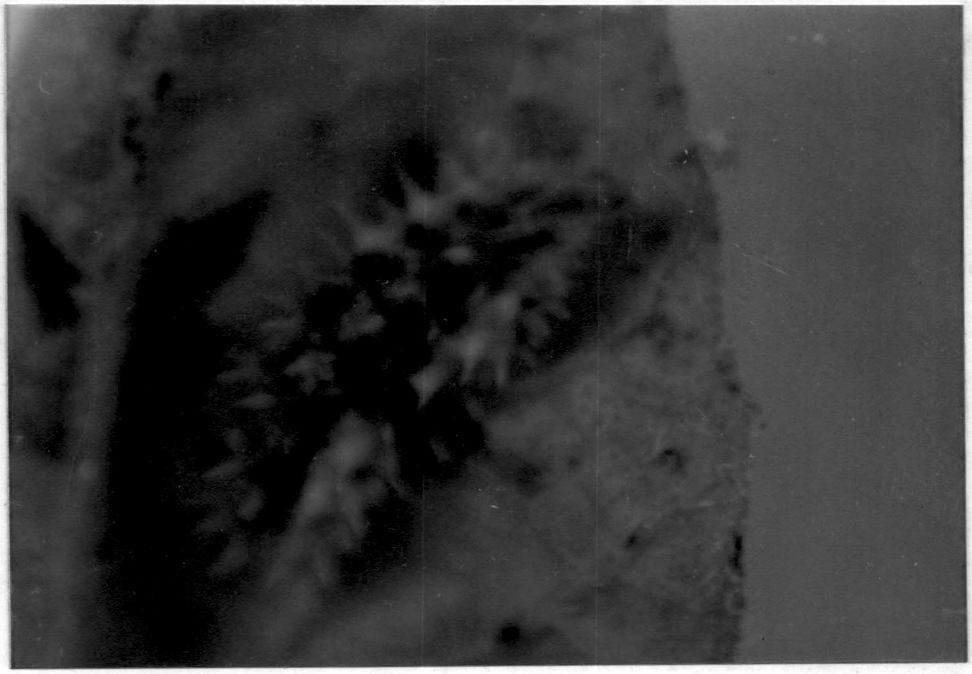
Treatments	Mean	Stability parameters	
		bi	S^2di
R_1	86.88	0.82	-3.78
R_2	93.54	0.55**	-10.83
R_3	96.25	0.18**	1.34
S_1	67.08	1.99**	-6.62
S_2	63.75	2.27**	19.75*
R_1S_1	80.63	1.26*	-9.01
R_1S_2	82.71	1.06	-10.73
R_2S_1	85.21	0.98	-9.92
R_2S_2	83.33	1.24	-5.68
R_3S_1	83.13	1.14	-10.79
R_3S_2	83.29	1.17	-10.01
$R_1R_2S_1$	86.78	1.06	-8.60
$R_1R_2S_2$	85.73	1.15	-4.05
$R_1R_3S_1$	87.64	0.66**	-10.02
$R_1R_3S_2$	86.37	0.88	-6.10
$R_2R_3S_1$	90.02	0.66*	-10.90
$R_2R_3S_2$	90.55	0.66**	-8.83
$R_1R_2R_3S_1$	91.67	0.69*	-10.85
$R_1R_2R_3S_2$	92.29	0.58*	-9.74
SEm±	3.64		
CD (P = 0.01)	13.99		

*P = 0.05; **P = 0.01

Plate XIII. Grub of *Menochilus sexmaculatus*

Plate XIV. Larva of *Ischiodon scutellaris*





of aphid resistance ($p = 0.01$) (Table 49). Among purelines, R_3 had the highest level of aphid resistance (96.25%) over all seasons (Table 52). The suscept S_2 was the most susceptible. Among treatments, the four way mixture $R_1R_2R_3S_2$ had the highest level of resistance (92.29%), deviation from regression (S^2di) non-significant and bi significantly different from unity ($p = 0.05$). The scatter diagram (Fig. 9) indicates that the pureline R_1 is average stable with regression tending to one and deviation from regression non-significant. It had 86.88% resistance to aphids.

E. Natural predators and their identification

The identified predators include two coccinellids and one syrphid. The coccinellids were Coccinella arcuata (Plate XII) and Menochilus sexmaculatus (Plate XIII). The syrphid was Ischiodon scutellaris (Plate XIV).

The coccinellids Coccinella septempunctata, Coccinella transversalis, Micraspis sp. and Scymnus spp. were also noted in the cowpea plots.

Discussion

DISCUSSION

Attempts on exploration of source(s) of resistance to aphids in cowpea germplasm are very much limited in India. Bell (1980) and Dhanorkar and Daware (1980) were the first to initiate work on identification of source(s) of resistance in India. Sulochana (1984) and Jayappa and Lingappa (1988) attempted to identify cowpea lines resistant to aphids. Use of host plant resistance in pest management in the country has not come to much reality. To strengthen this line of research, present investigations were carried out to evaluate varietal performance and understand nature of resistance, as this forms the bases in breeding for resistance to aphids.

A. Identification of source(s) of resistance to aphids in cowpea and estimation of level of resistance

Any breeding programme, including one that involves host-plant resistance to pathogens or vectors, must begin with extensive screening of germplasm. Success in identifying resistant source(s) is directly related to diversity of germplasm available and probability of resistance occurring in the host populations.

In initial stages of a screening programme, quicker easier and reliable techniques are desired to reduce the bulk of entries, and to eliminate potentially susceptible accessions. Two hundred and four cowpea accessions including exotic and indigenous collections were evaluated for resistance to aphid under field conditions. The population build up of aphids in different cowpea accessions was considered as the criterion to assess resistance. Observations on aphid infestation were recorded at frequent intervals in all varieties and estimates of aphids were made by counting and rating on a 0-2 scale. Evaluation of cowpea germplasm for absolute number of aphids is not possible particularly when testing is done under heavy natural infestation. Assessment of varietal performance was on relative basis. Similar rating for resistance based on aphid population was followed earlier by Ortman et al. (1953); Banks (1954); Saini and Chabra (1968); Dahms (1972) and Sulochana (1984). Hanifa et al. (1973) considered field bean cultivars as resistant, if they had less than 104 aphids/2.5 cm length of terminal shoot, while other cultivars were taken as susceptible. Cowpea varieties with less than one foliage damage index only were designated as resistant to aphids and the rest were treated as susceptible by Karel and Malinga (1980).

Based on preliminary evaluations of 204 lines under natural field conditions during eleven seasons, three, six and two lines falling in 0, 1 and 2 scales respectively were selected and evaluated rigorously to confirm their host response. Counts of aphids population build up on the terminal shoots, terminal leaves, flowers and pods were taken, and they were rated into 3 groups - low, medium and high. In the group rated as resistant, number of aphids on terminal shoots ranged from 20.3 (Vs 452) to 22.7 (Vs 350), in the moderately resistant group, it ranged from 33.4 (Vs 307) to 86.3 (Vs 456) and in susceptible group 504.6 (Pusa Komal) to 596.5 (Kanakamony). On terminal leaves, the ranges were 10.2 (Vs 350) to 26.6 (Vs 452) in resistant group, 39.8 (Vs 458) to 76.7 (Vs 457) in moderately resistant and in the susceptible group, the range was from 820.5 (Pusa Komal) to 912.7 (Kanakamony). On flowers, the ranges were 6.9 (Vs 438) to 28.5 (Vs 452), 12.1 (Vs 457) to 35.1 (Vs 306) and 96.1 (Pusa Komal) to 108.2 (Kanakamony) in the resistant, moderately resistant and susceptible groups, respectively. Ranges of aphids on pods were 10.4 (Vs 438) to 19.9 (Vs 452), 22.0 (Vs 147) to 77.6 (Vs 307) and 842 (Pusa Komal) to 910 (Kanakamony) on resistant, moderately resistant and susceptible groups respectively.

The repeated resistant behaviour of the three cowpea accessions Vs 350, Vs 438 and Vs 452 (Plate XV-XVII) confirmed their resistance to aphids. Based on consistent host responses, three resistant lines Vs 350, Vs 438, Vs 452, six moderately resistant lines (Vs 306, Vs 307, Vs 147, Vs 456, Vs 457, Vs 458) and two susceptible lines (Kanakamony and Pusa Komal) were selected and

Plate XV. Vs 350 - A cowpea line resistant to aphid

Plate XVI. Vs 438 - A cowpea line resistant to aphid

Plate XVII. Vs 452 - A cowpea line resistant to aphid

further evaluated under *in vitro* conditions. Aphid population multiplied at varying rates among the cowpea accessions. Multiplication rate in aphids ranged from 34.8 to 52.6 by 10 DAI and 86.4 to 143.2 by 15 DAI in the resistant group. In the moderately resistant group, multiplication rate varied from 56.2 to 84.0 by 10 DAI and 176.2 to 292.6 by 15 DAI. Rate of multiplication was the highest in the highly susceptible group. On 10 DAI, the population ranged from 187.6 to 208 and at 15 DAI it was 627.6 to 714.6. Apparently, the cowpea lines showed their suitability/ unsuitability for feeding and breeding. Among the eleven lines, the three lines Vs 350, Vs 438 and Vs 452 restricted aphid multiplication once again proving that these accessions did not form ideal hosts for growth and multiplication of the aphid.

Results in the present studies agree with earlier reports (Singh, 1977; Dhanorkar and Daware, 1980; Sulochana, 1984; Manawadu, 1985; Jayappa and Lingappa, 1988) showing varietal differences in susceptibility of cowpeas to field infestation by *Aphis craccivora*. The accessions Vs 350 (V-16) from Assam, Vs 438 (NI 778 IND) from Belgium and Vs 452 (P-912) from Bangalore were the least infested by aphids in natural field conditions and were confirmed as resistant in the succeeding field and *in vitro* studies. The lines Vs 306 (V-1) and Vs 307 (PI 476) from Tamil Nadu Agricultural University, Vs 147 (TVu 1889) from Nigeria, Vs 456 (ICV-10), Vs 457 (ICV-11), Vs 458 (ICV-12) from Kenya were moderately resistant in the field and in *in vitro* studies.

The line P 912 (Vs 452) reported resistant by Jayappa and Lingappa (1988) was resistant to aphids in the present studies as well. Singh (1977) and Jayappa and Lingappa (1988) stated that TVu 2740 was resistant to aphids. The present study did not corroborate this observation, the line TVu 2740 was susceptible to aphids. The line PI 476 reported resistant by Bell (1980) and Dhanorkar and Daware (1980) and moderately resistant by Jayappa and Lingappa (1988) was observed moderately resistant in the present studies. Contrary to the reports of Jayappa and Lingappa (1988) about resistant responses in cowpea lines - Mandya Local and MS 370, the current study revealed their susceptible responses. The line TVu 410 was highly susceptible in the present evaluations contrary to the finding of Karel and Malinga (1980). The line TVu 3273 observed resistant to aphids by Chari *et al*. (1976) succumbed to infestation in the present study. Pathak (1988) reported ICV-10, ICV-11, ICV-12 and TVu 310 to be highly resistant to aphids at Nairobi, Africa. But the lines ICV-10, ICV-11 and ICV-12 were only moderately resistant and TVu 310 was highly susceptible under the prevailing farming conditions. Sulochana (1984) found that the line TVu 1889 was completely free from aphid infestation on leaves, internodes and

Vs 456 (ICV-10), Vs 457 (ICV-11), Vs 458 (ICV-12) from Kenya were moderately resistant in the field and in *in vitro* studies.

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From the above observations, it is evident that the accessions reported resistant in a particular region, are not resistant in another region. Differences in performance of specific accession could be due to variation in the biotypes of aphids involved, nutritional factors, weather factors, alternative hosts/ carriers or the population level in the field. This observation was supported from the report that, cowpea cultivars resistant to Aphis craccivora at IITA, Nigeria, were not resistant to an aphid population introduced from Georgia (Chalfant, 1985). Breeding for aphid resistance is a complicated affair as aphids are capable of evolving biotypes to overcome host resistance. Three biotypes of A. craccivora were reported - biotypes A and B in Nigeria and biotype K in Upper Volta (IITA, 1981). The existence of Aphis craccivora populations with distinct and different patterns of pest behaviour in Africa, Asia and the USA emphasizes need for identification of multiple genes for resistance to aphids in major growing areas where this pest is a potential threat to cowpea crop. Growing multilines each possessing different resistant gene system would also be a functional alternative.

Mechanism of evolution and development of aphid biotypes are not fully understood and are open to theoretical speculations. According to Nielson et al. (1970), certainly the environmental forces acting upon a given population can ultimately cause that population to change to meet requirements of new environment for survival and perpetuation. Evolution of biotypes can also be the resultant of growing resistant plants, which provide differential hosts enabling biotypes to be recognised and the selective pressure for biotypes to evolve. The first spotted alfalfa aphid resistant cultivar was Lahontan, which possessed antibiosis and antixenosis. However, virulent biotypes have adapted to it (Nielson and Olsen, 1982). This type of aphid response can occur whenever selection pressure is exerted through use of resistant cultivars (Jimenez et al., 1989). If the host is tolerant to aphid infestation or if resistance is based on a morphological feature, biotypes rarely develop (Gallun, 1972), but variations in host physiology affecting aphid nutrition, or the production of toxic substance may well be matched by equivalent variation in ability to survive such features. According to Nielson et al. (1970) development of biotypes of spotted alfalfa aphid appeared to have resulted directly from the influence of resistant alfalfa cultivars. An apparent solution for control of a virulent biotype in an infested area, is replacement of the cultivar with those which have broader base of unrelated highly resistant germplasm. Cultivation of multilines is another possibility as this may block rapid build up of different biotypes of insects as has been the case with many race specific pathogens like Puccinia graminis f. sp. tritici causing stem rust of wheat, and Erysiphe graminis f. sp. hordei causing powdery mildew of barley.

B. Morphological and biochemical bases of host reaction to aphid infestation

Painter (1941) divided plant resistance mechanism to insect pests into three categories - preference/non-preference, antibiosis and tolerance. Plants may be non-preferred for oviposition, shelter or food, primarily because of lack of essential nutrients or presence of toxic chemicals or due to adverse physical or mechanical factors. The term antibiosis is proposed for those adverse effects on the insect's life history which result when a resistant host variety or species is used for food. Tolerance refers to the ability of a plant to withstand the damage or recover from attack in spite of supporting the population of insects that would normally cause greater injury to a susceptible plant.

Attempts were made in the present investigations to categorise the mechanisms of resistance, in the chosen lines, into preference/non-preference and antibiosis. Number of aphids migrated and settled on selected cowpea accessions, in the field and on the shoot tip clippings kept in a conical flask in the laboratory, under free choice conditions were counted. There was significant difference between cultivars in number of aphids migrated and colonized on the five cowpea accessions. The line Vs 350 recorded zero number of aphids, followed by the remaining two accessions Vs 438 and Vs 450 both in the field and laboratory studies. In general, aphid settling reflected non-preference, with fewer aphids settling on resistant lines when multiple choice is given. Field antixenosis has previously been observed in faba beans (Muller, 1958; Tambs-Lyche and Kennedy, 1958). Distinct differences in preferences by aphids for resistant and susceptible cowpea entries were found in glasshouse trial by Jayappa and Lingappa (1988) also.

Density of trichome cover differed notably among resistant and susceptible lines. Aphids colonise on tendermost shoot apices and growing points. In the case of resistant lines, the tender regions are protected by profuse cover of sharp trichomes of mixed length. The sharp points can readily penetrate the softer tissues of the aphids when they come in contact with them. Small aphid nymphs may become hooked in any part of the body or appendages, whereas the adult aphids more often become fastened or hooked in the soft tissue of the leg joints (McKinney, 1938; Johnson, 1953).

Several factors contribute in causing small insects to become impaled. Length of the trichomes in relation to insect size is an important factor which causes insects to become impaled while performing their natural movements around plants. The direct action of wind forces soft bodied insects on to the trichomes. Quick, unnatural movements, as in attempts to escape from parasites and predators, increases chances of becoming trapped on the sharp trichomes. Occurrence of mixed sized trichomes also favour this type of trapping. Trichomes as a resistance factor interfere with insect oviposition, attachment to the plant, feeding and ingestion. The purely mechanical effects of trichomes depend on its density, erectness, length and type. In aphids which feed from phloem, they have to insert their stylets deeper into the plant tissue. But profuse cover of trichomes may impede feeding.

Though all the resistant lines were densely pubescent, when compared to susceptible lines, the resistant lines differed among themselves in density and size of trichomes. Hence resistance cannot be attributed to pubescence alone. Definitely, it plays a role in protecting growing tips by interfering in aphids locomotion and phloem feeding. Pubescence is considered as a nonpreference mechanism, in combination with other biochemical or other factors. This view is supported by the observations of Bell (1980) who also reported more pubescence on aphid resistant cowpea cultivars. A resistant plant is one which possesses a complex of characteristics which reduce growth rate of its insect population.

Transverse sections of shoot apices from 3rd internode of all cowpea accessions were observed for arrangement of vascular bundles, thickness of cuticle, number of layers of cells in epidermis, hypodermis, endodermis and schlerenchymatous pericycle. No consistent anatomical differences were observed between shoot tips of resistant and susceptible plants, except for the highly lignified schlerenchymatous pericycle in the susceptible lines, in contrast to expectations. This suggests that the basis for resistance does not lie in structural differences in plants and lignified schlerenchyma was not large enough to constitute a biophysical barrier to prevent the aphid stylets from reaching the internal phloem, the feeding site, as susceptibility was more in lines which were more lignified. Similar results were obtained by Hackerott and Harvey (1959) and McMurthy and Stanford (1960) who demonstrated that resistance in alfalfa to spotted alfalfa aphids was of a physiological nature rather than anatomical.

Painter (1941) found that composition of available food in the host plant plays possibly the most important role in determining the relative resistance to aphids. According to Painter (1951, 1958), any adverse effect on growth, development and perpetuation of pest species feeding on the host plant may be affected by (1) deleterious effects of specific chemicals including toxins (2) lack of specific food materials in plants (3) differences in quantities of food present (4) food materials present but for some reasons not available to the insects and (5) the presence of materials so repellent that the insect will not eat the plant even though the plant will apparently support the life. Quantitative estimations of important food components, like reducing sugars, non-reducing sugars, total sugars, protein, nitrogen, phosphorus and potassium were made.

The resistant cowpea lines possessed more reducing sugars (3.80, 2.40, 1.12 mg/g in Vs 438) than susceptible lines (1.10, 0.92 and 0.65 mg/g) in Kanakamony at all stages of maturity (5, 10 and 15 days respectively). In contrast, the resistant lines had only lesser contents of nonreducing sugars (1.10, 1.95, 2.69 mg/g) in Vs 438 at all stages of maturity when compared to susceptible line (4.53, 4.82 and 4.94 mg/g) Pusa Komal. This is of significance in view of the report by Auclair (1965) that he was unable to rear pea aphids on chemically defined diets with less than 35% sucrose. In studies conducted by Barlow and Randolph (1978), using exudates from severed aphid stylets, the only sugar they could find was sucrose. In tomato also, Quiros et al. (1977) reported significantly higher sucrose concentration in susceptible plants to potato aphid (Macrosiphum euphorbiae). They found that the rest of the sugars especially fructose and glucose tended to be lower in concentration in susceptible plants. These reports lead to infer that a relationship possibly existed between sucrose and aphid reaction. Higher levels of total sugars were recorded in susceptible cowpea lines when compared to resistant lines. This is in agreement with the findings of Maltais and Auclair (1957) who reported that higher concentration of sugars in pea varieties was not preferred by the aphid Acyrthosiphon pisum. This also leads to assume that nutritional composition, particularly sugars, plays an important role in imparting resistance to aphids.

Total nitrogen content did not vary significantly among cowpea lines. The susceptible line Pusa Komal had the highest nitrogen content (4.08%) among all the lines and Kanakamony had 3.88%. Among the resistant lines only Vs 350 had higher nitrogen content (3.93%) than the susceptible line Kanakamony. Other two resistant lines (Vs 438 and Vs 452) had only 3.86% and 3.80% nitrogen respectively.

It is reported that aphids respond positively to increased nutrient elements in host plants, particularly nitrogen. This was true of the bean aphid, Aphis fabae (Davidson, 1925), the cabbage aphid Brevicoryne brassicae (Evans, 1938), the cotton aphid, Aphis gossypii (McGarr, 1942, 1943), sorghum aphid Rhopalosiphum maidis (Branson and Simpson, 1966) and cowpea aphid Aphis craccivora (Bell, 1980). Significant variations in fecundity of aphids due to variations in nitrogenous substrates in the phloem were reported by Kennedy (1958), Waghray and Singh (1965) and Crawley (1983). Hence it seems that, in the present study, though the differences in total nitrogen contents are small, it may probably reflect proportionally large differences in the soluble nitrogen fractions used by aphids.

Phosphorus content also did not vary among resistant and susceptible lines. The susceptible line Kanakamony had a phosphorus content of 0.34% and Pusa Komal 0.30%. The resistant line, Vs 452 had a phosphorus content of 0.30%, Vs 350, 0.31% and Vs 438, 0.33%.

Thevasagayam (1962) reported that population of cotton aphid increased due to higher doses of phosphorus applied. In studying role of phosphorus, Kalaichelvan (1974) reported higher amounts of phosphorus in bhindi varieties susceptible to Aphis gossypii, than in resistant sources. Bell (1980) also reported high phosphorus content in the susceptible lines of cowpea. Phosphorus plays a major role in various enzymatic reaction in carbohydrate metabolism including interconversion of carbohydrates and providing respiratory energy for chemical reduction of nitrates. In the present study, there being least difference in phosphorus contents among the resistant and susceptible lines, the resistance in these lines may not in any way be related to the phosphorus content, in these lines.

The potassium content also did not vary significantly among the lines. It was the highest in the susceptible line Pusa Komal (2.13%) followed by the resistant line Vs 350 (2.07%) and was the least in the resistant line Vs 438 (1.85%). Isely (1946) reported that potassium deficiency was one of the factors for slower development of Aphis gossypii in cotton. The present study suggested that the differences between resistant and susceptible accessions in potassium content were not significant enough to impart any promotive or inhibitory effect on Aphis craccivora. Protein contents in the resistant and susceptible lines also did not differ significantly. Protein content in the selected cowpea lines may not be related to resistant or susceptible host reaction. In vitro studies showed that the mechanism of resistance in all the three resistant lines Vs 350, Vs 438 and Vs 452 includes antibiosis. This was observed as lower fecundity of aphids (9.0

to 17.6) reared on them, compared to the susceptible lines (43.2 to 50.8). Antibiosis as a factor was responsible for resistance in a few other cowpea lines like PI 476, TVu 9836, TVu 9914, TVu 9929, TVu 9930 to Aphis craccivora (Bell, 1980; Jackai and Singh, 1983). All other climatic, ecological and cultural factors being same, the difference in rate of reproduction depends directly on the quality or quantity or both of the food materials, an aphid imbibes from its host. It appears that there is absence of specific food materials or presence of toxic chemicals in the resistant lines.

Cartier (1963) opined that antibiosis could be the result of two separate plant factors, acting on aphids, a restlessness factor and a nutritional factor. The restlessness factor would make the female overactive and inevitably unable to feed and sustain optimum reproduction. Investigations by several workers (Dahms and Painter, 1940; Harrington, 1941; Carnahan et al., 1963; Panda and Raju, 1972 and Fotedar and Kushwaha, 1976) revealed that the host plants resistant to aphids invariably possessed high antibiosis.

Antibiosis is used commonly as a criterion for the final selection of plants in resistance breeding programmes. The true type and nature of antibiosis have not been reported. Harrington (1941) demonstrated through green house tests that the resistant pea variety Pride, when compared with the susceptible variety Perfection, increased the period of development of nymphs by 3.1%, decreased reproduction by 12.5% and shortened the aphid life span by 20%. Maltais (1951) reported that the susceptible pea variety Perfection showed an average population of 209.6 aphids/plant sample for a total of nine years, whereas the resistant variety Champion of England had an average population of only 67.9. McMurthy and Stanford (1960) found that aphids confined to highly resistant alfalfa plants such as C-84 usually died within a period of 24 to 72 h. Though cowpea aphid (Aphis craccivora) completed its life cycle on the resistant accessions, biology of the pest was considerably affected. It is inferred that antibiosis was greatly responsible for imparting resistance. Non-preference regulating aphid migration, is also another mechanism explaining resistant host response. Total phenol content was high in resistant lines (88 to 96 ppm) and low in susceptible lines (64 to 69 ppm). Among the resistant lines, Vs 350 had the maximum total phenol content (96 ppm) followed by Vs 438 (92 ppm) and Vs 452 (87 ppm). The lowest total phenol content was observed in Kanakamony (64 ppm) and Pusa Komal had 69 ppm. The highest OD phenol content was also estimated in the resistant accessions. The line Vs 350 had 38 ppm OD phenol followed by Vs 438 (30 ppm) and Vs 452 (29 ppm). The OD phenol content was the lowest in Kanakamony (23 ppm). Pusa Komal had 27 ppm of OD phenol. Contents of total and OD phenols were higher in all the resistant accessions compared to susceptible accessions. Very limited research attempts are made on the role of phenolics in plants, resistant to insects. Chelliah (1971) reported more of total and OD phenols in melon varieties resistant to fruit fly. Bell (1980) reported more phenols and OD phenols in all the resistant varieties of cowpea to aphids. Houston (1976) also implicated total phenolics as an important factor for resistance in trees. It is suggested that the phenols and OD phenols play a unique and distinct role in the defence mechanism of the resistant cowpea lines to aphids.

Resistant lines Vs 438 and Vs 452 had 1.50 trypsin inhibitor (T.I.) units/g of the seeds. The line Vs 350 had 1.33 T.I. units/g of seed. Both the susceptible lines had no inhibitor present in their seeds. Inhibition of trypsin activity was 10.85% in Vs 438 and Vs 452 and the line Vs 350 inhibited the activity by 9.62%.

Ryan and Huisman (1970) viewed that these inhibitors might be intimately involved in deposition and mobilization of proteins in plants. The rapid accumulation of proteinase inhibitors in crop plants in response to wounding could have a major adverse effect on the ability of feeding insects to digest leaf proteins. With an inhibited system for digesting proteins, a severe nitrogen deficiency could result, which would arrest the normal development of the insect. Trypsin inhibitor activity in leaf extracts of legumes like lentil (Lens culinaris), alfalfa (Medicago sativa), kidney bean (Phaseolus vulgaris), pea (Pisum sativum), clover (Trifolium repens) and broad bean (Vicia faba) were reported by Walker-Simmons and Ryan (1977). Ng et al. (1987) reported that the T.I. contents in raw cowpea seeds ranged from 27 to 66 T.I. units/mg protein and was not related to resistance to bruchid pests. It is unlikely that inhibitors act alone to protect any given plant. It is more likely that inhibitors represent one line of protection among various other protective chemicals that may also be present.

C. Genetics of resistance to aphids in cowpea

All the F_1 plants were resistant indicating dominant nature of resistance over susceptibility. The F_2 generation, showed a segregation of 3 resistant:1 susceptible indicating that resistance to the aphid, in each case, was governed by a single dominant gene. These conclusions were confirmed from the reactions of back cross populations involving susceptible parents. All BC_2s segregated in a ratio of 1 resistant:1 susceptible. The F_1, F_2 and back cross data obtained from the present study indicated that inheritance of aphid resistance in cowpea is controlled by a single dominant gene. The single dominant gene inheritance for aphid resistance makes it rather easy to manipulate this trait in breeding programmes.

The A, B, C scaling tests were significant in crosses Vs 350 x Kanakamony and Vs 350 x Pusa Komal indicating presence of epistasis. In all other crosses the scaling tests were non-significant indicating the suitability of simple additive dominance model to explain level of aphid resistance.

The heritability in broad sense was high in all cases indicating that level of resistance to aphids was not altered much with environmental pressure. The characteristics inherited more as a mendelian trait.

The low K_2 value indicated that only one factor was involved in inheritance of resistance.

D. Development of physical mixtures in cowpea to manage aphids

Various investigations involving physical mixtures as potential cultivars in rice (Chin and Husin, 1982), wheat (Gacek, 1987), oat (Frey and Maldonado, 1967), soybean (Schutz and Brim, 1971) and maize (Funk and Anderson, 1964) indicated possibility of some favourable interaction among the mixture components. Such mixtures are useful in achieving greater yield through more efficient use of environment (Donald, 1963). As the different components in a mixture constitute a barrier to slow down and arrest spread of disease organisms, it appears possible that heterogeneous populations may act as non-polluting means of disease control (Vander Plank, 1968, 1975). The spectacular successes in controlling plant diseases using multilines suggest that against a few insect pests also, this approach may be effective by blocking rapid population build up and formation of specific biotypes. This is especially so in case of highly host specific insect pests like aphids, easily vulnerable to rapid development of biotypes. One of the basic informations, plant breeders require before embarking on a multiline variety concept, is the knowledge on relative performance of lines when grown singly and in physical mixtures. To be cost effective and successful, a physical mixture should yield at least to the level of average performance of its components when grown alone. Any consistent depression in yield of a mixture below this threshold level would indicate a lack of efficiency and consequent non-adoption of the technology. Knowledge on practical application of principles of varietal diversification, suited to risk situations, which provide sufficient barriers as given by resistant varieties to specific insects are very meagre. The present preliminary studies were taken up to collect basic information on better performance of multilines/ physical mixtures of cowpea for pod yield and level of aphid resistance.

Two, three and four component mixtures of cowpea involving three resistants (R_1, R_2, R_3) and two suscepts (S_1 and S_2) along with purelines were grown during three consecutive seasons. Data were collected on pods/plot, yield/plot and level of aphid resistance. During all the three seasons, the pureline monocultures and physical mixtures differed significantly for the above characters. When purelines were compared with physical mixtures as a whole, the difference was significant only for level of aphid resistance during all the three seasons. No significant difference was observed when purelines were compared with physical mixtures as a whole for yield/plot. The three resistants and two suscepts differed one another for yield/plot, during one or the other seasons. Three way and four way mixtures did not differ among themselves for level of aphid resistance during all the three seasons. Two way mixtures when compared with three or four way mixtures as a whole, significant differences were observed for yield/plot and level of aphid resistance during all the three seasons.

Pods/plot ranged from 1197.5 (R_2) to 2178.5 (R_3) in pureline monocultures and from 991 in $R_2R_3S_2$ to 1885 in R_3S_1 during first season in physical mixtures. The two way mixture R_3S_1 deviated by 7.47% over the expected values, had they been grown as monocultures. During second season, the 4 way mixture $R_1R_2R_3S_1$ deviated by 21.76% over the expected values. The pods/plot decreased in 8 out of 14 physical mixtures. During third season, eight physical mixtures had a positive deviation from expected values due to physical blending. Number of physical mixtures expressing compensatory effect with regard to three characters are presented in Table 53. During first, second and third seasons, 7, 4 and 7 out of 14 mixtures expressed compensatory effect for yield, respectively. During all the seasons, all the physical mixtures expressed compensatory effects for level of aphid resistance.

The common approach of selecting lines of a mixture on the basis of _per se_ performance does not necessarily lead to desirable results in physical mixing. Selection of physical mixtures based on knowledge of associative ability is relevant here for identification of desirable mixtures. Performance of component lines in physical mixtures is a function of the genotype of the line and its associative values with other lines. The associative value with other lines is to be assessed by actual field trials. If a tight relation can be worked out between _per se_ performance of line(s) and its general associative ability, then _per se_

Table 53 Number of physical mixtures expressing compensatory effect, range of compensatory effect and outstanding physical mixtures for pods/plot, yield/plot and level of aphid resistance during three seasons

Seasons	Number of physical mixtures expressing compensatory effect	Range of corresponding effect	Outstanding physical mixture	Character under observation
Season I	6/14	2.58%-7.47%	R_3S_1	Pods/plot
	7/14	2.24%-20.71%	R_3S_1	Yield/plot
	14/14	0.92%-26.43%	R_1S_2	Level of aphid resistance
Season II	6/14	1.39%-21.76%	$R_1R_2R_3S_1$	Pods/plot
	4/14	0.05%-1.82%	R_3S_1	Yield/plot
	14/14	2.25%-8.66%	$R_1R_2S_1$ $R_1R_2S_2$	Level of aphid resistance
Season III	8/14	0.62%-9.5%	$R_1R_3S_1$	Pods/plot
	7/14	1.12%-6.44%	$R_1R_2R_3S_1$	Yield/plot
	14/14	0.74%-5.02%	R_3S_2	Level of aphid resistance

performance can be used as an index for the character under study. The tedious process of field evaluation for subsequent studies can be avoided in such cases.

Data from pureline monocultures and 2 component physical mixtures were analysed to find out general associative ability of lines and specific associative ability of physical mixtures. The highest general associative ability effect was estimated in R_3 during all the three seasons for pods/plot (228.75, 55.75 and 239.67 respectively). The highest saa effect was manifested by R_3S_1 during first (143.08) and second (35.58) seasons and by R_3S_2 during third season (13.33). The highest gaa effect for yield/plot was manifested consistently by R_3 during all the three seasons (0.199, 0.412 and 0.280 respectively). The specific associative ability effect was maximum in R_2S_2 (0.32) during first season, in R_1S_2 (0.06) during second season and in R_1S_1 (0.02) during third season. During all the three seasons, the line R_2 had the highest value of gaa (1.458, 1.667 and 0.542 respectively) for level of aphid resistance. The mixtures R_2S_1 (2.71), R_1S_2 (0.42) and R_3S_2 (0.17) possessed high saa effects during first, second and third seasons respectively. It was also noted that the line showing high per se performance for pods/plot had high gaa for pods/plot and yield/plot, in 2 component mixtures.

General coexistence ability index is the ratio of average performance of a line in physical mixtures to its performance in purestand. The mean general coexistence ability of all the lines except S_2 (0.79) was one or equal to one for pods/plant and yield/plant. This may be the possible reason for observing a negative deviation from the expected values in seven out of seven physical mixtures involving S_2 during first season, five out of seven mixtures during second season and four out of seven mixtures during third season for pods/plot. Similar negative deviations from expected values were also observed for yield/plot also. Out of seven physical mixtures involving S_2, six, five and five combinations deviated negatively for yield/plot during first, second and third seasons respectively. It is evident that high yielding ability of a variety was not an assurance of its ability to survive in a heterogeneous population. Among the five purelines included in the present studies, S_2 has a different growth habit (bushy) while others are semiviny. It is not apparent whether such differences in maturity, height, growth habit, etc. are more important in allowing a genotype to its full expressivity of production potential, in heterogeneous varietal blends. In the present study, a greater percentage deviation from expected was obtained in blends with wide character differences than in blends with narrow character differences.

For level of aphid resistance, all the resistant lines had a GCoA equal to one. Both the susceptible lines had a GCoA greater than one (1.17 and 1.29) which is a clear indication of the improvement in performance (level of aphid resistance) over pure-stand of the suscepts. Results indicated that mixing more resistant components increases level of resistance. The physical mixtures have definite advantage over monocultures for higher level of aphid resistance. This advantage is derived by obstruction barriers created by resistant components in mixtures by slowing down aphid multiplication. This indicates that the concept of multi-lines cannot be ruled out in a risk situation like an insect epidemic though they have slightly lower efficiency of biological yield. Principle of diversification suited to risk situations involving pathogens proposed by Jensen (1952) could be a good fit in risk situations involving insects too. Now-a-days, multilines are assuming considerable significance in race specific resistance to pathogens in crop plants.

Development of biotypes in insect pests are comparatively not frequent because of the insects own complex physiology. Pest resistance in host plant is being often related to the host-finding behaviour of insects (Singh, 1986). But out of the eleven insects with known biotypes, six are aphids, which could be due to parthenogenetic reproduction and a relatively short life cycle

(Singh, 1986). Development of biotypes in insect pests is obviously traced to the severe selection pressure exerted by the resistant crop variety(s). When antibiosis is the component of resistance, such selection pressure is the most effective, if it results in mass mortality (Panda, 1979). An aphid that can survive a resistant plant can build up a new biotype within one or two crop seasons (Singh, 1986). Gallun (1972) observed that tolerance or non-preference is the main component of resistance inherent in the plant. When non-preference is the mechanism of resistance, a particular plant is not chosen as a host (a bad host) because of presence of another (in multilines) preferred one, whereas this plant or variety (non-preferred) is accepted as a host, if there is no choice (resistant pureline alone). Though there is no evidence to support presence of aphid biotypes in Kerala, the reduction of level of resistance of the test lines during course of present field studies, and difference in performance of reportedly resistant lines, lead to possible presence of biotypes of aphids even in Kerala.

The data collected during three seasons were pooled and analysed to study extent of variations due to treatments, seasons and treatments x seasons interactions. The treatments were significantly different (p = 0.01) for pods/plot, yield/plot and level of aphid resistance. The treatments x seasons interactions were highly significant ($p=0.01$) for pods/plot and yield/plot and were not significant for level of aphid resistance. The linear component of treatments x seasons interaction was highly significant for yield/plot and level of aphid resistance. Significance of the linear components of treatments x seasons interaction suggested that the treatments x seasons interactions were linear and the treatments differ considerably for yield and level of aphid resistance.

Eberhart and Russell (1966) defined an average stable variety as one with coefficient of regression tending to one and deviation from regression tending to zero. The non-linear stability parameter, deviations from regression, reflects the ability of a line or mixture to respond to a series of uniform environments in a repeatable way and reflects the kind of stability measured by treatments x seasons interactions. The line R_3 had the highest pods/plot (2077), regression tending to zero (-0.30) and deviation from regression non-significant. Among two way physical mixtures, R_3S_1 had the highest pods/plot (1715.17) and deviation from regression (S^2di) non-significant. The regression (bi) was however, significant. Among three way mixtures, $R_1R_3S_1$ was the most promising average stable physical mixture for yield/plot. Among pureline monocultures S_2 yielded the highest over the seasons (4.73 kg/plot). Among resistant lines, R_1 yielded the highest (3.87 kg/plot). The treatment R_3S_1 yielded 4.44 kg/plot, the highest among the physical mixtures. Its regression (bi) deviated significantly from unity, though S^2di was non-significant. Among three way mixtures, $R_1R_3S_1$ was promising with an overall mean of 4.02 kg/plot, regression tended to unity and deviation from regression non-significant. Among purelines, R_3 had the highest level of aphid resistance over seasons (96.25%). The suscept S_2 was the most susceptible. Among treatments, the four way mixture $R_1R_2R_3S_2$ had the highest level of resistance (92.29%), deviation from regression (S^2di) non-significant and bi, significantly different from unity ($p = 0.05$). The scatter diagram indicates that the pureline R_1 has 86.88% resistance, regression tending to zero and deviation from regression non-significant.

Whether or not, a multiline would yield higher than the highest yielding component pureline is of interest in commercial production. In the present study, none of the multilines exceeded the performance of S_2, the highest yielding component. As such, cowpea varietal blends as a production practice for higher yield per se require further experimentation. The GCoA of S_2 being less than one, we can take the second high yielding component line S_1 with a mean yield of 4.33 kg/plot. The two component multilines R_3S_1 (4.44 kg) exceeded the per se performance of S_1. It has a bi value of 0.90 and S^2di non-significant. R_3S_2 has an average yield of 4.25 kg, R_1S_1 has 4.14 kg and R_1S_2 4.12 kg.

Considering together higher yield and management of aphids the scope of physical mixtures like R_3S_1 needs to be tried as a cultural practice. The physical mixture R_3S_1 offers 83.13% resistance to aphids under field condition. Resistance of a plant variety/multiline to insect pests need not be absolute, to be of considerable economic utility. A level of resistance which reduces number of progeny of a pest by 50% may, in successive generations, reduce the pest population below economic threshold of damage (Newman and Pimental, 1974). Resistance which slowed the population growth rate by 25-50% may be important for field control, because of increased time to reach destructive levels. This can further be protected by only a fewer insecticides or other control treatments if absolutely required. Use of multilines offer a wider scope as a new cultural practice to deal with pest problems, which may otherwise lead to toxic health hazards, due to increased use of insecticides.

A multiline variety would be expected, on theoretical grounds, to possess characteristics of longer varietal life, greater stability of production, broader adaptation to environment, and greater protection against disease/pest. Small losses from diseases/pest would be expected perhaps to occur oftener in a mixture than in a single pureline variety.

E. Natural predators and their identification

The population cycle of all the three predators synchronised well with that of Aphis craccivora. Whenever there was a high population build up of aphids, there was an abundant development of predators too. Larvae of the three predators were very active feeders, and could get a rapid control of aphid population all the time.

Summary

SUMMARY

Cowpea, rich in vegetable protein, is gaining importance even in developed countries now-a-days. It is a very important component of the traditional cereal based diet of the people of Kerala. Area under the crop in Kerala is increasing due to accelerated demand and partly due to development of short duration varieties for homestead conditions and for cereal-legume intercropping. The overriding biological constraint is the serious damage caused by the insect pests, which necessitates application of insecticides. Isolation of line(s) resistant to insects will counteract this production constraint without the need for repeated insecticide sprays. In the present study 'Genetics of resistance to aphids (_Aphis craccivora_ Koch.) and utility of line mixtures in cowpea (_Vigna unguiculata_ L. Walp)' attempts were made to isolate line(s) resistant to an important cowpea pest - the aphids.

The studies were conducted during 1986-90 at the Vegetable Research plots of Kerala Agricultural University at Vellanikkara. Two hundred and four cowpea lines were evaluated for resistance to aphids, over eleven field trials. The lines were grouped into three - low aphid infestation group (resistant), medium infestation group (moderately resistant) and high infestation group (susceptible). The studies resulted in identification of three resistant (Vs 350,

Vs 438 and Vs 452) and six moderately resistant (Vs 306, Vs 307, VS 147, Vs 456, VS 457 and Vs 458) lines. None of the lines exhibited complete immunity to aphids.

Under no choice conditions in screenhouse, aphid population increased at different rates among identified lines. The three resistant lines recorded the minimum number of aphids at 10 DAI and 15 DAI and proved their least suitability for aphid multiplication.

Under free choice conditions, the aphids migrated in all directions but colonised more on susceptible lines. This reflected non-preference, with a fewer aphids settling on resistant lines when multiple choices were given.

Pubescence of resistant and susceptible lines were electronically scanned and found that the resistant line Vs 452 was the most pubescent with mixed type of trichomes, which are straight with sharp tips. The tendermost shoot tips of the resistant lines are also densely pubescent, thereby protecting the growing tips and making them unsuitable or non-preferred for aphid feeding, locomotion and colonisation. Non-preference mechanism acts in conjunction with other biochemical or physiological factors to impart host resistance to aphids.

Anatomical studies showed that lignification of the schlerenchymatous pericycle was more in susceptible lines, indicating that resistance is more of physiological nature rather than anatomical.

Biochemical bases of resistance were studied. Chemical composition of nutrient components viz. reducing, non-reducing and total sugars, proteins, nitrogen, phosphorus and potassium contents were determined. The resistant lines Vs 350, Vs 438 and Vs 452 had more reducing sugars but less non-reducing sugars and total sugars, when compared to susceptible lines. The protein, total nitrogen, phosphorus and potassium contents did not differ among resistant and susceptible lines. *In vitro* studies showed that mechanism of resistance in all lines included antibiosis and interfered with the biology of aphids, reducing aphid fecundity on resistant lines. Fecundity of aphids was significantly higher (43.1-50.8) on susceptible lines when compared to resistant lines (9.0-17.6).

The total phenol content was high in resistant lines (88 ppm-96 ppm) and low in susceptible lines (64 ppm-69 ppm). The orthodihydroxy phenols also were high in resistant lines (29 ppm-38 ppm) when compared to susceptible lines (23 ppm-27 ppm). Trypsin inhibitor content estimated in seeds of resistant lines ranged from 1.33 T.I. units/g of seed to 1.50 T.I. units/g of seed, whereas both the susceptible lines had no inhibitor present in their seeds. Observations on seasonal incidence of *Aphis craccivora* revealed that, the population was minimum during March, April and May months which coincided with high temperature, low humidity and less rainfall. Genetic bases of resistance to cowpea aphids were studied. Resistant behaviour was monogenic and dominant. Level of aphid resistance had high heritability (h^2 = 0.92 - 0.97) and one 'factor' was involved in inheritance of resistance.

Physical mixtures generated through mixing of seeds from three resistant and two susceptible lines in two, three and four ways were evaluated during August-October 1989, November 1989-February 1990 and June-August 1990. Present preliminary studies brought out a few basic information on performance of physical mixtures of cowpea. During all the three seasons, the pureline monocultures and physical mixtures differed significantly for pods/plot, yield/plot and level of aphid resistance. During all the three seasons, all the physical mixtures expressed compensatory effect for level of aphid resistance. There was a positive correlation with the level of aphid resistance expressed and the (%) obstruction created through physical blending.

The line Vs 438 (R_3) recorded the highest general associative ability for pods/plot and yield/plot during all the seasons. The highest specific associative ability effect for yield/plot was manifested by the two way mixtures Vs 438 + Kanakamony

(R_3S_1) during first and second seasons and by Vs 438 + Pusa Komal (R_3S_2) during third season. During all the seasons, the line Vs 350 (R_2) had the highest gaa effect for level of aphid resistance.

The general coexistence ability of the line Pusa Komal (S_2) was less than one for pods/plant and yield/plant. This indicates that Pusa Komal (S_2) is not a desirable component line in physical mixtures for yield and pods/plant. The high yielding ability of a variety was not an assurance of its ability to survive in a heterogeneous population. The mean general coexistence ability of all other lines were equal to one for pods/plant and yield/plant, thus proving their suitability to be grown in mixtures. Both the susceptible lines had a GCoA more than one for level of aphid resistance, showing improvement in level of aphid resistance over purestand of the suscepts. Though mixtures have a slightly lower biological yield, they are effective under risk situations like insect epidemics, especially when there are chances of biotype formation.

The mechanism of non-preference adds to the soundness of the concept of physical mixtures involving resistant and susceptible lines to manage aphid incidence. A particular non-preferred plant is not chosen as a host because of the presence of another preferred one, whereas the non-preferred plant is accepted as a host if there is no other choice. The mixtures were significantly different for pods/plot, yield/plot and level of aphid resistance. The treatments x seasons interactions were highly significant for pods/plot and yield/plot and were not significant for level of aphid resistance.

Parameters of phenotypic stability (bi, S^2di) were worked out for pods/plot, yield/plot and level of aphid resistance. The line Vs 438 (R_3) had the highest pods/plot (2077). Among the two way mixtures Vs 438 + Kanakamony (R_3S_1) had the highest pods/plot (1715.17).

Among pureline monocultures, Pusa Komal yielded the highest over the seasons (4.73 kg/plot). Among resistant lines, Vs 452 yielded the highest (3.87 kg/plot). The two way mixtures Vs 438 + Kanakamony (R_3S_1) yielded 4.44 kg/plot, the highest among physical mixtures.

Among purelines, R_3 had the highest level of aphid resistance (96.25%) over seasons. The mixture Vs 452 + Vs 350 + Vs 438 + Pusa Komal ($R_1R_2R_3S_2$) had the highest level of resistance (92.29%).

None of the mixtures exceeded the performance of Pusa Komal (S_2) for yield/plot. The mixture Vs 438 + Kanakamony (R_3S_1) performed better with 83.13% resistance under field conditions.

The predators of cowpea aphids were also indentified in the study. The predators were Coccinella arcuata, Menochilus sexmaculatus and Ischiodon scutellaris.

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* Originals not seen

GENETICS OF RESISTANCE TO APHIDS (*Aphis craccivora* Koch) AND UTILITY OF LINE MIXTURES IN COWPEA (*Vigna unguiculata* L. Walp)

By

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Abstract of a Thesis

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ABSTRACT

Direct damage caused by aphids by sucking plant sap and indirect damage caused by transmitting many viral diseases are serious havocs in cowpea. This constitutes a formidable obstacle in realisation of its yield potential, unless protected with insecticides. This, in turn, leads to high cost of production, serious health hazards and atmospheric pollution. In this context host plant resistance appears to hold great hope for cowpea production.

Experiments on "Genetics of resistance to aphids (Aphis craccivora Koch.) and utility of line mixtures in cowpea (Vigna unguiculata L. Walp)" were carried out during 1986-1990 at Department of Olericulture, Kerala Agricultural University at Vellanikkara to isolate cowpea line(s) resistant to aphids, to study mechanism of resistance, inheritance of resistance and to develop physical mixtures to manage aphids.

Three resistant and six moderately resistant lines were identified. The resistant lines are Vs 350, Vs 438 and Vs 452. The moderately resistant lines are Vs 306, Vs 307, Vs 147, Vs 456, Vs 457 and Vs 458.

The resistant lines were the least preferred for colonization. Growing tips of resistant lines were highly pubescent. Non-

preference and antibiosis mechanisms were the causes for observed resistance in cowpea.

Nitrogen, phosphorus, potassium and protein contents did not differ among resistant and susceptible lines. The resistant lines had more reducing sugars but less non-reducing sugars and total sugars when compared to susceptible lines.

Fecundity of aphids were significantly higher (43.1-50.8) on susceptible lines when compared to resistant lines (9.0-17.6). Total phenol content was high in resistant lines (88 ppm-96 ppm) and low in susceptible lines (64 ppm-69 ppm). Orthodihydroxy phenols also were high in resistant lines (29 ppm-38 ppm) when compared to susceptible lines (23 ppm-27 ppm). Trypsin inhibitors were also observed in resistant lines.

Aphid population was the lowest during March, April and May which coincided with high temperature, low humidity and less rainfall.

Aphid resistance was governed by a single dominant gene. Level of resistance when considered as a quantitative trait, one 'factor' was estimated governing resistance.

All the physical mixtures expressed compensatory effects for level of aphid resistance. There was a positive correlation with level of aphid resistance and (%) obstruction created through physical blending. None of the mixtures exceeded the performance of their pureline components for pods/plot and yield/plot. The mixture Vs 438 + Kanakamony was promising in yield with 83.13% resistance under field conditions.

Two coccinellids - Coccinella arcuata and Menochilus sexmaculatus and one syrphid Ischiodon scutellaris were the most prevalent predators of aphids.

Climate, natural enemies and host plant effect are the major factors affecting development of aphids on cowpea.