BIONOMICS AND MANAGEMENT OF THE WHITEFLY ON SUMMER VEGETABLES

THESIS

By

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CSK HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA
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IN
Partial fulfiliment of the requirements for the degree

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DEDICATED

TO MY

ADORABLE

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CERTIFICATE - I

This is to certify that the thesis entitled `**Bionomics and Management of the Whitefly on Summer Vegetables**` submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the subject of **Entomology** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Ms Sonika Sood** daughter of **Sh. S.K. Sood** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Palampur
Dated: the 6th September, 2002

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CERTIFICATE - II

This is to certify that the thesis entitled '**Bionomics and Management of the Whitefly on Summer Vegetables**' submitted by **Ms Sonika Sood** daughter of **Sh. S.K. Sood** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Agriculture) in the subject of Plant Pathology has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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INTRODUCTION

Whiteflies are the tiny insects which did not attract any attention till 1950. It is only in the last two decades when they posed a major threat to agricultural crops by becoming economically devastating and reducing the yields of various important crops. They have also extended their damage from tropics and subtropics to temperate climates in crops grown under open and protected environment (Lakshmanan, 2000).

The whiteflies are small, soft bodied homopteran insects belonging to family Aleyrodidae. They were first of all described by Reaumer in 1736 (Douglas *et al.*, 1878). The importance of whiteflies as economic pests seems to expand continually and more than 1200 species of whitefly have been reported, amongst which *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) have drawn the maximum attention due to their wider host range and the losses incurred. *B. tabaci* is distributed in the warmer regions (Byrne and Bellows, 1991) whereas *T. vaporariorum* is a serious pest in temperate regions under greenhouses and field crops with warmer summers (Hill, 1987). The nymphs and adults of the whitefly suck large quantities of phloem sap from the under surface of leaves and secrete a sticky viscous liquid, the honeydew, on which dark sooty moulds grow under humid conditions. This sooty mould interferes with the photosynthetic activity of the plant resulting in withering, premature dehiscence and defoliation and finally the death of the plant. They are also reported to act as vectors of several economically important viral plant pathogens (Byrne and Bellows, 1991).

In Himachal Pradesh, Bhalla and Pawar (1977) reported ten species of whiteflies namely *Aleurocanthus husaini* (Corbett), *A. spiniferus* (Quaintance), *A. woglumi* (Ashby), *Aleurolobus barodensis* (Maskell), *A. marlatti* (Quaintance), *B. tabaci* (Gennadius), *Dialeurodes citri* (Riley and Howard), *D. elongata* (Doz.), *Neomaskellia bergii* (Sign.) and *Trialeurodes bicolor* (Lamba) infesting various field crops and fruits. The whiteflies remained a low density pest in the state until last decade when it posed threat for the cultivation of indoor ornamental plants. Recently, Dhillon (1999) reported the serious damage inflicted by *T. vaporariorum* to some vegetable crops and ornamentals under protected and field conditions. The reasons for the spread of *T. vaporariorum* in temperate regions and sudden elevation from an incidental to a primary pest are attributed to the changes in agronomic practices and insecticide usage as well as passive transport of the whitefly on ornamental produce.

The presence of the pest on the underside of leaf makes its control difficult. Moreover, the rapid reproduction rate, longer incubation period, presence of waxy covering and wider host range adds to the difficulties in its management (Johnson *et al.*, 1982). The indiscriminate use of insecticides for its control has led to the development of resistance to various organophosphates, carbamates and synthetic pyrethroids (Elhag and Horn, 1983; Aida-Buitrago *et al.*, 1994; Zheng and Gao, 1995; Denholm and Jesperson, 1998). It has also resulted in the resurgence of the pest making its control more difficult, expensive and environmentally devastating.

Keeping in view the serious damage potential of whiteflies and the faster development of resistance to various insecticides, it was found pertinent to initiate studies on bionomics of the whitefly species present in the region and formulating management strategies against this notorious pest. The following broad objectives were set forth:

- To determine the identity of the whitefly and its host range.
- To study the annual life cycle of the whitefly under laboratory conditions.

- To study the seasonal abundance of whitefly in relation to abiotic factors on important summer vegetables viz. french bean and brinjal under open and protected environment.
- To evaluate some new insecticides and biopesticides for the management of whitefly.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Whiteflies are the pests of cosmopolitan distribution and more than 1200 species are associated with agricultural crops globally (Byrne and Bellows, 1991). As the species encountered in the present investigation has been identified as greenhouse whitefly, *Trialeurodes vaporariorum* Westwood, the literature pertaining to the aspects investigated in respect to greenhouse whitefly is reviewed in this chapter under the following heads:

2.1 Distribution and host range

2.2 Nature of damage

2.3 Biology

2.4 Population dynamics

2.5 Bioefficacy of insecticides

2.1 DISTRIBUTION AND HOST RANGE

Distribution

The greenhouse whitefly, *T. vaporariorum*, a worldwide pest, was first discovered in England in 1856 and later found in the North-Eastern United States in 1870 (Internet Download -1). It is a serious pest in temperate regions under protected cultivation situations and in field crops where the summers are warm enough. It is considered as a New World species having distribution throughout Europe, parts of Africa, Asia, Australasia, North America and South America (Hill, 1987).

In India, the incidence of *T. vaporariorum* was recorded first at Thummantty in the Nilgiri hills of Tamil Nadu on potato (David, 1971). But the first outbreak was reported during 1987 by Mohan *et al.* (1988) from the Nilgiri hills.

In Himachal Pradesh, *T. vaporariorum* remained a low-density pest upto late nineties when Dhillon (1999) identified and categorized it as a serious pest of vegetable crops and ornamentals in and around Solan.

Host Range

T. vaporariorum is a polyphagous pest and feeds on a large variety of herbaceous plants. Russell (1977) reported 249 host plants in 84 families of different crops and ornamental plants infested by the greenhouse whitefly in the temperate regions from six continents. Kim *et al.* (1986) listed 39 species of plants belonging to 27 families to be the hosts of *T. vaporariorum* in greenhouses of Korea Republic. In Crete, Roditakis (1990) observed 128 host plants of *T. vaporariorum* belonging to 48 families mainly to Compositae (20 species), Solanaceae (18 species), Malvaceae (7 species), Leguminosae (7 species) and Cucurbitaceae (4 species).

Le Pelley (1925) found beans as the main food plant of *T. vaporariorum* in greenhouses and fields in Guernsey. Laubert and Trappman (1929) reported azaleas and rhododendrons to be heavily infested by *T. vaporariorum* in Germany. Later in Bulgaria, Popov (1938) recorded it severely infesting tomato and cucumber and to a lesser extent roses and carnation plants. Mc Leod (1938) reported tobacco, tomato and squash as the most preferred hosts in Canada. In Spain, the above mentioned vegetable crops along with melons and cucurbits were recorded as the major horticultural crops attacked by the pest (Isart, 1977). Thereafter, in Bulgaria, Boyadzhiev and Natskova (1984) reported chrysanthemum and gerbera as the hosts of *T. vaporariorum*. In USA, poinsettia, verbena and gerbera were found infested by the whitefly (Baker, 1987). Later, Xu *et al.* (1994) reported paprika and cowpea as the hosts of the whitefly in China. Viscarret and Botto (1996) reported tomato, eggplant and squash as the hosts of *T. vaporariorum* in Argentina. In Korea Republic, cherry tomato was found to be infested with *T. vaporariorum* (Kim *et al.*, 1999). Zabel *et al.* (2001) reported tomato to be heavily infested with the whitefly in Yugoslavia.

In India, the incidence of the greenhouse whitefly was first recorded on potato and thereafter on tomato and soybean in Nilgiri hills (David 1971; Paul and David 1975). Later during the summer months of 1987 an outbreak of the pest was recorded in the Nilgiri region of Tamil Nadu when 20 plant species namely, *Phaseolus vulgaris, Lobelia laechenaillin, Eupatorium glandulosum, Lycopersicon esculentum, Brassica oleraceae* var *capitata, Pelargonium graveolens, Fagopyrum cymosum, Gompherina globosa, Capsella bursapartoris, Rubus ellipticus, R. nivens, R. racemosus, Leucas angularis, Tropaeolum majus, T. minus, Oenothera rosea, Galinsoga parviflora, Taraxum officinale and Bidens pilosa* were recorded to be infested by *T. vaporariorum* by Mohan *et al.* (1988). They also reported *Chenopodium amranticolor, Eupatorium globosum, Fuchis discolor* and *Fuchis globosa* as hosts for adult feeding only. Chandramohan and Nanjan (1992) also observed potato to be heavily infested by *T. vaporariorum* under glasshouse conditions in the Nilgiri hills.

In Himachal Pradesh, Dhillon (1999) reported tomato, brinjal, beans, cucurbits, Fuschia and carnation to be infested by *T. vaporariorum.*

2.2 NATURE OF DAMAGE

The greenhouse whitefly, *T. vaporariorum* inflicts damage to plants by extracting large amount of phloem sap from the leaves and in severe infestation also from the twigs. They produce copious amounts of honeydew which serve as a medium for the growth of sooty mould and lead to discolouration of the leaves hindering the photosynthetic activity of the plants, stunted growth, premature leaf fall and reduced yields (Hussey *et al.*, 1958). *T. vaporariorum* inflicts no damage to the mesophyll cells of the leaves though they become enlarged, oedematous and devoid of chloroplast (Baker and Bur, 1922). The pest was found to select the soft bast of vascular bundles for feeding.

The species seldom transmits viral diseases (Hill, 1987) and there are only a few records of the pest to act as vector of plant diseases. Hernandez and Hernandez (1972) recorded it to transmit the viral disease '*chino de jitomate*' in tomato in Mexico causing deformation, wrinkling and yellowing of leaves and stunting of plants. Zenbayashi *et al.* (1984) reported the whitefly to transmit cucumber yellow virus. Later Meunier and Verhoyen (1987) found it to transmit beet pseudo yellow virus on lettuce. Recently in Colombia, Salazar *et al.* (2000) found *T. vaporariorum* to be the vector of potato yellow vein mosaic virus.

2.3 BIOLOGY

T. vaporariorum passes through four stages during its life-cycle namely egg, nymph, pupa and adult. A wide variation exists in the number of eggs laid by the female as it ranged from 30 to 500 and the incubation period varied between 7 to 10 days. It has pre-oviposition period of 1 to 3 days. The nymphal period lasts for 7-16 days and the pupal period for 6-8 days. The adults live for 3-6 weeks.

Females of *T. vaporariorum* deposit eggs on the underside of leaves in a circular fashion on glabrous leaves although it abandons this pattern on pubescent leaves (Byrne and Bellows, 1991). The eggs being oval in shape and yellow when laid become black prior to hatching (Hill, 1987). The females insert the egg pedicel non-stomatally directly into the parenchymatous tissue of the host plant (Paulson and Beardsley, 1985; Byrne and Bellows, 1991). Hussey and Gurney (1957) reported each female of *T. vaporariorum* to lay 3-5 eggs/ day at 21.2°C, 2-9 at 29.4°C and 7-14 at 32.2°C on tomato in Southern England. Kim *et al.* (1986) observed the females of *T. vaporariorum* to lay 308 eggs on cucumber at 25 °C. At 21°C, Hill (1987) reported the females to lay 200-250 eggs during a life span of 3-6 weeks with a daily average of 8 eggs.

Dhillon (1999) reported the oviposition period of *T. vaporariorum* to last for 4.3±1.0 days with a fecundity of 256.7±6.8 on tomato. Later Ghahari and Hatami (2000) reported the daily rate of fecundity of the whitefly to vary between 1-10 eggs per day with an average of 6.0±1.7 on brinjal in Isfahan.

Hernandez and Hernandez (1972) reported the egg stage to last for 8 days at 23°C and for 6-7 days at 25-26°C. Hill (1987) reported the incubation period to last for 9 days at a lower temperature of 21°C. Natural mortality in the egg stage varied between 5.8-15.9 per cent at 22-27°C with a relative humidity of 79-87 per cent (Treifi, 1986).

T. vaporariorum passes through three nymphal instars (Hendi *et al.*, 1984), the first instar nymphs being pale green in colour, mobile and similar to a scale insect. They possessed functional walking legs with three apparent segments. The later nymphal instars were also pale green and scale like in appearance but were immobile with only one leg segment. They had an orifice on the back for expelling honeydew (Internet Download -1). Hussey and Gurney (1957) reported the nymphal stage to last for 9.3 days at 21.2°C, 7.8 days at 29.4°C and 7.7 days at 32.2°C on tomato in Southern England. On cucumber it was found to last for 8.3 days at 25°C (Kim *et al.*, 1986). The first, second and third instar nymphs measured 0.297, 0.382 and 0.711 mm (Dhillon, 1999). Ghahari and Hatami (2000) observed the first, second and third instar nymphs to occupy 3.4, 3.3 and 2.5 days, respectively at 24±1°C. Treifi (1986) observed mortality to the extent of 5.4-8.2 per cent amongst the nymphal instars at 22-27°C and 79-87 per cent relative humidity.

The fourth nymphal instar termed as pupa (Bemis, 1904; Hill, 1987), was oval in shape, greenish in colour with yellow body pigment of the adult visible below the pupal case and possessed a fringe of glassy setae on dorsal and lateral surface (Byrne and Bellows, 1991). Hussey and Gurney (1957) reported the pupal stage to last for 6 days at 21.2°C and 29.4°C and for 5.5 days at 32.2°C on tomato whereas, Kim *et al.* (1986) observed the pupal stage to last for 7.5 days on cucumber at 25°C. The pupa measured 0.74-0.78 mm in length (Dhillon, 1999). However, the duration lasted for 7.7 days at 24±1°C and 65±5 per cent relative humidity (Ghahari and Hatami, 2000). A natural mortality to the extent of 9.6-12 per cent occurred in the pupal stage at 22-27°C and 79-87 per cent relative humidity (Treifi, 1986).

Adults of *T. vaporariorum* were tiny (1 mm long) snowy white flies with a covering of white waxy powder on wings. They were mostly found on the under surface of the leaves (Hill, 1987). The females lived longer than the males and longevity of the females reared on tomato was of 12-51, 15-57 and 12-33 days at 21.1, 23.8 and 26.6°C, respectively (Hussey and Gurney, 1957). Castresana *et al.* (1981) reported the female longevity to vary between 51-83 days on tomato at 22°C, 80 per cent relative humidity and 12:12 (L: D). Dhillon (1999) reported the longevity of male and female adults to vary between 4-6 and 6-10 days, respectively, on tomato at 25-28°C and 77-84 per cent relative humidity. The life span of females varied from 20-28 days with an average of 26.4 days and that of males from 19-23 days with an average of 20.9 days on brinjal at 24±1°C (Ghahari and Hatami, 2000).

The average length of a generation of greenhouse whitefly was found to be of 32 days (varying from 21 days in summer to 41 days in winter) (Garman and Jewett, 1922). Ghahari and Hatami (2000) observed the total developmental period of 24.1 days on brinjal at 24±1°C. The survival rates from egg to adult were observed to be 70.3, 58.0 and 66.4 per cent at 22, 25 and 30°C, respectively, on cucumber (Kim *et al.*, 1986).

The host plants were found to have a pronounced effect on the selection, feeding, oviposition and development of *T. vaporariorum*. Marendonk and Lenteren (1978) and Boxtel *et al.* (1978) observed that the total mortality was lowest, fecundity highest and development most rapid on brinjal followed by cucumber, tomato and paprika. Kamp and Lenteren (1981) observed the development of the whitefly to be rapid on eggplant and cucumber followed by tomato whereas it was very slow on capsicum. Xu *et al.* (1994) reported that the whitefly preferred tobacco, cucumber, broad bean and cowpea significantly more than paprika with more probing time on preferred hosts.

2.4 POPULATION DYNAMICS

Estimation of Population

Estimation of the population of an insect is vital for understanding the temporal and spatial variations in the population and evaluation of different pest management tools.

Yamada *et al.* (1979) in studies on spatial distribution of different stages of *T. vaporariorum* observed that eggs and adults of the whitefly had a strong tendency to aggregate on the apical leaves of the plants whereas the nymphs were distributed less aggregately on leaves below those infested by eggs and adults. Xu *et al.* (1985) reported similar observations on beans, *Phaseolus vulgaris*. They also observed the third nymphal instar to be much less aggregated than the first instar nymphs due to high mortality rate in successive nymphal instars. Kim *et al.* (1986) observed the presence of adults and eggs on the apical, nymphs on the central and pupae on the basal leaves in cucumber after 40 days of transplanting.

Moreno (1985) in Spain observed leaflets to be the best sampling unit for *T. vaporariorum* in case of tomato and bean (except while the plants were very small), but the whole plant served as the best sampling unit in case of eggplant and cucurbits. Sangha *et al.* (1995) suggested visual counts of adults and different stages of *Bemisia tabaci* from leaves one each from upper, middle and lower canopy to be the best sampling technique in cotton. Kim *et al.* (1999) suggested a similar technique for sampling *T. vaporariorum*. They found the visual counts of nymph, pupa and adult from upper (150-180 cm), middle (90-120 cm) and lower (30-60 cm) parts of the plant to give a good estimate of the distribution of the pest population in cherry tomato.

Monitoring of adult population

T. vaporariorum adults exhibited a positive colorataxis and got attracted to bright yellow and yellow colour (Webb *et al.* 1985, Edigaryn *et al.* 1988). Yano *et al.* (1984) found yellow sticky boards of 30×30 cm to be efficient for monitoring the adults of whitefly. Georgeiv (1984) observed the sticky trap squares (25×25 cm) or rectangles (20×30 cm) made of polyvinyl chloride to be highly effective in trapping the adults of *T. vaporariorum.* Natskova (1986) demonstrated the effectiveness of the yellow sticky traps for its monitoring and the control.

Webb *et al.* (1985) observed several polybute type adhesives to be suitable in trapping the adults of *T. vaporariorum.* Roa *et al.* (1991) observed polyisobutane and castor oil as the most effective adhesives for trapping *B. tabaci.* The placement of the traps also influences the count significantly. Espanol and Corredor (1989) suggested that the traps should be placed from day 1-30 in lower section of the plants, from day 31-50 in medium section and from day 51-112 in the higher section of the tomato plants. Gillespie and Quiring (1992) observed the traps placed slightly below the tops of the plants to be effective in monitoring the adult population. However, Kim *et al.* (1999) suggested the placement of the traps 10 cm above the top of the canopy for effective monitoring of the whitefly adults.

Seasonal abundance

The number of generations of *T. vaporariorum* in a year depends mainly upon the climatic conditions prevailing in a particular region and the availability of the host plants. In Bulgaria, Khristova (1967) reported the pest to complete 8-10 generations in a year. In Spain, *T. vaporariorum* completed 7-8 generations in open and 8-10 generations in the greenhouse on different horticultural crops (Isart, 1977).

Garman and Jewett (1922) found *T. vaporariorum* to breed continuously throughout the year. However, the pest was found to overwinter in different stages under varying environmental conditions. In Australia, *T. vaporariorum* was found to overwinter in egg and adult stage in greenhouses (Tonnoir, 1937), whereas in Bulgaria, it was found to overwinter on plants in greenhouse and migrate to fields in spring returning to the greenhouse in autumn with the onset of cold weather (Khristova, 1967). In United Kingdom, Hussey (1981) reported the pest to survive the winters on outdoor weeds of glasshouses and after mild winters, the infestation in glasshouses originated from the overwintering sources. Choe and Park (1985) in the central and southern parts of Korea Republic observed *T. vaporariorum* to survive the winters in pupal stage whereas on Jeju Island and southern most coastal tip of Korea the pest was found to overwinter in any stage.

The study of seasonal incidence and abundance of the pest is essential for evolving timely and appropriate control strategies. The population of the greenhouse whitefly fluctuates in different seasons due to variation in climatic conditions. In Kentucky greenhouses, *T. vaporariorum* was found to increase slowly from January to April after which there was a marked increase which lasted until autumn (Garman and Jewett, 1922). In Japan, Nakata (1994) reported *T. vaporariorum* immigration in early June with adults appearing in mid-September on potato. Dhillon (1999) reported the activity of whitefly to begin on tomato and french bean by the end of August with the maximum population being during early to mid October declining thereafter by mid November in the mid-hill regions of Himachal Pradesh.

Influences of abiotic factors

The abiotic factors like temperature, relative humidity and sunlight have direct influences on the development and abundance of *T. vaporariorum*. Webber (1931) found relative humidity to affect the nymphs when the waxy secretions were not laid while the pupae were found to be resistant to the external conditions. Speyer *et al.* (1946) found high relative humidity to prolong the life cycle of the pest. Yano (1981) found the developmental period to be influenced by temperature greatly and the period from egg to adult emergence reduced from 60 to 20 days with an increase in temperature from 15-27°C. Further increase in temperature to 30°C increased the developmental period to 32 days. Survival also increased considerably from 19 to 81 per cent in the temperature range of 15-27°C and fell sharply to 3 per cent at 30°C. He also observed that in the temperature range of 15-30°C, the life span of adult females ranged between 16-40 days and the mean fecundity from 115-304 eggs per female. Noldus *et al.* (1985) reported the temperature to influence adult mobility and observed correlation between day temperature and the rate of movement of the adults of *T. vaporariorum*. Yano (1989) evaluated two temperature regimes of 30 & 20°C and 25 & 10°C during day and night, respectively and found that the survival among eggs and nymph decreased in low temperature regime whereas the intrinsic rate of natural increase was higher in the upper temperature regime.

2.5 BIOEFFICACY OF INSECTICIDES

Owing to the serious threat posed by the whiteflies to agriculture, efforts have been made since long for its control using different insecticides. In Bulgaria, Levterov (1967) in a test using organophosphates against *T. vaporariorum* found the emulsion sprays of endosulphan to be the most effective. Smith *et al.* (1970) reported the granular application of aldicarb to give a good control of the whitefly on tomato, cucumber, lettuce, lima bean and chrysanthemum in greenhouses of Maryland. Sleesman and Lindquist (1971) achieved the effective control of the greenhouse whitefly on tomato for at least 100 days by the use of 10 per cent granular formulation of aldicarb (Temik). Six to eight applications of Malathion at 10-12 days interval destroyed *T. vaporariorum* completely on flowering and decorative plants in the glasshouses of Moscow (Kosterina, 1976). Tremblay (1976) reported a rotation of oil sprays, quimethionate, malathion, synthetic pyrethroids and methomyl for the complete control and prevention of development of resistant population of *T. vaporariorum*.

Ekbom (1979) found two applications of a juvenile hormone kinoprene (Enstar 5 EC) at 0.05 per cent to be effective against the larval stages of *T. vaporariorum*. Fungicides mancozeb and chlorothalonil used for the control of mould fungi was also found to have ovicidal activity and toxicity to nymphs of *T. vaporariorum* (Sakai, 1979). Movsesyan (1982) found primiphos methyl (Actellic) to give an excellent control of the pest on ornamentals in greenhouses of USSR. In another study Collman and All (1982) found the effectiveness of kinoprene against the second and third instar nymphs and the early pupae. They also reported the moult inhibitors permethrin and penncapthrin to control second and third instar nymphs and to certain extent the adults. Puritch *et al.* (1982) found Safer (a soap formulation) to give 94 per cent mortality of nymphs and adults and 82.5 per cent mortality of the pupae of *T. vaporariorum*. In Japan, 2-3 high volume foliage sprays of buprofezin, a growth regulator, at 0.025 per cent at weekly intervals in late June was found to give an effective control of the nymphs of *T. vaporariorum* on beans (Naba *et al.*, 1983). In 1988, Dirlbeck reported a microbial formulation of *Beauveria bassiana* to be effective against *T. vaporariorum* in Czechoslovakia.

In greenhouses of Georgia, imidacloprid, an insecticide with novel mode of action, was found effective against the whitefly on poinsettias as a foliar application of 240 SC at 0.05 per cent formulation (Oetting and Anderson, 1990). In Colombia, Aida-Buitrago *et al.* (1994) reported *T. vaporariorum* to be resistant to monocrotophos, methamidophos, profenophos, methomyl, cypermethrin and deltamethrin. In 1994, Cresswell *et al.* observed a single dose of acephate (80 mg/l) to kill all the immature stages of *T. vaporariorum* in 10 days. Later in California, acephate and biphenate (a pyrethroid) were found to reduce the lifetime fecundity of the greenhouse whitefly by 29 per cent and 30 per cent, respectively (Omer and Leigh, 1995). Seed treatment of *Phaseolus vulgaris* with imidacloprid (70 WS formulation) effectively checked the whitefly population for 35 days whereas granular application gave a complete control up to 55 days (Orozco *et al.*, 1998). Cahill *et al.* (1996) reported *T. vaporariorum* to be resistant to various organophosphates, carbamates, pyrethroids and endosulfan.

Zheng *et al.* (1997) worked out the LC_{50} values of dimethoate to be 0.859 mg/g against the adults of *T. vaporariorum* in China. Ota *et al.* (1999) reported Botani Gard TM, a preperation of *B. bassiana*, effective against *T. vaporariorum* on tomato in Italy. Formulations of two botanicals Derris and Neem were found to result in 82.2 and 68.9 per cent mortality amongst the nymphs of whitefly (Bene *et al.*, 2000). Zabel *et al.* (2001) reported acetamiprid to be effective in controlling *T. vaporariorum* on tomatoes. Under protected conditions on salvia, imidacloprid (0.004%), dimethoate (0.03%) and *B. bassiana* (7.5×10^6 cfu/ ml) proved very effective in suppressing the adult population of *T. vaporariorum* (Anon., 2001).

MATERIAL AND METHODS

MATERIAL AND METHODS

The present studies were conducted in the laboratory of Department of Entomology and the experimental farm of the Department of Entomology and Landscaping Unit, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur at an altitude of 1290 m a m s l, between 32.11° North latitude and 76.23° East longitude during 2001-02. For recording the host range of the whitefly, field crops, vegetable crops, ornamentals, medicinal plants and weeds in and around Palampur were observed.

RAISING OF CROPS

French bean and brinjal were raised under open (field) and protected (polyhouse) environment by following all agronomic practices as per the Package of Practices for the Vegetable crops (Anon., 1995) in insecticide free environment.

French bean: Two crops of french bean (cv. Contender) were raised as spring-summer and autumn crop. Sowing of spring-summer crop was done on March 13 and 15, 2001 under protected and open environment and on August 5 and September 13 for autumn crop, respectively. A spacing of 45×10 cm was followed.

Brinjal: Summer crop of brinjal (cv. Arka Nidhi) was raised by transplanting 30 days old seedlings under protected and open environment on April 10 and 24, 2001, respectively with a spacing of 60×45 cm.

LABORATORY REARING OF THE WHITEFLY

For laboratory studies, the whitefly *T. vaporariorum* was reared on french bean (cv. Contender) plants raised in plastic pots (9.5×9.5 cm). The pots were filled with soil having adequate nutrients and were kept in abundant sunshine to facilitate the growth of the plants. Stock culture of whiteflies was raised by exposing the 10 days old french bean plants for 24 hours to the adults in glass chimneys (20×15 cm) at a regular interval. Thereafter the adults were removed and the plants were shifted to nylon mesh rearing cages (45×45×45 cm) for rearing to adult stage.

3.1 IDENTITY OF THE WHITEFLY

The characteristic features of pupal cases were used for generic classification of whiteflies. The permanent mounts of the pupal cases were made in order to get whitefly species identified. The pupal cases were gently removed from the leaf surface after slight wetting (to avoid any breakage) with a camel hair brush and were discoloured in 10 percent sodium hydroxide solution for 10 minutes. Thereafter, they were transferred to glacial acetic acid for 2 minutes to remove the waxy coating. The pupal cases were then picked up with a needle having blunt end and placed in 1.0 per cent acid fuschin dye for staining. They were again transferred to glacial acetic acid for a few seconds to get rid of the excess stain and for dehydration. The specimens were then cleared in carboxylol (mixture of carbolic acid and xylol in the ratio of 1:3) for 10-15 minutes. Finally the stained pupal cases were mounted on a slide using DPX mountant by keeping the dorsal side upward. The mounts were sent to Dr B.V. David, Consultant, Chennai for identification.

3.2 HOST RANGE

The host range of the whitefly was recorded under protected (polyhouse/ greenhouse) as well as open environment (field conditions) in and around Palampur throughout the year. Observations were made on the plants utilized for breeding as well as for adult feeding alone. Counts of immature stages (nymph and pupa) and adults were recorded by examining undersides of three leaves, one each from lower, middle and upper canopy of the five randomly selected plants as per the method suggested by Sangha *et al.* (1995). For establishing the hosts exclusively utilized for adult feeding, the adults were enclosed for 2-3 days on host plants to observe their survival. These observations were made at fortnightly interval to record the incidence and to determine the period of activity on different host plants. The abundance of whitefly on different host plants under open and protected environment was also ascertained by using a scale (Table 1) as suggested by Sood and Kakar (1990).

Table 1. Parameter for ascertaining abundance of the whitefly

Whitefly population	Intensity of infestation
<15	Low
15-30	Medium
30-45	High
>45	Very high

3.3 POPULATION DYNAMICS

3.3.1 Seasonal Abundance

Observations on the population counts of immature stages (nymph and pupa) and adults were made on french bean and brinjal as per the method described in section 3.2 on ten randomly selected plants at weekly interval. The level of infestation was also recorded by observing 50 plants. These observations were utilized to work out infestation index as per the method outlined by Sood and Bhalla (1996):

$$\text{Infestation index} = \frac{[\text{Number of (Nymphs and Pupae)} + \text{Adults}] \times \%\ \text{Plant Infestation}}{100}$$

3.3.2 Relationship of Abiotic Factors with Whitefly Population

Relationship of population counts of the whitefly with abiotic factors of the environment namely, minimum and maximum temperature and relative humidity under protected and open environment were worked out. In addition relationship with rainfall and wind velocity was also established under open environment.

3.3.3 Vertical Distribution of the Whitefly Population in French Bean and Brinjal

Distribution of different developmental stages of the whitefly within the plant canopy was determined. Observations recorded on population count coinciding to the peak period of activity and one before and after that were analyzed and pooled for french bean and brinjal crops in different cropping situations to work the proportion of nymphs, pupae and adults in different canopy heights.

3.3.4 Monitoring of adult population by using yellow sticky traps

The adults were monitored by using yellow sticky traps (9×12") with castor oil as adhesive at weekly interval by exposing traps for 24 hours under open as well as protected environment. Correlation of trap count was also worked out with the weather factors and the population counts under respective cultivation situation in french bean and brinjal.

3.4 BIOLOGY

3.4.1 Description and Measurements of Developmental Stages

Colour, shape and size of different developmental stages of the whitefly was observed under a stereo binocular microscope. The length and breadth of the egg, nymph, pupa and adult was measured using an ocular micrometer.

3.4.2 Annual life-cycle of the whitefly

Annual life-cycle of the greenhouse whitefly was studied under laboratory conditions on french bean (cv. Contender) throughout the year starting from February, 2001. French bean plants (n=3) exposed to the adults as per method described earlier for 24 hours were utilized to record the observations on various aspects of biology. A pre-oviposition period of one day was observed for continuing the next generation. A cohort of about one hundred eggs was marked to record subsequent observations.

Egg: Daily observations were recorded on the eggs to determine the incubation period and hatchability. Mean incubation period was established as the period between oviposition and 50 per cent egg hatching.

Nymph: Observations were recorded on the number of instars. Daily observations were recorded to determine the duration and survival of respective nymphal instars. The mean duration was established when 50 per cent of the individuals moulted to the next stage and total nymphal period and nymphal survival was also worked out.

Pupa: The mean duration of pupal period was established as the period between pupal formation to 50 per cent adult emergence. Observations were also recorded on the survival in pupal stage.

Adult: Total number of adults emerged were recorded to establish the total survival. The sex ratio was also recorded in different generations. 10 pairs of adults were enclosed in glass chimneys (n=3) on french bean plants and observations were recorded on longevity and fecundity of the adults.

3.4.3 Life Cycle of the Whitefly on Summer Vegetables

Life-cycle of the whitefly was studied on six summer vegetable crops namely, brinjal, capsicum, chilli, cucumber, french bean and tomato. The method used for rearing the greenhouse whitefly was the same as detailed earlier. The following observations were recorded:

Ovipositional preference: Differential behavior of *T. vaporariorum* adults to utilize six summer vegetables (listed above) for deposition of eggs was studied under free choice test. Potted plants of the six vegetables were exposed in nylon mesh cages (45×45×45 cm) to about 200 females (2-3 days old) for 24 hours, replicating thrice. Observations on the number of eggs deposited were recorded on each host plant and the proportion of eggs laid on each host was worked out to determine the oviposition preference of adult females to different hosts.

Developmental biology: Observations were recorded on different aspects of developmental biology of the whitefly on summer vegetables at a room temperature varying between 28-30°C. One generation of *T. vaporariorum* was reared on each host and the adults that emerged were used to initiate the studies on developmental biology on respective hosts by following the procedure outlined in this chapter under rearing of the whitefly. Observations were recorded on the incubation period, hatchability, duration and survival of nymphal and pupal stage, adult longevity and fecundity. Growth indices on each host were worked out with the help of formulae given by Sharma *et al.* (1982) to determine the suitability of the host plants:

$$\text{Nymphal Growth Index (NGI)} = \frac{\text{Nymphal Survival (\%)}}{\text{Total Nymphal Period (days)}}$$

$$\text{Total Growth Index (TGI)} = \frac{\text{Adult Emergence (\%)}}{\text{Total Developmental Period (days)}}$$

3.5 BIOEFFICACY OF INSECTICIDES

3.5.1 Intrinsic Toxicity

Intrinsic toxicity of six insecticides namely, acephate, acetamiprid, dimethoate, imidacloprid, MTI-446 and triazophos was studied against the adults of the greenhouse whitefly under laboratory conditions. Leaf dip bioassay as described by Cahill *et al.* (1995) was followed. Leaf discs of french bean (dia 4.5 cm) were dip treated for one minute in each test concentration, shade dried and placed on a bed of agar gel (1.3%) in glass petri dishes (1.5×5.0 cm) by keeping the ventral surface of the leaf discs exposed for feeding. Each test concentration was replicated three times. One set of leaf discs without any treatment was kept as check with equal number of replications. About 10-15 adults (1-2 days old), inactivated by exposing to low temperature in freezer, were transferred to each petri dish which were then covered with close fitting ventilated lids and secured tightly with rubber bands. As the adults recovered, the dishes were inverted to facilitate normal orientation and feeding of adults. All the sets were maintained at 25±1°C and 16:8 (L:D) photoperiod in BOD incubator and mortality was recorded after 24 hours of exposure. For each bioassay a minimum of five concentrations were used. Preliminary experiments were conducted to ascertain concentrations of insecticides giving mortality range of 20-80 per cent for each insecticide. For working out LC_{50} and LC_{90} values the mortality data were subjected to probit analysis detailed by Finney (1971).

3.5.2 Field Efficacy

Field efficacy of the insecticides used for bioassay studies and a growth regulator (buprofezin), a microbial insecticide (*Beauveria bassiana*) and a botanical insecticide (azadiractin) were evaluated against greenhouse whitefly on french bean (cv. Contender) under polyhouse condition during May 2002. The formulations used are given in Table 2. The temperature in the polyhouse ranged between 28-35°C and relative humidity between 38-44%. Crop grown in 2 m rows spaced at 45 cm was converted to plots having two rows each with the third as border row. One plot was also kept as untreated check. All the treatments were replicated thrice. Pre treatment counts of immature stages (nymph and pupa) and adults were recorded from randomly selected five plants in each plot. Post treatment counts of immature stages and adults were recorded 1, 7 and 14 days after treatment. Reduction in population over untreated check was worked out as per the modified formula of Abbott given by Fleming and Retnakaran (1985):

$$\text{Per cent reduction in population} = 1 - \left(\frac{\text{Post-treatment population in treatment}}{\text{Pre-treatment population in treatment}} \times \frac{\text{Pre-treatment population in check}}{\text{Post-treatment population in check}} \right) \times 100$$

Table 2. Insecticides evaluated against *Trialeurodes vaporariorum*

Common name	Trade name	Formulator
Acephate	Asataf 75% SP	Rallis India Limited
Acetamiprid	Pride 20% SP	De- Nocil Crop Protection Limited
Azadirachtin	Achook 0.15%EC	Godrej Agrovet Limited
B. bassiana	Daman (c.f.u. 2×10^9)	International Panacea Limited
Buprofezin	Applaud 25EC	Rallis India Limited
Dimethoate	Rogor 30 EC	Rallis India Limited
Imidacloprid	Confidor 200 SL	Bayer India Limited
Triazophos	Hostathion 40 EC	Aventis Crop Science India Limited
-*	MTI- 446 20 WP	Rallis India Limited

* Coded Sample

METEOROLOGICAL DATA

In the laboratory, the minimum and maximum temperature and relative humidity were recoded with the help of thermo-hygrograph (Hisamatsu Manufacturing Company, Japan) throughout the course of studies (Appendix I).

Meteorological data in respect to minimum and maximum temperature, relative humidity, rainfall, sunshine and wind velocity during 2001-02 (Appendix II) under field conditions (open environment) were procured from the Meteorological Observatory of the University. The data on minimum and maximum temperature and relative humidity under protected environment (polyhouse conditions) was procured from the Department of Agricultural Engineering (Appendix III).

RESULTS

RESULTS

The present investigation entitled 'Bionomics and Management of the Whitefly on Summer Vegetables' was undertaken to study the biology, host range, population build-up of the whitefly and to evaluate some insecticides for its management. The results obtained on various aspects are being presented in this chapter.

4.1 IDENTITY OF THE WHITEFLY

The whitefly was identified as *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) on the basis of the characteristics of the pupal case. The pupal case, when viewed from the side, appeared slightly convex and elevated above the leaf surface. The pupal case had waxy setae like projections and waxy fringe all over without any dark area (Plate 3).

4.2 HOST RANGE

Field surveys were conducted during 2001-02 in and around Palampur to study the occurrence and host range of the greenhouse whitefly, *T. vaporariorum*.

A perusal of the data contained in Table 1 revealed that the whitefly was prevalent on 44 species of plants belonging to 20 families including Acanthaceae (3 species), Campalunaceae (1), Compositeae (7), Convolvulaceae (1), Cucurbitaceae (2), Euphorbiaceae (1), Geraniaceae (1), Labiatae (2), Leguminosae (2), Lythraceae (1), Malvaceae (4), Nycataginaceae (1), Onagraceae (2), Polygonaceae (1), Primulaceae (1), Saxifragaceae (1), Solanaceae (8), Tropeaolaceae (1), Verbenaceae (3) and

Table 1. **Host plants of *Trialeurodes vaporariorum* in and around Palampur**

S.No.	Common name	Scientific name	Family
Vegetable crops			
1.	Brinjal	*Solanum melongena*	Solanaceae
2.	Cucumber	*Cucumis sativus*	Cucurbitaceae
3.	French bean	*Phaseolus vulgaris*	Leguminosae
4.	Okra	*Abelmoschus esculentus*	Malvaceae
5.	Summer squash	*Cucurbita pepo*	Cucurbitaceae
6.	Tomato	*Lycopersicon esculentum*	Solanaceae
Field crops			
1.	Mash	*Phaseolus mungo*	Leguminosae
2.	Potato	*Solanum tuberosum*	Solanaceae
Medicinal plants			
1.	Mentha	*Mentha pipereta*	Labiatae
2.	Safed Dhatura	*Datura stramonum*	Solanaceae
3.	Tobacco	*Nicotiana tobaccum*	Solanaceae
Ornamentals			
1.	Abutilon	*Abutilon hybridum*	Malvaceae
2.	Bleeding heart	*Clerodendrum thomsonai*	Verbenaceae
3.	Bougainvillea	*Bougainvillea spectabilis*	Nycataginaceae
4.	Calendula	*Calendula officinalis*	Compositae
5.	Chrysanthemum	*Dendranthema grandiflora*	Compositae
6.	Cup and saucer	*Holmisleioldia sanguinea*	Campanulaceae
7.	Cuphea	*Cuphea pinnata*	Lythraceae
8.	Dahlia	*Dahlia variabilis*	Compositae
9.	English Daisy	*Bellis perennis*	Compositae
10.	Flemingo plant	*Jacobinia carnea*	Acanthaceae
11.	Fuschia	*Fuschia magellanica*	Onagraceae
12.	Geranium	*Pelargonium hortorum*	Geraniaceae
13.	Hibiscus	*Hibiscus rosa-sinensis*	Malvaceae
14.	Hollyhock	*Althea rosea*	Malvaceae
15.	Hydrangea	*Hydrangea macrophylla*	Saxifragaceae
16.	Indian Pink	*Ipomoea purpurea*	Convolvulaceae

17.	Jerusalem cherry	*Solanum pseudo-capsicum*	Solanaceae
18.	Nasturtium	*Tropaeolum majus*	Tropeaolaceae
19.	Ornamental brinjal	*Solanum mamossum*	Solanaceae
20.	Pachy-stachys	*Pachystachis lutea*	Acanthaceae
21.	Pansy	*Viola tricolor*	Violaceae
22.	Petunia	*Petunia hybrida*	Solanaceae
23.	Poinsettia	*Poinsettia pulcherrima*	Euphorbiaceae
24.	Pol-ka-dot	*Hypoestes phyllostachya*	Onagraceae
25.	Primula	*Primula spp.*	Primulaceae
26.	Ribbon bush	*Homalocladium platycladium*	Polygonaceae
27.	Salvia	*Salvia officinalis*	Labiatae
28.	Shrimp plant	*Belliperone guttata*	Acanthaceae
29.	Variegated duranta	*Duranta sellowiana*	Verbenaceae
Weeds			
1.	*Eupatorium*	*Eupatorium adenophorum*	Compositae
2.	Krishna-neel	*Erigeron canadensis*	Compositae
3.	Neela Phulnu	*Ageratum coinyzoids*	Compositae
4.	Wild sage	*Lantana camara*	Verbenaceae

Violaceae (1). These hosts included six vegetable crops, two field crops, twenty nine ornamentals, three medicinal plants and four weed hosts under open/ field and protected environment.

4.2.1 Hosts under Open Environment/ Field Conditions

T. vaporariorum infested 24 plants under open environment/ field conditions (Table 2) comprising of vegetables (6), field crops (2), ornamentals (12), medicinal plants (1) and weeds (3). Incidence of greenhouse whitefly was low (<15 nymphs, pupae and adults/ three leaves) on 8 plant species, moderate (15-30/ three leaves) on 9 plant species. But the population levels of high to very high (mean population >30/ three leaves) was recorded on 7 host plants comprising of 5 ornamentals and 2 vegetable crops. Amongst the ornamental plants, mean population was maximum on hydrangea (*Hydrangea macrophylla*) (145.3/ three leaves) followed by primula (*Primula* spp.) (143.8) and hollyhock (*Althea rosea*) (125.9). Among the vegetable crops, tomato supported the highest population (57.7/ three leaves). *T. vaporariorum* remained active from March to October-November on different hosts but it bred throughout the year on two ornamental plants namely, fuschia and salvia.

4.2.2 Hosts under Protected Environment

Under protected environment, incidence of greenhouse whitefly was observed on 23 plants comprising of vegetable crops (4), ornamental plants (17), medicinal plants (1) and weeds (1) (Table 3). *T. vaporariorum* remained a low density pest on six plants, whereas moderate to high incidence was recorded on twelve host plants. On tomato, fuschia and patchy stachys, incidence was recorded to be high, whereas incidence was very high on cucumber (*Cucumis sativus*), flemingo plant (*Jacobinia carnea*), primula (*Primula* spp.), Abutilon (*Abutilon hybridum*) and variegated duranta (*Duranta sellowiana*), where the mean population per three leaves was more than 45, highest being on abutilon (252.6). Fuschia and salvia also provided continuous regular support to the breeding population of *T. vaporariorum* throughout the

Table 2. **Seasonal activity of *Trialeurodes vaporariorum* on different host plants under open environment**

S. no.	Host plant	Period of activity	Peak period	Mean Population per three leaves		
				Nymph + Pupa	Adult	Total
Vegetable crops						
1.	Brinjal	May-September	June	12.2 (2.0-53.4)	9.1 (2.3-14.7)	21.3 (4.8-70.2)
2.	Cucumber	April-June	May	24.0 (5.0-27.0)	21.3 (5.0-42.0)	45.3 (10.0-65.5)
3.	French bean	April-June September-January	June	10.5 (0.4-28.8)	12.1 (0.6-13.4)	22.6 (3.6-55.6)
4.	Okra	May-July	June	3.1 (1.3-6.3)	3.1 (2.0-4.0)	6.2 (4.3-8.6)
5.	Summer squash	April-May	April	16.0 (2.0-23.0)	12.3 (5.0-38.0)	28.3 (6.0-58.0)
6.	Tomato	May-June October-January	June	38.6 (17.5-60.3)	19.1 (15.3-25.0)	57.7 (40.7-76.6)
Field crops						
1.	Mash	August-September	September	3.9 (1.3-8.0)	4.3 (3.3-5.0)	8.2 (4.6-12.5)
2.	Potato	March-April	April	2.3 (1.0-10.0)	3.5 (2.0-6.0)	5.8 (3.0-10.0)
Ornamentals						
1.	Cup and saucer	April-June	May	5.5 (1.0-9.0)	9.7 (4.5-13.5)	15.2 (5.5-22.5)
2.	Cuphea	February-June	April	5.5 (2.0-8.3)	6.5 (3.0-17.5)	12.0 (5.0-22.5)
3.	Flemingo plant	April-July	May	36.9 (2.0-63.0)	32.1 (11.5-47.0)	69.0 (14.8-103.0)
4.	Fuschia	Throughout the year	April	15.7 (5.0-19.3)	7.3 (1.3-26.0)	23.0 (7.7-40.7)
5.	Geranium	March-June	April	6.5 (1.0-10.3)	4.7 (2.0-15.0)	11.2 (2.0-20.5)
6.	Hibiscus	May-July	June	7.6 (2.0-12.0)	2.2 (1.0-3.0)	9.8 (3.0-14.0)
7.	Hollyhock	February-September	April	72.3 (5.0-145.0)	53.6 (14.0-125.0)	125.9 (19.0-225.0)

8.	Hydrangia	February-September	August	78.1 (2.0-223)	67.2 (10-179.5)	145.3 (10-240.5)
9.	Jerusalem cherry	March-June	April	5.3 (1.0-10.0)	5.3 (3.0-8.0)	10.6 (3.0-16.0)
10.	Nasturtium	March-June	April	14.4 (3.5-27.5)	20.7 (7.5-30.0)	35.1 (15.5-57.5)
11.	Primula	March-August	April	48.0 (2.0-84.0)	95.8 (10-205)	143.8 (10.0-247.5)
12.	Salvia	Throughout the year	April	17.5 (2.0-36.0)	6.3 (4.0-28.0)	23.8 (9.0-67.0)
Medicinal plants						
1.	Mentha	May-July	June	4.5 (1.0-3.5)	12.0 (4.0-14.7)	16.5 (3.4-15.5)
Weeds						
1.	*Ageratum*	March-July	June	5.5 (1.0-7.7)	9.7 (2.3-15.5)	15.2 (3.0-20.7)
2.	*Eupatorium*	April-July	April	8.9 (2.5-13.0)	10.2 (1.5-22.3)	19.1 (4.0-27.7)
3.	Wild sage	May	May	2.0 (2.0-4.0)	8.5 (6.0-11.0)	10.5 (6.0-15.0)

* Figures in parentheses are minimum and maximum population levels

Table 3. **Seasonal activity of *Trialeurodes vaporariorum* on different host plants under protected environment**

S. No.	Host plant	Period of activity	Peak period	Mean Population per three leaves		
				Nymph + Pupa	Adult	Total
Vegetables crops						
1.	Brinjal	May-October	June and September	7.6 (0.6-46.8)	15.3 (1.4-37.8)	22.9 (1.4-56.4)
2.	Cucumber	April- June	May	28.0 (4.2-34.0)	24.5 (6.5-52.0)	52.5 (11.0-70.5)
3.	French bean	April-June August-November	June	8.4 (0.6-37.6)	5.3 (1.8-10.8)	13.7 (1.8-41.2)
4.	Tomato	October-January	December	33.1 (5.3-39.8)	4.0 (3.0-5.0)	37.1 (8.6-101.7)
Ornamentals						
1.	Abutilon	February April-October	July	197.3 (10.0-496.0)	55.3 (23.5-180.0)	252.6 (45.5-500.0)
2.	Bleeding heart	April-May	May	17.0 (14.0-19.0)	7.3 (7.0-8.0)	24.3 (22.0-26.0)
3.	Cuphea	February-June	March	8.7 (2.0-14.7)	10.95 (2.5-22.3)	19.65 (4.5-28.0)
4.	English Daisy	February	February	2.8 (2.0-5.5)	8.3 (7.5-9.0)	11.1 (9.0-13.0)
5.	Flemingo plant	April-July	May	55.0 (5.0-95.0)	48.5 (14.0-63.0)	103.5 (18-173)
6.	Fuschia	Throughout the year	April	23.5 (4.0-22.0)	9.8 (2.0-29.0)	33.3 (6.0-48.8)
7.	Geranium	March-November	April	8.0 (2.0-14.5)	6.9 (0.5-22.0)	14.9 (3.0-26.7)
8.	Hibiscus	March-October	May	10.5 (1.5-18.0)	5.4 (1.0-8.0)	15.9 (2.0-22.0)
9.	Ornamental brinjal	April-May	May	8.3 (2.0-13.0)	8.3 (5.0-10.0)	16.6 (7.0-21.0)
10.	Pachy-stachys	April-May	April	12.0 (10.0-14.0)	20.0 (12.0-28.0)	32.0 (22.0-42.0)
11.	Poinsettia	February-March	February	12.7 (5.0-19.0)	12.3 (10.0-15.0)	25.0 (15.0-31.0)
12.	Pol-ka-dot	March-April	April	5.5 (1.0-10.7)	5.1 (3.7-7.7)	10.6 (3.7-18.4)

13.	Primula	March-August	April	67.2 (5.0-96.0)	104.8 (20.0-190.0)	172.0 (27.0-285.0)
14.	Ribbon bush	March	March	4.2 (3.7-4.7)	3.5 (2.3-4.7)	7.7 (6.0-9.4))
15.	Salvia	Throughout the year	April	23.5 (3.0-41.0)	10.3 (4.5-34.0)	3.8 (8.0-98.0)
16.	Shrimp plant	March-April	March	3.8 (3.0-4.5)	12.8 (12.5-13.0)	16.6 (16.0-17.0)
17.	Variegated duranta	July-September	August	108.3 (4-303)	42.0 (26-59)	150.3 (30-340)
Medicinal plants						
1.	Tobacco	May-June	May	7.3 (2.0-15.0)	33.3 (2.0-6.0)	10.6 (3.0-17.0)
Weeds						
1.	Krishna Neel	October-February	December	13.9 (2.5-23.0)	5.2 (2.0-8.5)	19.1 (4.5-28.0)

* Figures in parentheses are minimum and maximum population levels

year, whereas on others the pest remained active from March to October. During winters, the incidence of greenhouse whitefly was also recorded on a weed, *Erigeron canadensis* growing around the glasshouses.

4.2.3 Hosts Utilized as Adult Food

Among the listed hosts of the whitefly, six host plants namely, bougainvillea (*Bougainvillea spectabilis*), calendula (*Calendula officinalis*), chrysanthemum (*Dendranthema grandiflora*), dahlia (*Dahlia variabilis*), dhatura (*Datura stramonum*) and pansy (*Viola tricolor*) were utilized by *T. vaporariorum* for adult feeding only as no immature stages (nymph and pupa) were observed on these hosts except the adults (Table 4). Apart from bougainvillea which had moderate incidence, *T. vaporariorum* remained low density pest on all the hosts utilized for adult feeding.

Table 4. Seasonal activity of *Trialeurodes vaporariorum* on host plants used for adult feeding only

S. No.	Common name	Period of activity	Peak period	Mean adult population per three leaves
1.	Bougainvillea *	February	February	19.5 (16.0-23.0)
2.	Calendula	March-April	March	3.5 (2.0-5.0)
3.	Chrysanthemum*	April	April	7.0 (7.0)
4.	Dahlia	April-June	May	8.5 (5.0-12.0)
5.	Dhatura	September	September	4.85 (4.7-5.0)
6.	Pansy	March-April	March	2.8 (1.0-4.5)

* Under protected environment

4.3 POPULATION DYNAMICS

4.3.1 Seasonal Abundance

Seasonal abundance of *T. vaporariorum* was studied on spring-summer and autumn-winter crop of french bean (cv. Contender) and on summer crop of brinjal (cv. Arka Nidhi) under open/ field and protected environment. The observations recorded are being summarized in Tables 5 to 10.

4.3.1.1 Open environment

French bean

Spring-summer crop: The adults first appeared on spring crop of french bean on April 15 when 20 per cent of the plants were found infested with population level of 3.6 adults/ plant (Table 5). Adult population increased sharply afterwards to reach the peak level of 14.4 adults per three leaves on May 6 and fluctuated between 10.8-14.4 throughout up to June 10 and followed declining trend afterwards.

The nymphs were first observed a week later to adults on April 22 with the population level of 0.4 nymphs/ three leaves with corresponding level of plant infestation being 36 per cent. The population of nymph and pupa was at its peak on June 3 (43.6/ three leaves) declining sharply thereafter to reach a population level of 3.0 nymph and pupa at final harvest on June 24.

Based on the count of immature stages, adult population and level of plant infestation, the infestation index was calculated which increased from 0.72 as observed on April 15 to reach the highest value of 55.60 on June 3. Thereafter it declined sharply to reach the level of 1.45 at final harvest on June 24 (Figure 1).

Autumn-winter crop: The adult activity of *T. vaporariorum* was first recorded on October 7, 2001 on autumn-winter crop of french bean when 22 per cent of the plants were found infested with a population level of 5.4 adults/ plant (Table 6). The population attained its maximum level (27.0/ three leaves) on October

Table 5. Seasonal abundance of *Trialeurodes vaporariorum* in french bean under open environment (spring - summer crop) during 2001

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
April 8	0.0	0.0	0	0.00
15	0.0*	3.6*	20	0.72
22	0.4	7.2	36	2.74
29	0.6	10.8	58	6.61
May 6	3.0	14.4	62	10.79
13	4.2	10.8	64	9.60
20	15.0	10.8	80	20.64
27	25.8	14.4	84	33.77
June 3	43.6	12.0	100	55.60
10	28.8	14.4	68	29.38
17	6.6	7.2	30	4.14
24	3.0	3.6	22	1.45

* Population per plant

Date of sowing: March 15, 2001; Date of final harvest: June 25, 2001

Table 6. Seasonal abundance of *Trialeurodes vaporariorum* in french bean under open environment (autumn-winter Crop) during 2001-02

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
September 30	0.0*	0.0*	0	0.00
October 7	0.0*	5.4*	22	1.19
14	0.0	5.4	24	1.30
21	0.6	5.4	28	1.68
28	3.6	27.0	36	11.02
November 4	12.0	21.6	56	18.82
11	22.8	20.4	78	33.70
18	27.6	16.2	90	39.42
25	7.2	10.8	82	14.76
December 2	7.2	16.2	78	18.25
9	5.4	10.8	66	10.69
16	7.8	16.2	60	14.40
23	4.2	16.2	52	10.61
30	1.8	12.6	30	4.32
January 6	0.6	9.0	16	1.54

* Population per plant
Date of sowing: September 13, 2001; Date of final harvest: January 8, 2002

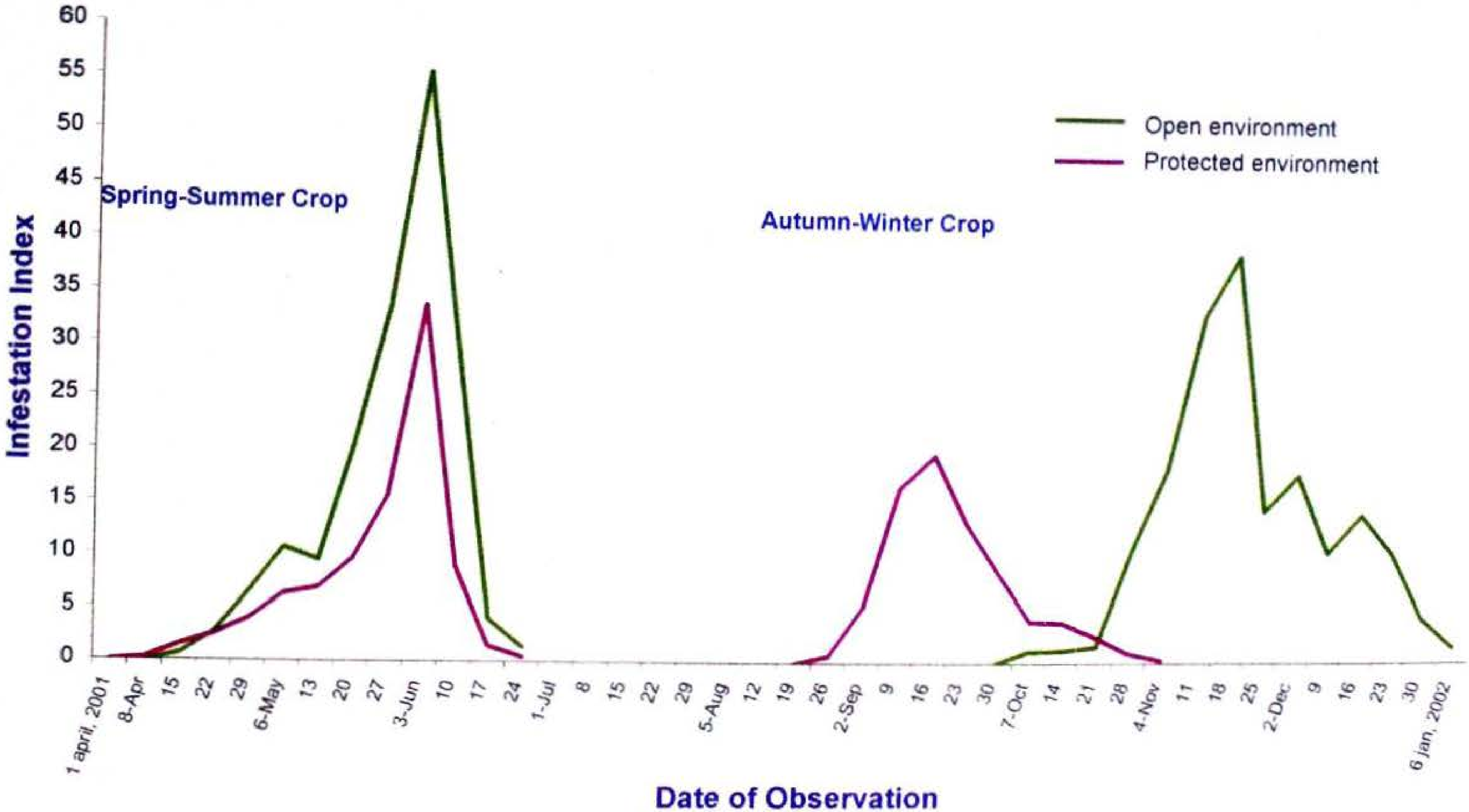

Figure 1. Infestation Index of *Trialeurodes vaporariorum* under Open and Protected Environment in French Bean

28 with the corresponding level of plant infestation being 36 per cent. Thereafter, a decline in adult population was set in and a population of 9.0 adults/ three leaves was recorded even before final harvest on January 6, 2002.

Nymphs were first observed on October 21, 2001 with a population level of 0.6 nymphs/ three leaves. Population of immature stages (nymph and pupa) was at its peak on November 18 (27.6/ three leaves) with the corresponding plant infestation level of 90 per cent. Thereafter, the population declined sharply to reach the minimum population level of 0.6 nymph and pupa on January 6, 2002.

Data contained in Table 6 revealed the infestation index to increase from 1.19 as on October 7 to 39.4 on November 11 after which it declined gradually (Figure 1).

Brinjal

In brinjal, the adults of *T. vaporariorum* first appeared on May 13 when 2.3 adults per plant were recorded with the level of infestation being 12 per cent (Table 7). The population level rose up to June 24 when the maximum numbers of adults were sampled (18.9 adults/ three leaves) with the corresponding plant infestation level of 70 percent. Thereafter the adult population declined gradually to 4.2 at final harvest.

The nymphs were first recorded (3.0 nymphs/ three leaves) a week later than the appearance of adults on the crop i.e. on May 20. The population reached at its maximum (53.4 nymphs and pupa/ three leaves) on June 10 with highest plant infestation (98%). Thereafter, a declining trend was set in and population reached at its minimum (0.6 nymph and pupa / three leaves) before the final harvest on September 9, 2001.

Based on population counts and plant infestation level, infestation index revealed a initial value of 0.28 on May 13 which went on increasing up to June 10 when the maximum value of infestation index was worked out (68.80)

Table 7. Seasonal abundance of *Trialeurodes vaporariorum* in brinjal under open environment during 2001

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
May 6	0.0*	0.0*	0	0.00
13	0.0*	2.3*	12	0.28
20	3.0	4.2	20	1.44
27	11.4	4.2	24	3.74
June 3	19.2	6.3	38	9.69
10	53.4	16.8	98	68.80
17	34.8	4.2	72	28.08
24	19.8	18.9	70	27.09
July 1	12.0	12.1	32	7.71
8	8.4	10.8	30	5.76
15	8.4	14.7	26	6.01
22	7.2	8.3	20	3.10
29	7.8	12.6	28	5.71
August 5	6.6	10.8	36	6.26
12	5.4	10.5	24	3.82
19	4.2	8.4	18	2.27
26	2.4	8.4	16	1.73
September 2	2.0	6.3	16	1.33
9	0.6	4.2	12	0.58

* Population/ plant
Date of transplanting: April 24, 2001; Date of final harvest: September 10, 2001

Table 8. Seasonal abundance of *Trialeurodes vaporariorum* in french bean under protected environment (spring-summer crop) during 2001

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
April 1	0.0*	0.0*	0	0.00
8	0.0*	1.8*	14	0.25
15	0.0	6.0	26	1.56
22	0.8	7.2	32	2.56
29	2.2	8.0	40	4.08
May 6	3.0	8.0	58	6.38
13	3.6	8.0	60	6.96
20	6.0	10.8	58	9.74
27	19.2	5.4	64	15.74
June 3	37.6	3.6	82	33.78
10	16.6	3.6	44	8.98
17	4.2	1.8	26	1.56
24	1.8	1.8	14	0.50

* Population/ plant

Date of sowing: March 13, 2001; Date of final harvest: June 25, 2001

(Figure 2). Thereafter a decline was set in and infestation index revealed low values reaching 0.58 on September 9, 2001.

4.3.1.2 Protected environment

French bean

Spring- summer crop: Under protected environment, on summer crop of french bean, the adults appeared first on April 8, 2001 (1.8 adults/ plant) with the level of infestation being 14 per cent (Table 8). The adult population increased to reach 8.0 adults/ three leaves on April 29 which was maintained for three successive weeks and attained the peak population level of 10.8 adults on May 20 with 58 per cent plants showing infestation. Afterwards, the population decreased gradually and remained at a level of 1.8 adults at final harvest on June 24, 2001.

The nymphs were recorded first on April 22 (0.8 nymphs/ three leaves) and reached its maximum (37.6 nymph and pupa/ three leaves) on June 3 with 82 per cent plants bearing infestation of *T. vaporariorum*. Thereafter, the population declined sharply to reach its minimum on June 24, 2001.

The infestation index calculated from population count and plant infestation increased from 0.25 to reach the maximum value of 33.78 on June 3 (Figure 1) beyond which it declined rapidly to reach a level of 0.50 at final harvest in the fourth week of June.

Autumn crop: The autumn crop of french bean under protected environment was first observed to harbour the adults on August 26 (1.8 adults/ plant) with the infestation level of 38 per cent. The adult population fluctuated between 3.6-7.2 adults per three leaves throughout the growing season (Table 9).

The nymphs of the whitefly were first observed on September 2 with a population of 1.2 nymphs/ three leaves and corresponding level of infestation being 66 per cent. The population reached at its peak in the second week of September (16.8 nymph and pupa/ three leaves) with the highest level of plant

Table 9. Seasonal abundance of *Trialeurodes vaporariorum* in french bean under protected environment (autumn crop) during 2001

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
August 19	0.0*	0.0*	0	0.00
26	0.0*	1.8*	38	0.68
September 2	1.2	7.2	66	5.54
9	16.8	5.4	76	16.87
16	16.8	3.6	98	19.99
23	10.2	7.2	78	13.57
30	8.4	7.2	56	8.74
October 7	6.6	5.4	34	4.08
14	6.0	7.2	30	3.96
21	4.2	5.4	26	2.50
28	2.4	3.6	16	0.96
November 4	0.6	1.8	14	0.34

* Population/ plant
Date of sowing: August 5, 2001; Date of final harvest: October 25, 2001

Table 10. Seasonal abundance of *Trialeurodes vaporariorum* in brinjal under protected environment during 2001

Date of observation	Mean population/ three leaves		Per cent plant Infestation	Infestation index
	Nymphs and Pupae	Adults		
April 15	0.0*	0.0*	0	0.00
22	0.0*	1.4*	18	0.25
29	0.0	2.1	26	0.55
May 6	0.6	4.2	40	1.92
13	3.0	8.4	48	5.47
20	3.6	6.3	52	5.15
27	6.6	8.4	60	9.00
June 3	10.2	8.4	72	13.39
10	7.2	25.2	84	27.22
17	10.2	23.1	64	21.31
24	46.8	27.3	88	65.21
July 1	7.2	31.5	56	21.67
8	5.4	23.1	52	14.82
15	3.6	21.0	38	9.35
22	1.8	16.8	28	5.21
29	1.8	21.0	24	5.47
August 5	1.2	12.6	20	2.76
12	1.2	6.3	18	1.35
19	1.2	4.2	18	0.97
26	2.4	2.1	26	1.17
September 2	11.4	35.7	66	31.09
9	27.0	29.4	90	50.76
16	13.2	37.8	72	36.72
23	4.2	14.7	48	9.07
30	4.8	8.4	36	4.75
October 7	1.2	2.1	18	0.59

* Population/ plant

Date of transplanting: April 10, 2001; Date of final harvest: October 10, 2001

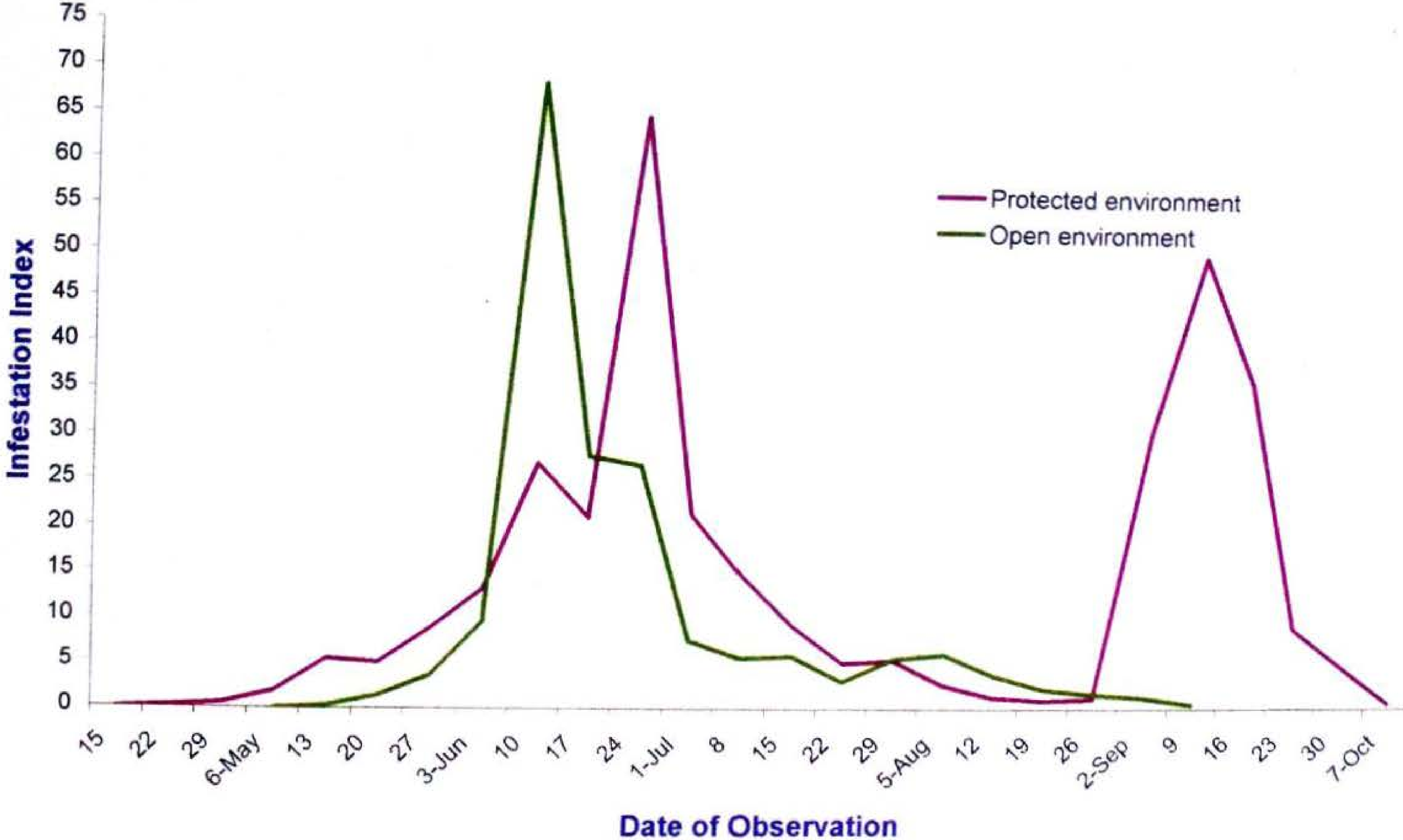

Figure 2. Infestation index of *Trialeurodes vaporariorum* under Open and Protected Environment in Brinjal

infestation being 98 per cent on September 16. The population declined gradually thereafter to reach the level of 0.6 nymph and pupa at final harvest of the crop.

The infestation index to the extent of 19.99 was recorded on September 16 (Figure 1) after which it declined sharply at first and then gradually reaching a level of 0.34 at final harvest of the crop on November 4, 2001.

Brinjal

On summer crop of brinjal under protected environment, the adults were first sampled on April 22 (1.4 adults/ plant) with plant infestation being 18 per cent (Table 10). Two peaks of adult activity were recorded during the cropping period, the first being on July 1 and the second on September 16, 2001 with 31.5 and 37.8 adults per three leaves, respectively.

Immature stages (nymphs and pupae) were at its peak on June 24 and September 9 with corresponding population levels of 46.8 and 27.0 nymph and pupa per three leaves along with plant infestation level of 88 and 90 per cent, respectively (Table 10).

The infestation index increased from the initial level of 0.25 on April 22 to 65.21 on June 24 (Figure 2) after which it declined gradually reaching a level of 0.97 as on August 19, 2001. Thereafter it again started increasing and attained a level of 50.76 on September 9.

4.3.2 Relationship of Abiotic Factors with Whitefly Population

Correlation between the abiotic factors namely, minimum and maximum temperature (°C), relative humidity (%), rainfall (mm) and wind velocity (km/h) and the infestation index on french bean and brinjal was worked out. The findings are presented in Tables 11 and 12.

Table 11. Correlation coefficient (r) between abiotic factors and infestation index of *Trialeurodes vaporariorum* under open environment

Abiotic factors	French bean		Brinjal
	Spring-summer crop	Autumn crop	
Temperature (°C)			
Minimum	0.2669	-0.0262	-0.4184
Maximum	0.0865	-0.0800	-0.1973
RH (%)	0.1689	-0.6563*	0.0108
Rainfall (mm)	0.3346	0.0547	-0.1746
Wind velocity (km/hr)	-0.2465	0.2371	0.0322

* Significant at 5% level of significance

4.3.2.1 Open environment

French bean

In the spring summer crop of french bean, infestation index when subjected to correlation analysis with that of abiotic factors (Table 11) revealed a positive but non-significant correlation with the minimum and maximum temperature, relative humidity and rainfall. But a negative correlation with wind velocity was established, though it was statistically non-significant.

In the autumn crop of french bean, the correlation analysis revealed that the infestation index had a negative but non-significant correlation with minimum and maximum temperature. Relative humidity also correlated negatively with the infestation index but significantly, (r = -0.6563). On the other hand, infestation index had positive but non-significant correlation with rainfall and wind velocity.

Brinjal

In brinjal, the infestation index revealed a negative but non-significant correlation with the minimum and maximum temperature and rainfall. However, relative humidity and wind velocity were related positively but non-significantly with the infestation index.

4.3.2.2 Protected environment

French bean

In the summer crop of french bean the infestation index when subjected to correlation analysis with that of various abiotic factors under protected environment revealed a positive but statistically non-significant correlation with the minimum and maximum temperature. Relationship with relative humidity was found to be non-significantly negative (Table 12).

Whereas in autumn crop a positive relationship between infestation index and temperature (minimum and maximum) as well as the relative humidity was

Table 12. Correlation coefficient (r) between abiotic factors and infestation index of *Trialeurodes vaporariorum* under protected environment

Abiotic factor	French bean		Brinjal
	Spring-summer crop	Autumn crop	
Temperature(°C)			
Minimum	0.2180	0.2704	0.1116
Maximum	0.2509	0.6779*	-0.2532
RH (%)	-0.0306	0.1382	0.2314

* Significant at 5% level of significance

established, the value of 'r' being significant (0.6779) with maximum temperature only.

Brinjal

In brinjal grown under protected environment, the correlation analysis (Table 12) revealed that the infestation index had a non-significant correlation with minimum and maximum temperature and relative humidity being negative with the maximum temperature only.

4.3.3 Vertical Distribution of the Whitefly Population in French Bean and Brinjal

Observations with regard to vertical distribution of nymphal, pupal and adult population of *T. vaporariorum* on different canopy heights of french bean and brinjal revealed them to aggregate more on middle, lower and upper parts of the plants, respectively. Data were pooled under different crop situations for french bean and brinjal and is being presented hereunder:

In case of french bean, the proportion of nymphal population varied between 25.97 to 46.37 per cent at three vertical canopy heights with significantly higher population on middle canopy followed by lower parts of the plants (Table 13). Significantly higher proportion of pupal population was observed on lower leaves (53.52%) being 31.65 per cent in the middle and only 14.82 per cent in the upper canopy. The proportion of adult population sampled was maximum in upper canopy (43.53%) but was on par to that observed in middle canopy. Proportion was significantly minimum in the lower canopy (17.35%) (Figure 3).

In brinjal, almost similar pattern with regard to distribution of different stages of the whitefly was observed as in case of french bean (Table 13) but the differences were significant for all the stages in different canopy heights. The proportion of nymphal population was highest in middle part of the plants

(44.75%) whereas the pupal and adult population confined mostly (50.95 and 40.15%, respectively) in the lower and upper canopy of brinjal plants (Figure 4).

Table 13. Vertical distribution of different developmental stages of *Trialeurodes vaporariorum* within french bean and brinjal plants

Canopy height	Percent distribution		
	Nymph	Pupa	Adult
French bean			
Upper	25.97 (30.61)	14.82 (22.56)	43.53 (41.25)
Middle	46.37 (42.89)	31.65 (34.21)	39.12 (38.70)
Lower	37.65 (31.58)	53.52 (47.00)	17.35 (24.48)
CD (P = 0.05)	(5.20)	(3.14)	(3.79)
Brinjal			
Upper	33.00 (35.00)	14.30 (22.21)	40.15 (39.30)
Middle	44.75 (41.95)	34.75 (36.10)	37.50 (37.74)
Lower	22.25 (28.13)	50.95 (45.53)	22.35 (28.20)
CD (P = 0.05)	(5.36)	(2.09)	(0.45)

4.3.4 Monitoring of Adult Population by Using Yellow Sticky Traps

Open Environment

Seasonal fluctuations in the adult population of *T. vaporariorum* monitored with the help of yellow sticky traps (Table 14) revealed that the whitefly first appeared in the 11th standard week (SW) (mid March) with a trap catch of 6 adults/ 24 hours/ trap. It kept fluctuating between 4-8 adults/ trap up to 18th SW (first week of May) when a count of 12 adults/ trap was observed and reached the peak (18 adults / trap) a week later (Figure 5). Thereafter, a gradual decline was set in and the trap count remained at low level varying between 2-4 adults from 25-37th SW (fourth week of June to second week of September) and increased gradually to result in second peak of 11 adults/ trap in 47 and 48th SW (end of November and early December). The trap count

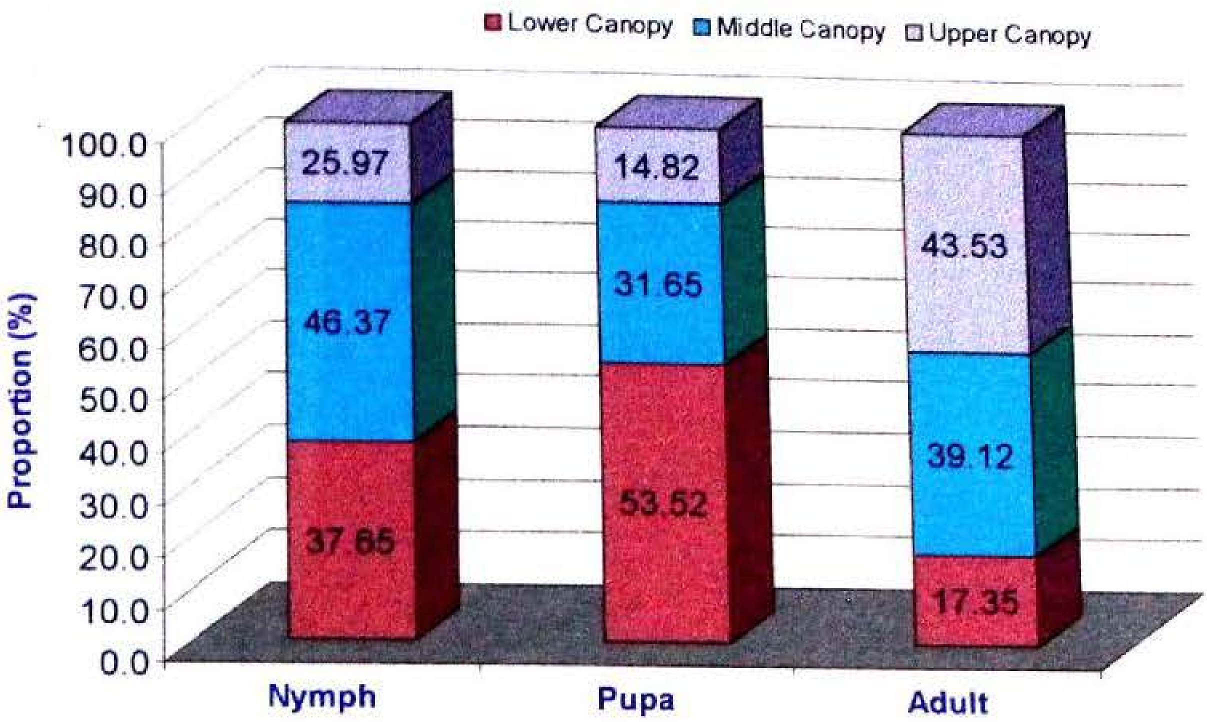

Figure 3. Vertical Distribution of Different Developmental Stages of *Trialeurodes vaporariorum* on French Bean

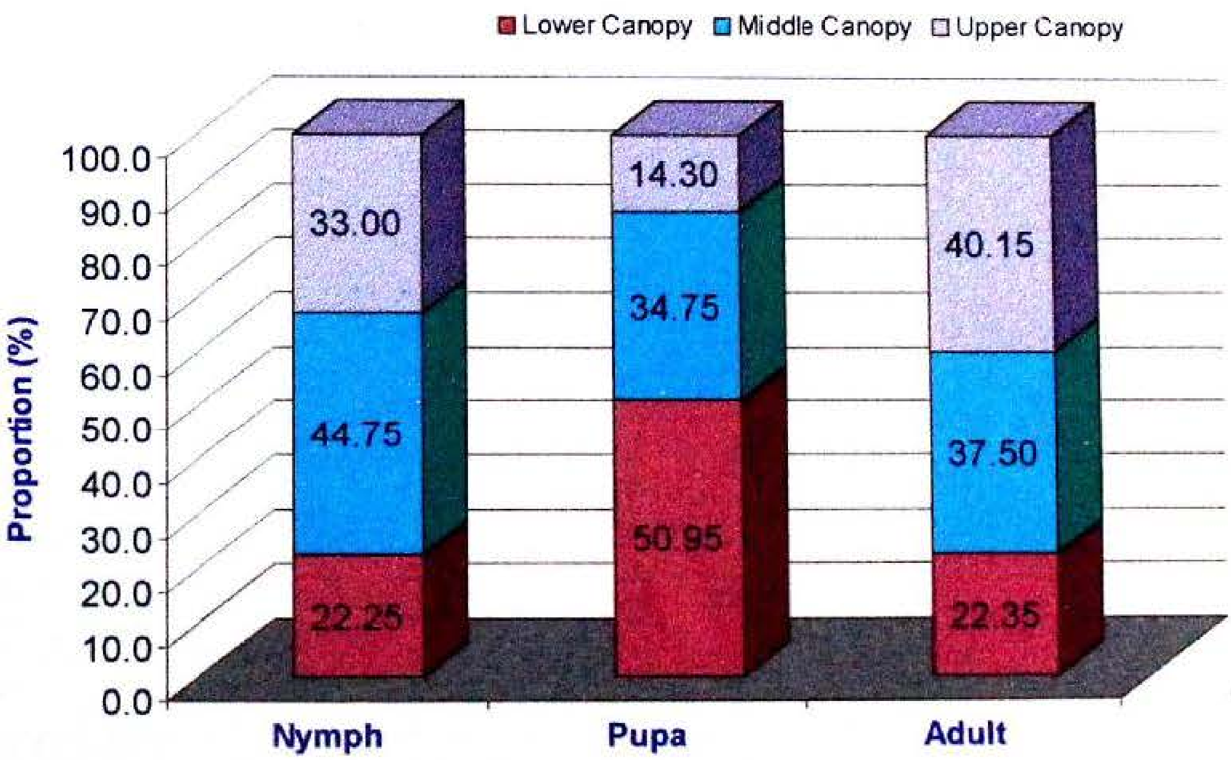

Figure 4. Vertical Distribution of Different Developmental Stages of *Trialeurodes vaporariorum* on Brinjal

Table 14. **Monitoring of adult population of *Trialeurodes vaporariorum* with yellow sticky trap during the cropping season of 2001-2002**

Sampling Week	Standard Week	Adult population per 24 h/trap	
		Open environment	Protected environment
March 18, 2001	11	6	0
25	12	8	0
April 1	13	6	0
8	14	5	2
15	15	6	1
22	16	4	1
29	17	6	1
May 6	18	12	3
13	19	18	3
20	20	9	9
27	21	12	3
June 3	22	6	6
10	23	5	3
17	24	8	1
24	25	2	1
July 1	26	2	1
8	27	1	3
15	28	1	1
22	29	2	2
29	30	1	1
August 5	31	1	1
12	32	2	6
19	33	2	6
26	34	1	15
September 2	35	4	18
9	36	2	24
16	37	4	18
23	38	6	15
30	39	6	12
October 7	40	6	6
14	41	3	6
21	42	3	3
28	43	3	3
November 4	44	3	2
11	45	6	
18	46	9	
25	47	11	
December 2	48	11	
9	49	9	
16	50	9	
23	51	6	
30	52	3	
January 6, 2002	1	1	

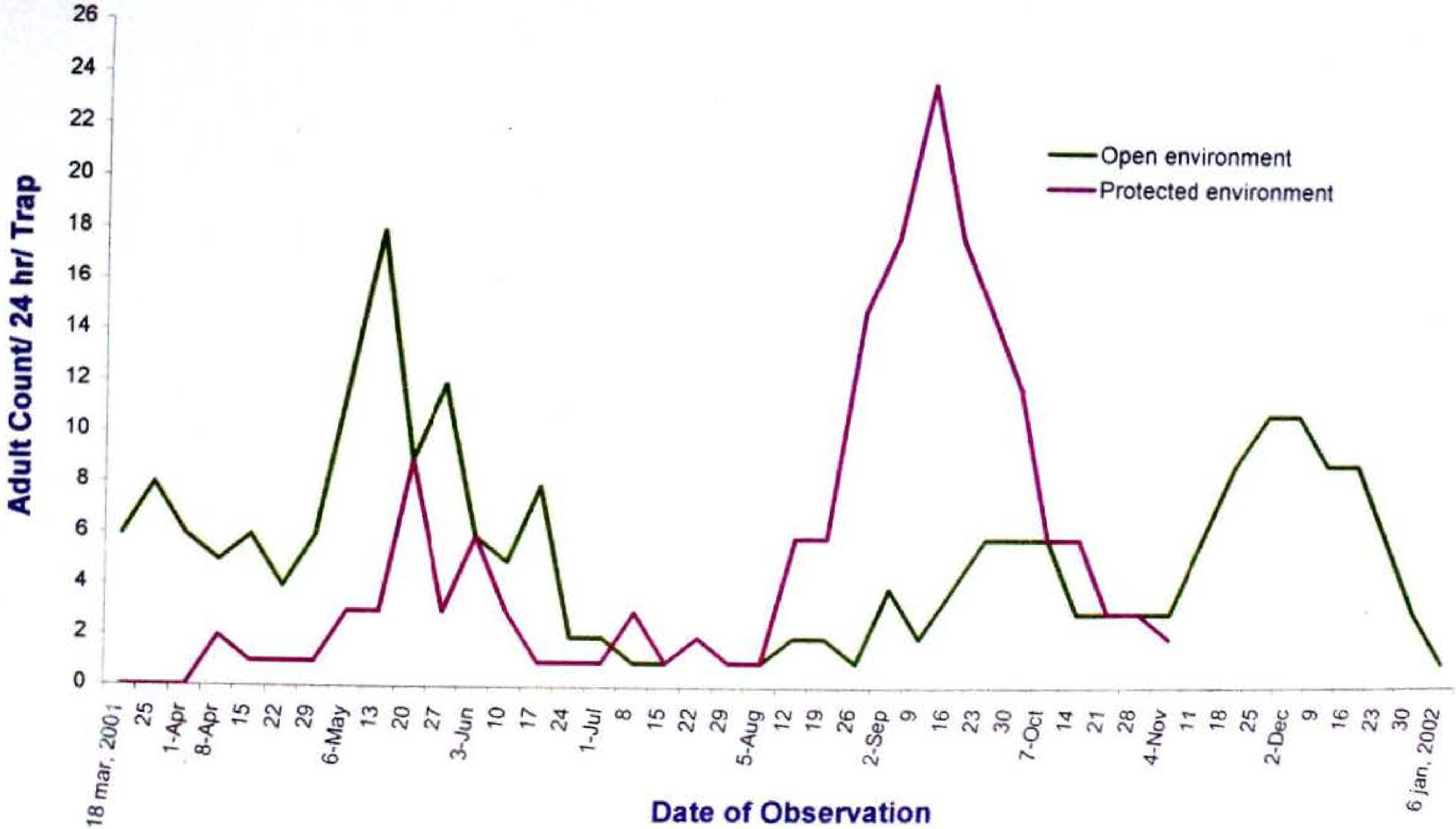

Figure 5. Yellow Trap Catch Count of *Trialeurodes vaporariorum* during the Cropping Period of 2001-02

decreased sharply to reach at its minimum of 1 adult in the first week of January at final harvest of the autumn crop of french bean.

The trap count in open environment subjected to correlation analysis with that of various abiotic factors and population counts on french bean and brinjal revealed a positive correlation with maximum temperature in french bean (summer crop) and brinjal being significant with the value of 'r' being 0.6847 and 0.8701, respectively (Table 15). The trap count in spring-summer crop of french bean also responded positively to minimum temperature but non-significantly. In others the minimum temperature had negative but non-significant relationship with the trap catch. Relative humidity was negatively correlated with trap catch being significant in spring summer crop of french bean (r = -0.5895) and brinjal (r=-0.8851). Rainfall also exerted negative influences on the trap count except in autumn crop of french bean, being significant only in brinjal (r = -0.6356). However, sunshine hours had positive and significant relationship in spring-summer crop of french bean and brinjal (r = 0.5729, 0.7796, respectively). Wind velocity also had a positive relationship except in autumn crop of french bean being significant in brinjal (r = 0.8001).

However, trap count had non-significant relationship with immature population (nymph and pupa), adult as well as infestation index in french bean and brinjal grown in open environment (Table 15).

Protected environment

In protected environment, the adult activity was delayed to 14^{th} SW (April 8) with a trap catch of 2 adults/ trap (Table 14). The population increased to result in peak trap count of 9 adults in 20^{th} SW (third week of May) declining gradually thereafter. Trap count remained low before 33^{rd} SW (August 19) when trap count of 6 adults was observed. It increased sharply and resulted in the second peak (24 adults/ trap) on 36^{th} SW (September 9) and declined thereafter gradually to reach the level of 2 adults per trap at final harvest of the crop during 44 SW (first week of November) (Figure 5).

Table 15. Correlation coefficient (r) of trap catch with abiotic factors and population of *Trialeurodes vaporariorum* under open environment

Factors	French bean		Brinjal
	Spring-summer crop	Autumn-winter crop	
Abiotic factor			
Temperature (°C)			
Minimum	0.4639	-0.1091	-0.2180
Maximum	0.6847*	-0.1575	0.8701*
RH (%)	-0.5895*	-0.4105	-0.8851*
Rainfall (mm)	-0.5342	0.2601	-0.6356*
Sunshine (hr)	0.5729*	-0.1825	0.7796*
Wind velocity (km/hr)	0.5276	-0.0937	0.8001*
Population			
Nymph and Pupa	0.0038	0.3805	0.0127
Adult	0.4390	0.0265	-0.3411
Infestation index	0.1530	0.3466	-0.0554

* Significant at 5% level of significance

Table 16. Correlation coefficient (r) of trap catch with abiotic factors and population of *Trialeurodes vaporariorum* under protected environment

Factors	French bean		Brinjal
	Spring-summer crop	Autumn crop	
Abiotic factor			
Temperature (°C)			
Minimum	0.1179	0.1209	-0.0062
Maximum	0.3961	0.2521	0.2691
RH (%)	-0.0784	0.1461	-0.1401
Population			
Nymph + Pupa	0.8075*	0.7966*	0.2621
Adult	0.2459	0.6370*	0.3060
Infestation index	0.9000*	0.7899*	0.3565

* Significant at 5% level of significance

In protected environment, trap count had positive but non-significant relationship with maximum and minimum temperature in all the cropping situations except in brinjal where a negative but non-significant relationship was evident with minimum temperature (Table 16). Similarly, relative humidity also had non-significant relationship with trap catch of *T. vaporariorum* except in autumn crop of french bean where a positive relationship was observed.

But the trap catches had a positive relationship with the population count in french bean and brinjal being significant with nymphal and pupal population in summer and autumn french bean (r = 0.8075, 0.7966, respectively), adult population in autumn crop of french bean (r = 0.6370) and infestation index in summer and autumn crop of french bean (r = 0.9000 and 0.7899, respectively).

BIOLOGY

4.4.1 Description and Measurements of Developmental Stages

Egg: The females deposited eggs singly or in clusters of 5-6 eggs on the lower surface of the leaves (Plate 1a), whereas on glabrous leaves a circular pattern of egg laying was observed (Plate 1b). The freshly laid eggs were creamish-yellow in colour and turned dark prior to hatching. The eggs were stalked and rounded at the base with apical tapering. The length of eggs ranged between 0.180 to 0.230 mm (average=0.201 mm) and breadth from 0.07 to 0.105 mm (average=0.096 mm) (Table 17).

Nymph: There were three nymphal instars. The freshly hatched nymphs were oval and light yellow in colour (Plate 2a). They possessed functional legs and crawled throughout the leaf on which they hatched. They got settled in a few hours and inserted their proboscis into the phloem tissue for sucking up sap. The nymphs thereafter remained sessile except during moulting when they showed some displacement from their position. The second and third instar nymphs were oval in shape, depressed, scale like and greenish-yellow in colour (Plates 2b, c). The setae like projections were more prominent in these stages. The features of all the three instars were quite similar except a variation in size

(Table 17). The length and breadth of the first instar nymphs ranged from 0.228 to 0.315 mm (mean: 0.267 mm) and 0.105 to 0.175 mm (mean: 0.145 mm), respectively. The average length and breadth of the second instar was 0.370 and 0.217 mm and that of third instar being 0.658 and 0.377 mm, respectively.

Pupa: The pupae were flattened and translucent initially and became expanded and opaque with the white lateral and dorsal setae in the later stages (Plate 3a). In the last stage, red eyes and yellow body pigment was prominently visible below the transparent pupal case (Plate 3b) whereas the empty pupal case were colourless and glassy (Plate 3c). The length and breadth of the pupa varied from 0.700 to 0.770 mm (mean: 0.728 mm) and 0.385 to 0.455 mm (mean: 0.415 mm), respectively (Table 17).

Adult: The yellow bodied adults had two pairs of wings covered with white waxy powder. In resting position, the forewings covered the hind wings and were held flat but loosely over the body (Plate 1c). They preferred to feed and oviposit on the lower surface of tender leaves. The females were larger than the males. The females measured 0.963 mm in length with the mean wing expanse of 2.613 mm, whereas in males, the corresponding values were 0.844 mm and 2.174 mm, respectively (Table 17).

4.4.2 Annual Life-Cycle of the Whitefly

4.4.2.1 Number of generations

Under laboratory conditions, the greenhouse whitefly when reared on french bean completed 13 overlapping generations from March 2001 – March 2002 in a year (Table 18) lasting from March 8 – April 9, 2001, April 11 – May 6, May 8 – May 30, June 1 – June 27, June 29 – July 17, July 19 -- August 11, August 13 – September 4, September 6 – September 24, September 26 - October 18, October 20 – November 19, November 21 – December 30, January 1 – February 13, 2002 and February 15 – March 24.

Table 17. Measurements of different developmental stages of *Trialeurodes vaporariorum*

Stage	Length (mm)		Breadth (mm)	
	Mean ± S.E.	Range	Mean ± S.E.	Range
Egg	0.201 ± 0.014	0.180-0.230	0.096 ± 0.015	0.070-0.105
Nymph				
I	0.267 ± 0.019	0.228-0.315	0.145 ± 0.015	0.105-0.175
II	0.370 ± 0.025	0.325-0.420	0.217 ± 0.020	0.175-0.245
III	0.658 ± 0.023	0.595-0.700	0.377 ± 0.021	0.350-0.415
Pupa	0.728 ± 0.020	0.700-0.770	0.415 ± 0.019	0.385-0.455
Adult			Wing Expanse	
Male	0.844 ± 0.043	0.770-0.938	2.174 ± 0.282	1.824-2.074
Female	0.963 ± 0.042	0.843-1.083	2.613 ± 0.067	2.450-2.743

Table 18. Number of generations of *Trialeurodes vaporariorum* under laboratory conditions

Generation	Period	Mean Temperature (°C)		Mean RH (%)
		Minimum	Maximum	
I	March 8-April 9, 2001	13.52	25.38	52.35
II	April 11-May 6	21.95	31.25	80.38
III	May 8-May 30	24.00	32.13	63.41
IV	June 1-June 27	24.20	29.50	65.08
V	June 29-July 17	28.50	28.80	77.76
VI	July 19-August 11	26.40	27.98	71.65
VII	August 13-September 4	26.18	28.18	72.33
VIII	September 6-September 24	25.75	27.78	53.75
IX	September 26-October 18	27.42	29.04	40.91
X	October 20-November 19	24.96	27.48	30.19
XI	November 21-December 30	18.33	23.36	33.63
XII	January 1-February 13, 2002	14.98	19.94	38.03
XIII	February 15-March 24	17.13	21.40	39.16

4.4.2.2 Developmental biology

Observations made on the developmental biology of *T. vaporariorum* throughout the year under laboratory conditions are being presented in Tables 19-22.

Egg: The mean duration of incubation period was influenced by the prevailing temperature during different generations and was maximum in winter generations of January - February (XII) and February - March (XIII) occupying 12.7 and 11.3 days, respectively. The incubation period was of shortest duration (4.7 days) in June - July generation (V), which in turn was on par to May (III), June (IV), and July - August (VI) generations (Table 19).

Wide variation in hatchability of eggs was evident during different generations, which ranged between 52.8 to 92.0 per cent (Table 20). Hatchability was comparatively more in the generations occurring during low temperature regimes. Highest hatchability was recorded during March-April generation, which was at par to generations occurring during September (VIII), November - December (XI) and January - February (XII). It was minimum (52.85) during July-August (VI) being on par to October-November (X) generation.

Nymph: Observations recorded on the duration of different nymphal instars revealed that the first instar occupied the maximum (mean of different generations being 6.5 days) followed by third (5.8 days) and second instar (5.3 days) (Table 21). In case of first instar, the maximum duration (11.3 days) was recorded in first generation (March - April) differing significantly from the rest of the generations. It was minimum (3.7 days) during eighth generation (September) being on par to fifth generation (June - July). The second nymphal instar occupied 7.7 days during XI and XII generation (November - December and January - February) being significantly higher to rest of the generations whereas the lowest duration of 3.3 days was recorded during VIII generation (September) which in turn was on par to generations occurring during June,

Table 19. Developmental biology of *Trialeurodes vaporariorum* during different generations

Generation	Duration (Days)							
	Incubation period		Total nymphal period		Pupal period		Total Developmental period	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
I	7-10	8.3	21-23	22.0	4	4.0	32-36	35.3
II	4-7	6.0	16-17	16.3	3-5	4.7	26-29	27.3
III	4-6	5.3	15-16	15.7	3-4	3.7	22-24	23.7
IV	4-6	5.3	13-16	14.3	4-5	4.3	23-26	24.7
V	4-6	4.7	12-15	13.0	4-6	5.0	22-25	23.3
VI	4-7	5.0	14-17	15.3	5-8	6.0	24-27	25.7
VI	5-8	6.0	12-14	13.3	3-4	3.7	22-25	23.3
VIII	6-8	6.7	10-12	11.0	2-4	3.0	19-22	20.7
IX	5-7	6.3	13-15	14.3	5-6	5.7	25-28	26.0
X	6-9	7.3	16-19	17.7	6-9	7.7	32-35	33.3
XI	9-12	10.3	22-24	23.0	6-8	6.7	38-42	40.3
XII	11-14	12.7	22-24	23.3	7-8	7.3	40-45	43.3
XIII	10-13	11.3	18-20	18.7	4-6	5.3	34-37	35.3
Mean		7.3		16.8		5.2		29.4
CD $_{(P=0.05)}$		1.25		1.14		0.93		1.84

Table 20. Survival of different developmental stages of *Trialeurodes vaporariorum* during different generations

Generation	Survival (%)			
	Egg	Nymph	Pupa	Total
I	92.0 (72.70)	80.3 (63.70)	91.9 (75.69)	74.2 (59.62)
II	73.6 (59.08)	87.4 (69.34)	100.0 (89.96)	63.9 (53.03)
III	68.8 (56.06)	52.4 (46.28)	73.9 (59.37)	36.7 (37.24)
IV	69.5 (56.50)	64.9 (53.64)	89.4 (78.37)	45.0 (42.11)
V	70.1 (56.86)	56.3 (48.62)	86.3 (68.91)	40.4 (39.39)
VI	52.8 (46.59)	72.6 (58.44)	94.2 (78.92)	38.6 (38.37)
VII	82.4 (65.33)	48.4 (44.06)	76.1 (60.74)	40.2 (39.32)
VIII	86.4 (68.41)	83.3 (65.93)	100.0 (89.96)	71.7 (57.88)
IX	64.7 (53.56)	74.6 (59.73)	97.7 (84.85)	49.9 (44.94)
X	55.6 (48.23)	78.2 (62.24)	100.0 (89.96)	42.4 (40.63)
XI	89.4 (71.03)	82.6 (65.32)	100.0 (89.96)	74.1 (59.56)
XII	89.3 (71.76)	81.0 (64.21)	93.9 (79.51)	71.4 (59.55)
XIII	81.7 (64.80)	90.5 (73.32)	99.4 (87.47)	73.8 (59.35)
Mean	75.1 (60.84)	73.3 (59.60)	92.5 (79.51)	55.6 (48.54)
CD $_{(P=0.05)}$	(5.99)	(4.64)	(11.32)	(5.66)

* Figures in parentheses are the angular transformed values

Table 21: Duration and survival of nymphal instars of *Trialeurodes vaporariorum* during different generations

Generation	Duration (days) and survival (%) of Nymphal Instar					
	I		II		III	
	Duration	Survival	Duration	Survival	Duration	Survival
I	11.3	92.2 (73.69)	6.0	95.4 (80.09)	6.3	100.0 (89.96)
II	6.0	93.2 (75.66)	5.0	93.6 (75.93)	6.7	100.0 (89.96)
III	6.3	83.8 (66.45)	4.7	86.7 (68.83)	5.3	100.0 (89.96)
IV	6.0	85.7 (67.95)	4.0	89.8 (71.76)	5.3	95.4 (82.70)
V	4.0	79.6 (63.32)	4.3	84.2 (66.62)	4.7	94.9 (82.27)
VI	5.0	87.6 (69.37)	5.0	90.0 (71.74)	5.7	96.3 (83.48)
VII	6.0	78.0 (62.18)	3.7	83.7 (66.24)	4.0	97.2 (84.37)
VIII	3.7	87.2 (69.04)	3.3	96.4 (81.01)	4.0	99.2 (87.06)
IX	5.0	80.8 (64.00)	4.0	94.8 (76.90)	5.7	100.0 (89.96)
X	6.0	84.4 (67.06)	6.7	95.0 (79.77)	7.0	97.1 (82.27)
XI	9.0	86.2 (68.38)	7.7	95.9 (78.44)	7.3	100.0 (89.96)
XII	8.3	87.4 (69.61)	7.7	96.7 (83.82)	8.0	100.0 (89.96)
XIII	8.3	95.5 (78.12)	6.3	98.0 (83.61)	5.3	97.5 (82.58)
Mean	6.5	86.3 (68.83)	5.3	92.3 (75.75)	5.8	98.3 (86.50)
CD $_{(P=0.05)}$	1.10	(7.46)	0.76	(9.61)	0.75	(N.S.)

* Figures in parentheses are the angular transformed values

NS: Non-significant

August - September and September - October (generation: IV, VII and IX). The third nymphal instar occupied 4.0-8.0 days in different generations and was maximum during XII generation (January - February) being on par to November-December generation (XI), whereas the lowest duration coincided to VII and VIII generation (August - September and September generation) which in turn was on par to generation occurring during June – July (generation V).

Among the three nymphal instars, the first instar experienced highest mortality as depicted from the minimum mean survival of 86.3 per cent as compared to 92.3 and 98.3 per cent recorded in second and third, respectively (Table 21). Survival amongst first instar nymphs varied between 78.0 and 95.5 per cent in different generations, the maximum was during XIII generation (February - March) being on par to first and second generations (March - April and April - May). The minimum survival corresponded to August - September generation being on par to rest of the generations. In case of second instar nymphs, the maximum survival (98.0%) was observed in February-march generation (XIII) being on par to generations during September to May (VIII–XIII, I, II). The survival was minimum (83.7%) in seventh generation occurring during August - September which was on par to generations III to VI (May to July-August) generations. In third instar, survival ranged between 94.9 and 100.0 per cent in different generations but differed non-significantly.

The total nymphal period ranged between 10.0 to 24.0 days during different generations, the mean duration being maximum (23.3 days) in winter generation of January - February (XII) which in turn was on par to the preceding generation of November - December (Table 19). The nymphal period was significantly minimum in the VIII generation (September) (mean: 11.0 days) as compared to others and was followed by the duration recorded in the fifth generation occurring during June - July (13.0 days) which in turn was on par to seventh generation.

The total nymphal survival was maximum (90.5 %) during February - March (generation XIII) being on par to that observed in the second (April - May) generation. It was minimum (48.4 %) in seventh generation occurring during August - September being on par to third and fifth generations (May and June-July) (Table 20).

Pupa: The mean duration of pupal period varied between 3.0 to 7.7 days amongst different generations, occurring comparatively more in winter generations as the maximum occurred during October - November (X) generation which in turn was on par to the generation occurring during January - February (XII). The minimum duration was recorded during eighth generation (September) which in turn was on par to the generations during May and August- September (III and VII). This was followed by generations during March to May and in June which were on par to each other (Table 19).

Pupal stage experienced mortality ranging between 73.9-100.0 per cent (Table 20). No mortality in pupal stage occurred in April-May (II), September (VIII), October - November (X) and November - December (XI) generations being on par to July - August (VI), January - February (XII) and February-March (XIII) generations. The minimum survival corresponded to third (May) generation and was on par to June – July (V) and August – September (VII) generation.

Total developmental period: Total developmental period from egg deposition to adult emergence occupied 20.7 to 27.3 days in generations occurring during April- May to September – October being minimum in September (VIII) generation. However the developmental period of longer duration (33.3-43.3 days) was observed in the generations occurring during October - November (X) to March - April (I). It was minimum (20.7 days) in September generation which was on par to May-August generations (Table 19). Generation survival varied between 36.7 to 74.2 per cent, being significantly higher during winter generations of November - December, January - February, February - March and March - April and again in September generation (Table 20). The minimum survival (36.7%) was recorded during May (III) generation being on par to the generations occurring during June to August - September and October-November (generation: V-VII and X).

Adult: The temperature influenced the adult longevity greatly being comparatively more during the winter generations of October – March (Table 22). The females lived longer than the males and lived for 7.1-42.6 days in different generations, whereas the male longevity was of 5.5-26.7 days.

The sex ratio was found to be in favour of females. A total of 1873 adults observed in the present studies, resulted in male to female ratio of 1:2.8 (Table 22) with a range of 1.9 to 3.1 during different generations.

The females on an average laid 108-373 eggs in different generations. Fecundity was comparatively more during winter generations of October to March-April (Table 22). The maximum egg laying was observed during October-November (X) generation being on par to eleventh (November-December) generation, whereas the minimum fecundity corresponded to July - August (VI) generation being on par to June, July and August generations (V-VII).

4.4.3 Life Cycle of the Whitefly on Summer Vegetables

The observations recorded on utilization of summer vegetables namely, brinjal, capsicum, chilli, cucumber, french bean and tomato for oviposition and their influences on the development of the greenhouse whitefly are summarized in Tables 23 to 25.

4.4.3.1 Ovipositional preference

Ovipositional preference of *T. vaporariorum* to different hosts in free choice test revealed the french bean to be utilized most by the ovipositing females for depositing eggs followed by brinjal and cucumber which were on par to each other (Table 23), the proportion of eggs deposited on these hosts

Table 22. Adult longevity, sex ratio and fecundity of *Trialeurodes vaporariorum* during different generations

Generation	Longevity (Days)*		Sex Ratio (Male: Female)	Fecundity (Number of eggs/ female)*
	Male	Female		
I	6.7	8.4	1:2.3	196.5
II	6.4	8.1	1:2.5	181.5
III	6.5	7.6	1:2.4	172.5
IV	6.1	7.4	1:3.1	128.0
V	5.5	7.1	1:3.0	120.0
VI	6.9	7.3	1:2.3	108.0
VII	6.1	8.8	1:2.6	139.4
VIII	13.7	19.7	1:2.7	235.2
IX	15.4	22.3	1:2.6	288.5
X	20.3	35.2	1:2.3	373.0
XI	26.7	42.6	1:1.9	342.3
XII	17.6	22.6	1:2.9	241.5
XIII	8.0	10.1	1:2.3	189.0
Mean	11.2	15.9	1:2.8	208.9
CD $_{P=0.05}$	5.80	4.97	0.44	49.32

* Based on ten pairs replicated thrice

Table 23. Ovipositional preference of *Trialeurodes vaporariorum* to summer vegetables

Host plant	Proportion of eggs deposited (%)
Brinjal	23.91 (29.26)
Capsicum	5.93 (14.06)
Chilli	2.45 (8.99)
Cucumber	22.56 (28.33)
French bean	35.51 (36.56)
Tomato	10.30 (18.70)
CD(P=0.05)	(1.38)

* Figures in parentheses are the angular transformed values

being 35.51, 23.91 and 22.56 per cent, respectively. Chilli was the least preferred host with 2.45 per cent of the egg deposition only (Figure 6).

4.4.3.2 Developmental biology

The studies on developmental biology could be initiated on the four vegetable crops viz., brinjal, cucumber, french bean and tomato as no nymphal survival beyond first instar on chilli and second instar on capsicum was recorded in the present studies.

Data contained in Table 24 revealed that at 28±2°C, the incubation period was significantly minimum on french bean (8.0 days) and maximum on tomato (10.0 days). Hatchability was also found to be highest on french bean (90.3%) followed by brinjal and differed significantly with cucumber and tomato which in turn were on par to each other.

The differences with regard to the duration of first instar nymphs were non significant where it varied from 6.3 to 7.0 days. However, survival was significantly minimum on cucumber (70.7%) as compared to others where it ranged between 84.0 to 91.3 per cent, being maximum on brinjal. Duration of second instar nymphs varied between 6.0 to 7.3 days on different hosts being significantly minimum on brinjal. Also the survival to the extent of 97.1 per cent corresponded to brinjal being on par to other hosts except cucumber (84.9%). Almost similar trend with respect to duration and survival in third instar nymphs was recorded which varied between 6.0 to 9.7 days and 95.0 to 100.0 per cent, respectively.

The total nymphal period revealed significantly faster development on brinjal (17.6 days) as compared to others. French bean resulted in slow development (22.6 days). Brinjal also proved supportive to *T. vaporariorum* as it resulted in significantly higher survival in the nymphal stage (92.5 %) as compared to others (76.5-77.5 %) which in turn were on par to each other (Table 24).

Table 24. Developmental biology of *Trialeurodes vaporariorum* on different vegetable crops at 28 ± 2°C

Developmental Stage/ Parameter		Brinjal	Cucumber	French bean	Tomato	CD (P=0.05)
Egg	Incubation period (days)	8.7	9.0	8.0	10.0	1.09
	Hatchability (%)	87.2 (69.4)	71.9 (58.2)	90.3 (72.0)	66.1 (54.4)	(7.99)
Nymphal Instar						
I	Duration (days)	6.3	6.7	7.0	6.7	NS
	Survival (%)	91.3 (73.3)	70.7 (57.3)	87.3 (69.3)	84.0 (66.5)	(7.06)
II	Duration (days)	6.0	7.0	7.3	7.3	0.73
	Survival (%)	97.1 (80.4)	84.9 (67.3)	92.6 (74.3)	96.7 (81.8)	(9.23)
III	Duration (days)	6.0	6.7	9.7	7.0	0.73
	Survival (%)	100.0 (89.9)	99.3 (87.3)	95.1 (79.6)	98.8 (86.4)	(NS)
Total nymphal	Duration (days)	17.6	20.0	22.6	20.3	1.51
	Survival (%)	92.5 (74.1)	76.5 (61.1)	77.0 (61.3)	77.5 (61.7)	(4.78)
Pupa	Duration (days)	7.3	6.3	8.3	7.0	0.91
	Survival (%)	98.1 (85.4)	96.6 (82.2)	97.5 (82.5)	89.3 (70.9)	(NS)
Total Developmental Period (days)		23.7	25.0	27.0	26.7	1.63
Adult emergence (%)		76.4 (60.9)	70.8 (57.3)	68.8 (56.0)	65.7 (54.2)	(4.17)
Adult Longevity (days)	Male	7.3	6.4	6.5	6.5	NS
	Female	7.6	7.4	7.0	7.6	NS
Fecundity (Number of eggs/female)		192.5	176.0	187.0	154.0	NS

* Figures in parentheses are the angular transformed values

NS: Non-significant

The nymphs of *T. vaporariorum* fed on cucumber exhibited minimum pupal period (6.3 days) being on par to others except french bean (8.3 days) where the differences were significant. The pupal stage experienced mortality ranging between 1.9 to 10.7 per cent, however the differences were non significant.

Total developmental period from egg laying to adult emergence was minimum on brinjal (23.7 days) being on par to cucumber, whereas, it was maximum on french bean (27.0 days). Adult emergence on different host varied between 65.7 to 76.4 per cent, being highest on brinjal and minimum on tomato. The male and female longevity varied between 6.4 to 7.3 and 7.0 to 7.6 days, respectively on different hosts. However, differences with regard to male and female longevity as well as fecundity, which varied between 154.0-192.5 eggs per female, were non significant.

Growth indices: The nymphal growth index (NGI) and total growth index (TGI) calculated on the basis of duration and survival (Table 25) revealed that both were maximum in brinjal followed by cucumber, the values being 8.2 & 3.2 and 6.9 & 2.8, respectively. NGI was minimum in tomato (5.7) whereas the TGI was found to be minimum in french bean and tomato (2.5) (Figure 7).

Table 25. Nymphal Growth Index and Total Growth Index of *Trialeurodes vaporariorum* on different hosts

Host plant	Nymphal Growth Index (NGI)*	Total Growth Index (TGI)**
Brinjal	8.2	3.2
Cucumber	6.9	2.8
French bean	5.8	2.5
Tomato	5.7	2.5

* NGI = Nymphal survival (%) / Nymphal period (days)

** TGI = Adult emergence (%) / Total developmental period (days)

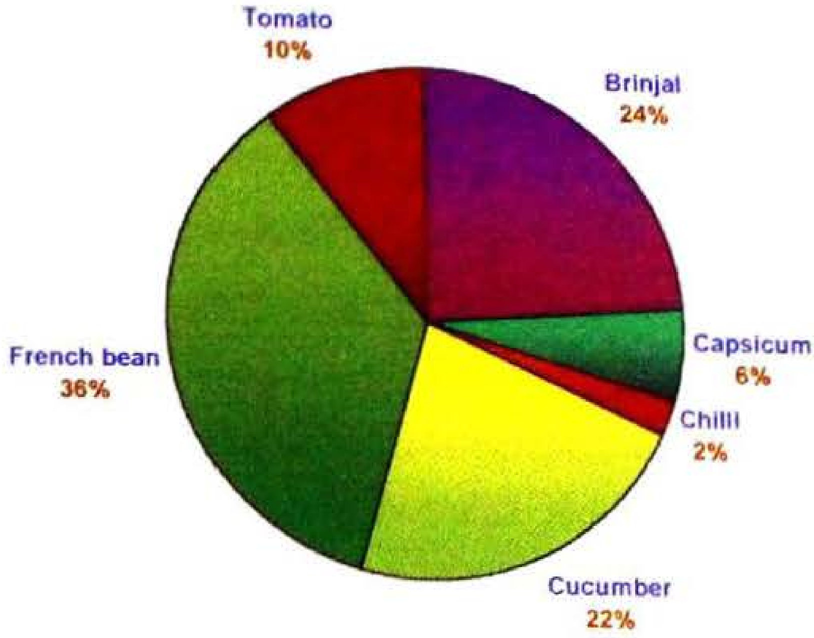

Figure 6. Proportion of Eggs Deposited on Different Vegetable Crops by *Trialeurodes vaporariorum*

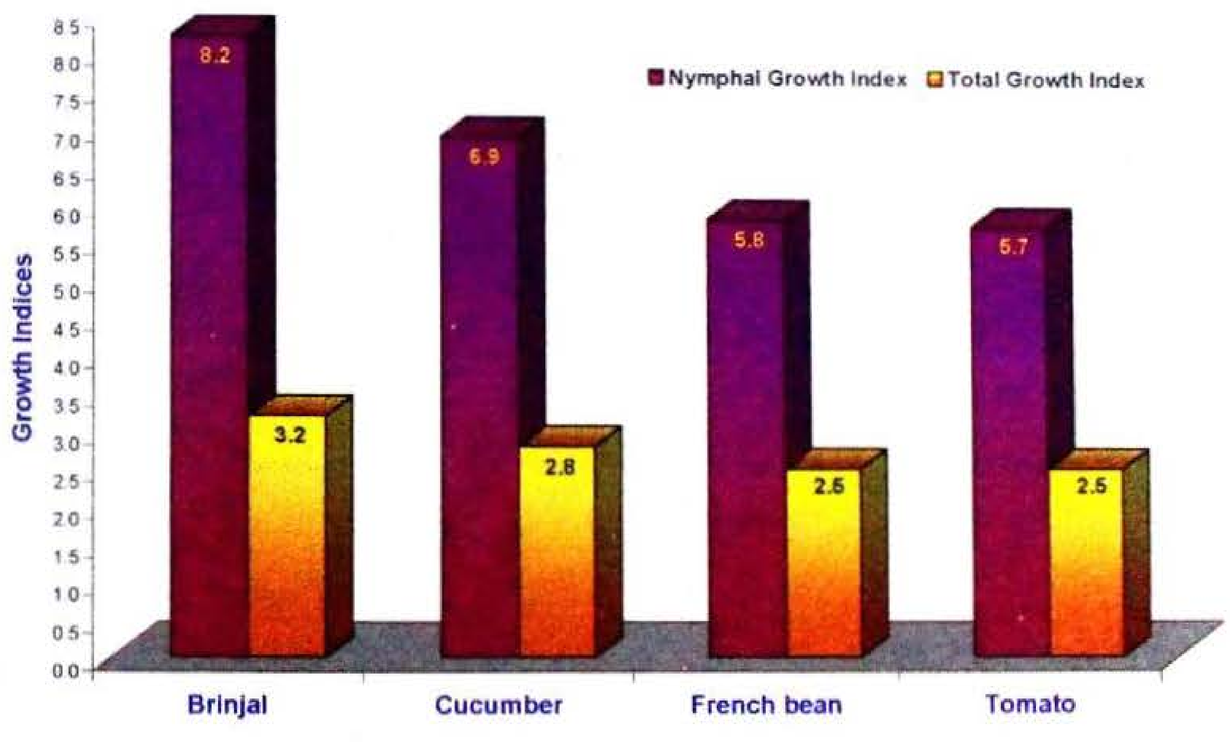

Figure 7. Growth Indices of *Trialeurodes vaporariorum* on Vegetable Crops

4.5 BIOEFFICACY OF INSECTICIDES

4.5.1 Intrinsic Toxicity

Results pertaining to laboratory bioassay studies of six insecticides namely, acephate, acetamiprid, dimethoate, imidacloprid, MTI-446 and triazophos using leaf disc dip method against the adults of *T. vaporariorum* are being presented in Tables 26-31.

Acephate: French bean leaves dipped in acephate concentrations 0.0005, 0.01, 0.025, 0.05, 0.1 and 0.2 per cent when offered to 2-3 day old adults of *T. vaporariorum* resulted in mortality of 13.5, 24.3, 48.6, 63.2, 72.9 and 81.1 per cent in the respective concentrations after 24 hours (Table 26). The data were subjected to probit analysis. The χ^2 test showed the homogeneity of the test population as the calculated value of χ^2 was 0.148, lower than the tabulated value of 9.5 at p=0.05. The regression equation obtained from the data had a slope of 1.0192 (Figure 8a). The LC_{50} value worked out was 0.0257 per cent with fiducial limits of 0.0236 and 0.0278 per cent, the LC_{90} value being 0.4656 per cent with fiducial limits of 0.4642 and 0.4670 per cent.

Acetamiprid: The 2-3 days old adults of *T. vaporariorum* when fed on french bean leaves dip treated for one minute in acetamiprid concentrations of 0.001, 0.0025, 0.005, 0.007 and 0.01 per cent gave 20.0, 43.9, 51.2, 61.9 and 82.5 per cent mortality, respectively. No mortality was recorded in the control. The data were homogeneous at p=0.05 as the calculated value of χ^2 (2.69) was less than the tabulated value (7.8) at three degrees of freedom (Table 27). The LC_{50} value was calculated to be 0.0036 per cent, fiducial limits being 0.0035 and 0.0037 per cent while the LC_{90} value was 0.025 per cent with fiducial limits of 0.0251 to 0.0255 per cent. The regression equation (Figure 8b) obtained from the mortality data had a slope of 1.5234.

Dimethoate: The dose mortality data for the adults of *T. vaporariorum* is given in Table 28 and presented graphically in Figure 8c. It was observed that 0.0075

Table 26. Concentration - mortality response of adults of *Trialeurodes vaporariorum* to acephate

Concentration (%)	Log (conc. $\times 10^3$) x	No. of adults (n)	Mortality (%)
0.005	0.70	37	13.5
0.01	1.00	37	24.3
0.025	1.40	37	48.6
0.05	1.70	38	63.2
0.1	2.00	37	72.9
0.2	2.30	37	81.1
Control	-	30	-

Regression Equation

$Y = 3.5624 + 1.0192\ X$

Heterogeneity

χ^2 calculated = 0.148

χ^2 tabulated = 9.5 (p = 4df)

$LC_{50} = 0.0257 \pm 0.0021\%$ Fiducial limit : 0.0236 – 0.0278%

$LC_{90} = 0.4656 \pm 0.0014\%$ Fiducial limit : 0.4642 – 0.4670%

Table 27. Concentration mortality response of adults of *Trialeurodes vaporariorum* to acetamiprid

Concentration (%)	Log (conc.$\times 10^4$) x	Number of adults (n)	Mortality (%)
0.001	1.00	40	20.0
0.0025	1.40	41	43.9
0.005	1.70	41	51.2
0.007	1.06	42	61.9
0.01	2.00	40	82.5
Control	-	40	

Regression Equation

$Y = 2.6188 + 1.5234\ X$

Heterogeneity

χ^2 calculated = 2.69

χ^2 tabulated = 7.8 (p = 3df)

$LC_{50} = 0.0036\% \pm 0.0001$ Fiducial limit : 0.0035 - 0.0037%

$LC_{90} = 0.025\% \pm 0.0002$ Fiducial limit : 0.0251 – 0.0255%

per cent dimethoate gave 21.7 per cent mortality and 0.12 per cent gave 81.8 per cent mortality. There was no mortality in the control. The data were homogeneous at p=0.05. The LC_{50} and LC_{90} values were calculated to be 0.0245 and 0.1941 per cent with fiducial limits of 0.0244 to 0.0246 per cent and 0.1937 to 0.1945 per cent, respectively.

Imidacloprid: The per cent corrected mortality in imidacloprid treatments ranging from 0.00025 to 0.15 per cent was found to vary between 17.9 to 82.5 per cent, respectively, after 24 hours of treatment (Table 29). The data were subjected to probit analysis. The χ^2 calculated (3.211) was found to be less than tabulated value (11.020) and proved the homogeneity of the data. The regression equation had a slope of 0.5597 (Figure 8d). The LC_{50} value was found to be 0.00291 per cent with fiducial limits of 0.00289 and 0.00293 per cent while the LC_{90} value was 0.5674 per cent with fiducial limits of 0.5673 and 0.5675 per cent.

MTI-446: The dose mortality data for the adults of T. *vaporariorum* revealed a mortality of 14.71, 22.86, 36.11, 51.42, 63.89 and 80.56 per cent at the concentrations of 0.0005, 0.001, 0.0025, 0.005, 0.01 and 0.02 per cent, respectively after 24 hours of treatment. The χ^2 test confirmed the homogeneity of the test population. The regression equation had a slope of 1.1625 (Figure 8e). The LC_{50} and LC_{90} values were 0.0047 and 0.0596 per cent with the respective fiducial limits of 0.0045 to 0.0049 and 0.0594 to 0.0598 per cent.

Triazophos: French bean leaves treated with triazophos concentrations of 0.001, 0.0025, 0.005, 0.01, 0.025 and 0.05 per cent and offered to the adults of T. *vaporariorum* resulted in corresponding mortality of 20.0, 30.0, 36.8, 66.7, 72.2 and 84.2 per cent after 24 hours. There was no mortality of adults in untreated control. The regression line had a slope of 1.8191 (Figure 8f). The data were homogeneous at p=0.05 and four degrees of freedom. The LC_{50} and LC_{90} values were calculated as 0.0065 and 0.0941 per cent with fiducial limits of 0.0063 to 0.0067 and 0.0938 to 0.0944 per cent, respectively.

Table 28. Concentration mortality response of adults of *Trialeurodes vaporariorum* to dimethoate

Concentration (%)	Log (conc. $\times 10^4$) x	No. of adults (n)	Mortality (%)
0.0075	1.88	43	21.7
0.015	2.18	43	39.1
0.03	2.48	42	54.5
0.06	2.78	42	72.7
0.12	3.01	42	81.8
Control	-	43	-

Regression Equation

$Y = 1.5917 + 1.4264 X$

Heterogeneity

χ^2 calculated = 0.11

χ^2 tabulated = 7.8 (p = 3df)

$LC_{50} = 0.0245 \pm 0.0001\%$ Fiducial limit : 0.0244 – 0.0246%

$LC_{90} = 0.1941 \pm 0.0004\%$ Fiducial limit : 0.1937 – 0.1945%

Table 29. Concentration mortality response of adults of *Trialeurodes vaporariorum* to imidacloprid

Concentration (%)	Log (conc. $\times 10^5$) x	No. of adults (n)	Mortality (%)
0.00025	1.40	39	17.9
0.0005	1.70	39	41.0
0.001	2.00	40	42.5
0.0025	2.30	39	48.7
0.005	2.70	41	56.1
0.01	3.00	41	60.9
0.15	4.18	40	82.5
Control	-	40	-

Regression Equation

$Y = 3.6208 + 0.5597 X$

Heterogeneity

χ^2 calculated = 3.211

χ^2 tabulated = 11.020 (p = 5df)

$LC_{50} = 0.00291 \pm 0.00002\%$ Fiducial limit : 0.00289 – 0.00293%

$LC_{90} = 0.5674 \pm 0.0001\%$ Fiducial limit : 0.5673 – 0.5675%

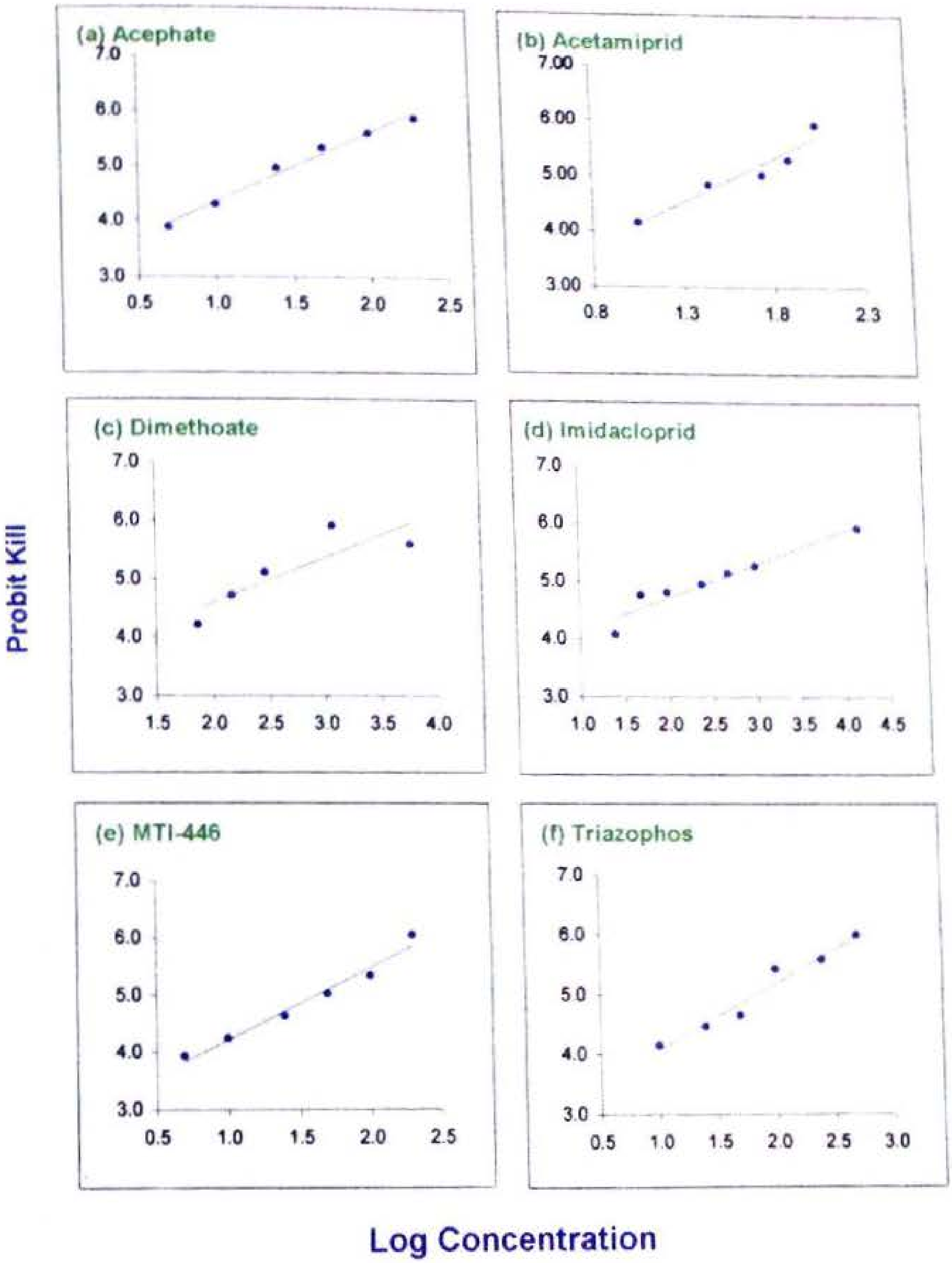

Figure 8. Concentration - Mortality Response of Different Insecticides to Adults of the Greenhouse Whitefly

Table 30. Concentration - mortality response of adults of *Trialeurodes vaporariorum* to MTI-446

Concentration (%)	Log (conc. $\times 10^4$) x	No. of adults (n)	Mortality (%)
0.0005	0.70	34	14.71
0.001	1.00	35	22.86
0.0025	1.40	36	36.11
0.005	1.70	35	51.43
0.01	2.0	36	63.89
0.02	2.30	36	80.56
Control	-	30	-

Regression Equation

$Y = 3.08526 + 1.1625 X$

Heterogeneity

χ^2 calculated = 0.42

χ^2 tabulated = 9.5 (p = 4df)

$LC_{50} = 0.0047 \pm 0.00025\%$ Fiducial limit : 0.0045 – 0.0049%

$LC_{90} = 0.0596 \pm 0.0002\ \%$ Fiducial limit : 0.0594 – 0.0598%

Table 31. Concentration mortality response of adults of *Trialeurodes vaporariorum* to triazophos

Concentration (%)	Log (conc. $\times 10^4$) x	No. of adults (n)	Mortality (%)
0.001	1.00	40	20.0
0.0025	1.40	40	30.0
0.005	1.70	38	36.8
0.01	2.00	36	66.7
0.025	2.40	36	72.2
0.05	2.70	38	84.2
Control	-	40	-

Regression Equation

$Y = 2.9738 + 1.8191X$

Heterogeneity

χ^2 calculated = 1.24

χ^2 tabulated = 9.49 (p = 4df)

$LC_{50} = 0.0065 \pm 0.0002\ \%$ Fiducial limit : 0.0063 – 0.0067%

$LC_{90} = 0.0941 \pm 0.0003\ \%$ Fiducial limit : 0.0938 – 0.0944%

4.5.2 Field Efficacy

Field efficacy of nine insecticides namely acephate (0.05%), acetamiprid (0.004%), dimethoate (0.025%), imidacloprid (0.05%), MTI-446 (0.007%) and triazophos (0.03%) (synthetic insecticides), azadiractin (0.00045%) (botanical insecticide), *Beauveria bassiana* (7.5×10^6 cfu/ ml) (microbial insecticide) and buprofezin (0.02%) (growth regulator) was evaluated against the immature stages (nymphs and pupae) and adults of *T. vaporariorum* on french bean (cv. Contender) under protected (polyhouse) environment. The results are presented in Tables 32 and 33.

4.5.2.1 Efficacy against immature stages

A perusal of the data presented in Table 32 revealed that the population of immature stages (nymph and pupa) at the initiation of experiment ranged between 70 to 103.5/ three leaves. One day after treatment (DAT) all the synthetic insecticides except acephate brought about significantly higher reduction in population of immature stages ranging between 70.57 to 82.58 per cent, the maximum coinciding with acetamiprid followed by imidacloprid. Acephate was in turn on par to dimethoate and triazophos. Insecticides belonging to other groups resulted in significantly lower reduction in population. Almost similar trend was observed 7 DAT with respect to synthetic insecticides with reduction in population being 62.45 to 94.54 per cent. MTI-446 resulted in significantly higher reduction in population being on par to imidacloprid and acetamiprid. Effectiveness of azadiractin and *B. bassiana* also improved considerably and resulted in 81.56 and 73.50 per cent reduction in population over untreated check, respectively. However 14 DAT, buprofezin brought about highest reduction in population of immature stages (98.01%) being on par to imidacloprid. This was followed by acetamiprid, MTI-446 and dimethoate resulting in reduction in population over control ranging between 77.91 to 84.47. In the remaining treatments efficacy declined significantly as compared to 7 DAT and reduction in population fell below 50 per cent except azadiractin.

Table 32. Field efficacy of some insecticides against immature stages (nymph and pupa) of *Trialeurodes vaporariorum*

Insecticide	Concentration (%)	Pre-count (Nymph & Pupae/ 3 leaves)	Per cent reduction in population over Untreated check after days of treatment			
			1	7	14	Mean
Acephate	0.05	70.0	57.20 (49.16)	62.45 (52.44)	41.31 (39.62)	53.65 (47.07)
Acetamiprid	0.004	78.5	82.58 (65.44)	92.07 (73.85)	84.47 (67.07)	86.37 (68.79)
Azadiractin	0.00045	80.0	12.89 (20.93)	81.56 (64.73)	65.23 (54.11)	53.23 (46.59)
Beauveria bassiana	7.5×10^{6} cfu/ml	91.0	2.93 (9.55)	73.50 (59.11)	24.57 (28.92)	33.92 (32.53)
Buprofezin	0.02	103.5	4.45 (12.04)	58.20 (50.25)	98.01 (82.17)	53.55 (48.15)
Dimethoate	0.03	73.5	70.57 (57.35)	76.58 (61.36)	77.91 (62.05)	75.02 (60.25)
Imidacloprid	0.05	98.5	81.47 (65.10)	92.19 (73.80)	90.58 (72.17)	88.08 (70.35)
MTI-446	0.007	78.9	73.47 (59.30)	94.54 (76.48)	79.04 (63.00)	82.35 (66.26)
Triazophos	0.03	84.0	72.89 (59.46)	71.06 (57.54)	38.41 (37.16)	60.79 (51.38)
Mean			50.94 (44.26)	78.02 (63.28)	66.61 (56.25)	
Population in untreated check **		88.5	108	134.3	148.5	
CD (P=0.05)	Treatments		3.48			
	Days after treatment		6.03			
	Treatment × Days after treatment		10.44			

* Figures in parentheses are the angular transformed values

** Number of nymph and pupa/ three leaves

In all, imidacloprid followed by acetamiprid were most effective in reducing the population of immature stages, being on par to each other and was followed closely by MTI-446 and dimethoate. *B. bassiana* proved least effective. Efficacy of the insecticides improved significantly 7 DAT but thereafter declined marginally but significantly on 14 DAT revealing the insecticides evaluated to have a more pronounced effect upto 7 days only.

4.5.2.2 Efficacy against adult whiteflies

A perusal of the data presented in Table 33 revealed that adult population prior to insecticide application ranged between 17.5 to 25.0/ three leaves. After one day of application, MTI-446 brought about maximum reduction in population (91.27%) being on par to imidacloprid, acetamiprid and azadiractin. Other treatments resulted in significantly lower reduction in population. Seven days after treatment, the highest reduction in population was observed in MTI-446 (95.74%) being on par to dimethoate and imidacloprid. This was followed by acetamiprid, azadiractin, *B. bassiana* and triazophos which were in turn on par to each other. However 14 DAT, buprofezin emerged as the most effective treatment giving 98.06 per cent reduction over untreated check and being significantly superior to all other treatments.

Among all the treatments, MTI-446 remained significantly the most effective treatment. It was followed by imidacloprid being on par to acephate, dimethoate, acetamiprid, azadiractin and triazophos. The efficacy of the insecticides improved till 7 DAT and remained on par to 14 DAT. The population in untreated check showed a slight decline 14 days after treatment though it kept increasing until 7 days after treatment.

Table 33. Field efficacy of some insecticides against adult population of *Trialeurodes vaporariorum*

Insecticide	Concentration (%)	Pre-count (Adults/ 3 leaves)	Per cent reduction in population over Untreated check after days of treatment			
			1	7	14	Mean
Acephate	0.05	25.0	76.50 (61.21)	76.69 (61.40)	66.39 (54.66)	73.19 (59.09)
Acetamiprid	0.004	18.5	80.13 (63.65)	86.71 (68.76)	87.39 (69.68)	84.74 (67.36)
Azadiractin	0.00045	21.3	82.54 (65.42)	78.85 (63.08)	52.50 (46.45)	71.30 (58.31)
Beauveria bassiana	7.5x10^{6} cfu/ml	22.0	47.29 (43.39)	73.27 (59.20)	32.61 (32.51)	51.05 (45.03)
Buprofezin	0.02	24.8	20.05 (26.06)	45.35 (42.18)	98.06 (84.42)	54.48 (50.88)
Dimethoate	0.03	17.5	72.70 (58.56)	89.53 (71.43)	86.50 (69.09)	82.91 (66.36)
Imidacloprid	0.05	20.0	87.79 (70.57)	92.16 (74.15)	79.86 (63.82)	86.60 (69.51)
MTI-446	0.007	22.6	91.27 (72.94)	95.74 (79.71)	85.91 (68.23)	90.97 (73.63)
Triazophos	0.03	21.8	77.04 (61.41)	73.23 (59.35)	71.52 (58.11)	73.93 (59.62)
Mean			70.59 (58.13)	79.06 (64.36)	73.42 (60.77)	
Population in untreated check **		30	35.3	47.8	41.5	
CD (P=0.05)	Treatments		3.32			
	Days after treatment		5.75			
	Treatment × Days after treatment		9.97			

* Figures in parentheses are the angular transformed values

** Number of nymph and pupa/ three leaves

DISCUSSION

Chapter - V

DISCUSSION

Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) is an important polyphagous pest of vegetable crops and ornamental plants. First reported from England, it is considered as the 'New World' species. Damage to the plants is inflicted by sucking up of phloem sap by the nymphs and adults and result in production of large quantities of honey dew which serves as the medium for development of sooty mould. This further hinders the photosynthetic activity of the plants resulting in development of chloratic areas, withering of plants and premature leaf fall. The control of *T. vaporariorum* is difficult because the species has rapid reproduction rate, wider host range and ability to develop resistance to insecticides. The results obtained in the present investigation are discussed in this chapter.

5.1 IDENTITY OF THE WHITEFLY

The whitefly species was determined as *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) on the basis of pupal case characteristics. The pupal case had short glass-like waxy fringe all over and around the margins with no dark area and appeared slightly elevated above the leaf surface when viewed laterally. Byrne and Bellows (1991) also reported the pupal case of *T. vaporariorum* to possess dorsal and lateral wax like rods as well as waxy fringe all over.

5.2 HOST RANGE

In surveys conducted in and around Palampur, *T. vaporariorum* was found to infest 44 species of plants belonging to 20 families. Plant families Solanaceae and Compositeae comprised the major proportion of host plants of

T. vaporariorum constituting 9 and 7 plant species, respectively followed by Malvaceae (4 species). Most of the hosts belonged to ornamentals (29) followed by vegetable crops (6), weed hosts (4), medicinal plants (3) and field crops (2). Earlier, Roditakis (1990) had reported Compositae, Solanaceae, Malvaceae, Leguminosae and Cucurbitaceae as major families infested by *T. vaporariorum* in Crete.

T. vaporariorum infested 24 plant species under open environment/ field conditions comprising of vegetable crops (6), field crops (2), ornamental plants (12), medicinal plant (1) and weed hosts (3). Whereas, under protected environment 23 species of plants belonging to vegetable crops (4), ornamental plants (17), medicinal plant (1) and weed hosts (1) were designated as host plants.

Earlier Le Pelley (1925) found beans as host of *T. vaporariorum* in Guernsey whereas in Bulgaria Popov (1938) recorded it severely infesting tomato and cucumber. It was also reported to infest summer food plants in Canada, tobacco, tomato and squash being the most preferred hosts (Mc Leod, 1938). Tomato, brinjal and cucumber have been reported as the hosts of whitefly in Netherlands (Marendonk and Lenteren, 1978). But, in India potato (*Solanum tuberosum*) (David, 1971), potato, tomato (*Lycopersicon esculentum*) (Paul and David, 1975), tomato, french bean, potato, nasturtium (*Tropaeolum majus*), *Eupatorium globosum, E. glandulosum* and geranium (*Pelargonium graveolens*) (Mohan *et al.*, 1985), has been reported to be the hosts of *T. vaporariorum* in Nilgiri hills. Whereas in Himachal Pradesh french bean, tomato, cucumber, brinjal and fuschia were earlier reported to be the host plants of *T. vaporariorum* (Dhillon, 1999). Thirty nine host plants listed in the study are being recorded for the first time from Himachal Pradesh whereas thirty seven seem to be the new records from India.

The whitefly remained active from March to October-November on most of the host plants and throughout the year on fuschia (*Fuschia magellanica*) and salvia (*Salvia officinalis*). Population level was high to very high on seven host plants comprising of five ornamental plants and two vegetable crops. The maximum population of nymph, pupa and adult was recorded on hydrangea (*Hydrangea macrophylla*) (145.3/ three leaves), followed by primula (*Primula* spp.) (143.8) and hollyhock (*Althea rosea*) (125.9). Among the vegetable crops, tomato harboured the highest mean population of 57.7/ three leaves. However under protected environment, incidence was very high on five plant species namely cucumber (*Cucumis sativus*), flemingo plant (*Jacobinia carnea*), primula (*Primula* spp.), abutilon (*Abutilon hybridum*) and variegated duranta (*Duranta sellowiana*). Amongst the listed host plants namely bougainvillea (*Bougainvillea* spp.), calendula (*Calendula officinalis*), chrysanthemum (*Dendranthema grandiflora*), dahlia (*Dahlia variabilis*), dhatura (*Datura stramonum*) and pansy (*Viola tricolor*) were designated as the hosts for adult feeding only.

Le Pelley (1925) found heavy infestation of the whitefly on beans (*Phaseolus vulgaris*) in Guernsey whereas, Eggplant (*Solanum melongana*), cucumber (*Cucumis sativus*) and tomato (*Lycopersicon esculentum*) have been reported to be infested heavily by *T. vaporariorum* in Netherlands by Boxtel *et al.* (1978). Mohan *et al.* (1985) in the Nilgiri hills found *Phaseolus vulgaris, Solanum tuberosum, Lycopersicon esculentum* and *Eupatorium glandulosum* as the major hosts of *T. vaporariorum*.

5.3 POPULATION DYNAMICS

5.3.1 Seasonal Abundance

French bean

In the summer crop, the incidence of *T. vaporariorum* was recorded first in the third week of April (April 15) in open environment and reached its peak in the first week of May whereas in protected environment, the infestation initiated in the first week of April, a week prior to open environment, with the peak of activity occurring in the second fortnight of May (37.6 nymph and pupa and 10.8 adults/ three leaves).

In case of autumn-winter crop of french bean infestation started in the first week of October under open environment reaching the peak period of infestation in the last week of October with infestation index of 39.42. Under protected conditions the infestation was first recorded in the last week of August and resulted in the peak of infestation index (19.99) during the second week of September.

The incidence was comparatively more in summer crop as compared to the autumn crop both under open and protected environment. Also, the population level was high under open conditions as compared to the protected conditions in both the crops and can be due to very high temperature under protected environment (polyhouse) affecting the population build-up adversely.

Brinjal

In brinjal crop grown under field conditions, the infestation initiated in the first week of May. In the field crop only one peak of the infestation index during the second fortnight of June was observed and declined thereafter. However, under protected environment, two peaks of infestation index were observed, one during the last week of June and the other during the second week of September. The field crop showed higher infestation as compared to the later. This can be attributed to the persistent very high temperature (mean temperature of 27.8°C with the maximum and minimum of 45.7 and 23.0°C) throughout under protected environment as compared to (mean temperature of 23.3°C with the maximum and minimum of 32.5 and 20.2°C) being more congenial under open environment.

The observations find support from the findings of Garman and Jewett (1922) who reported a rise in the population of *T. vaporariorum* till the summer months declining thereafter and lasting until autumn. Khristova (1967) also reported *T. vaporariorum* to migrate to the fields in spring season and breed in large numbers there. Contrary to the findings, Dhillon (1999) observed the incidence of greenhouse whitefly on tomato from August to October only at Solan representing the mid hill region of Himachal Pradesh.

5.3.2 Relationship of Abiotic Factors with Whitefly Population

5.3.2.1 Open environment

The correlation analysis in open environment revealed the infestation index to be negatively but non-significantly correlated with minimum and maximum temperature in autumn crop of french bean and brinjal but was related positively in the spring-summer crop of french bean. This can be attributed to moderate temperature range (minimum: 11.8-19.7°C; maximum: 22.4-32.5°C) during spring-summer crop of french bean as compared to temperature during brinjal where it was high. Also in autumn-winter crop of french bean comparatively low temperature (minimum: 4.0-14.5°C; maximum: 17.2-26.0°C) would have resulted in low proportion levels.

Significant negative correlation of infestation index with relative humidity in autumn-winter crop of french bean was evident signifying the influences of lower relative humidity levels (mean: 37.5-53.0%) as compared to high relative humidity levels during other crop growing periods. Rainfall exerted negative influences on infestation in brinjal only whereas it was positive in french bean and this can be attributed to the length of cropping season because the brinjal crop grown during summer was extended through rainy season experiencing more rains as compared to others.

The wind velocity was also related negatively with the infestation index in spring-summer crop of french bean only whereas, with others a positive but non-significant relationship was evident. This can be attributed to comparatively high wind velocity during spring- summer crop (4-7 km/hr).

5.3.2.2 Protected environment

Infestation index exhibited a positive but non-significant relationship with minimum temperature in french bean and brinjal. However, it was related positively with maximum temperature in french bean being significant in autumn crop and negatively but non-significantly in brinjal. This can be attributed to the congenial temperature limits (mean: 20.0-31.5°C) in autumn-winter crop of french bean. The cause of negative relationship in brinjal can be ascribed due to the high temperature during summer and rainy season in the polyhouse (mean: 22.0-34.5°C).

The relative humidity had a positive relationship with the infestation index in the autumn crop of french bean and brinjal but spring crop established marginally negative relationship. This is attributed to low levels of humidity in the summer season in polyhouse (mean: 33-56%) as compared to relative humidity levels of 55-82.5 per cent in brinjal and 35-65 per cent in autumn crop of french bean.

5.3.3 Vertical Distribution of the Whitefly Population in French Bean and Brinjal Plants

To ascertain the aggregation of the whitefly population in different canopy heights of french bean and brinjal, three observations recorded on seasonal incidence were analyzed for a week prior to and after the peak period of activity. It was found that the nymphs were distributed more in the middle (46.37%) and pupae in lower (53.52%) canopy of french bean plants. The adults were more abundant in upper canopy (43.53%) being on par to those in the middle canopy. In brinjal, significantly higher proportion of adult population was observed in upper (40.15%), nymphs in middle (44.75%) and pupae in lower (50.95%) canopy of plants. This can be attributed to the preference of adults to young tender leaves for feeding and oviposition resulting the nymphs to be more below the new growth (middle canopy) and pupa on older leaves in lower canopy of plants, owing to the corresponding duration of nymphal and pupal period.

Findings of Yamada *et al.* (1979) and Kim *et al.* (1986) recorded on cucumber are supportive to the present results. They also observed the adults of *T. vaporariorum* to be more on upper parts of the plants, nymphs below the parts infested by adults and pupae on lower parts of the plants.

5.3.4 Monitoring of Adult Population by Using Yellow Sticky Traps

The adult activity monitored using yellow sticky traps revealed that the adults were trapped first in the field/ open environment during third week of March whereas it was delayed to second week of April under protected environment. There occurred two peaks of adult trap catch, the first during second week of May and was more prolific than the other occurring in the second week of September in protected environment and second fortnight of November in open environment. During summer months trap catch was comparatively more in open environment as compared to protected environment and can be attributed to the favourable temperature range of 25-28^{0}C resulting in high incidence of *T. vaporariorum* owing to more abundance whereas under protected conditions (polyhouse conditions) very high temperature (38-45°C) could have resulted in lower incidence of *T. vaporariorum* and thereby reducing the adult activity. Whereas in autumn crop, the environmental conditions were more favourable to the multiplication of *T. vaporariorum* under protected environment which can be attributed to comparatively higher temperature under protected environment which also influenced the adult movement of *T. vaporariorum* as suggested by Noldus *et al.* (1985).

Relationship of adult trap count with abiotic factors and population of *T. vaporariorum*

The adult catch was related positively and significantly with the maximum temperature in spring-summer crop of french bean and brinjal. However, a negative relationship was observed in autumn crop. The adult trap catch also responded positively to minimum temperature in spring-summer crop of french bean but negatively in brinjal and autumn-winter crop of french bean. The findings clearly depict a higher trap count in a high temperature regime of 22.4-32.5°C which find support from the findings of Noldus *et al.* (1985) who reported more adult movement at high temperature regime.

Relative humidity influenced the trap catch negatively and significantly in spring-summer crop of french bean and brinjal. The relationship with rainfall was also negative except in autumn-winter crop of french bean. The influences were significant in brinjal owing to more number of rainy days affecting the adult activity adversely. The findings are also supported by the positive relationship observed with sunshine hours.

Wind velocity also influenced the trap catch positively being significant in brinjal but a marginally negative relationship was evident in french bean autumn-winter crop which can be attributed to comparatively higher wind velocity in the cropping period during summer months as compared to autumn crop resulting in more adult activity. The findings of Lenteren and Noldus (1990) are supportive to present observations who recorded the flight activity of adults to be under the influence of wind. The trap catch was correlated positively with population of nymph and pupa, adults as well as infestation index except in case of brinjal where a negative and non-significant relationship was evident with the adult population and infestation index, which can be attributed to lower trap catch during rainy season owing to more number of rainy days as evident from the negative relationship between adult catch and rainfall and positive with sunshine hours.

In protected environment almost similar relationship between trap catch and abiotic factors was established as in case of open environment but the relationship being non-significant. However, trap catch was found to give a good estimate of the whitefly population under protected environment as evident from the positive correlation being significant with the immature stages, adults and infestation index in both the crops of french bean except with the adult population in spring-summer crop. Positive but non-significant relationship of the trap count was established with population parameters in brinjal. The positive relationship can be attributed to the limited flight space for the adults and comparatively high temperature in protected environment.

5.4 BIOLOGY

5.4.1 Description and Measurements of Developmental Stages

Egg: The eggs were laid singly or in small clusters of 5-6 eggs or in a circular fashion on glabrous leaves on the underside of the leaves. They were oval in shape, yellow when laid turning dark prior to hatching. Observations recorded are in conformity to Hill (1987). The average length and breadth of the eggs was 0.201 and 0.096 mm, respectively. The measurements recorded are in proximity to those observed by Dhillon (1999) who reported them to be 0.238 mm in length and 0.094 mm in breadth on tomato.

Nymph: The greenhouse whitefly had three nymphal instars which were oval and light greenish yellow in colour. They possessed functional legs on hatching but remained sessile thereafter except during moulting. The last two nymphal instars possessed setae like projections of wax. The average length and breadth of the first, second and third instars was 0.267 & 0.145 mm, 0.370 & 0.217 mm and 0.658 & 0.377 mm, respectively. The findings of Dhillon (1999) are supportive to the present observations with slight variation.

Pupa: The pupa were flattened initially but became expanded and opaque later with submarginal and dorsal setae. In the last stage, red eyes and yellow body pigment was also visible below the transparent pupal case and measured 0.700 to 0.770 mm in length and 0.385 to 0.455 mm in breadth. Byrne and Bellows (1991) and Internet Download (2) also revealed similar observations.

Adult: The adults were snowy white flies with yellow bodies and a covering of white waxy powder on wings. The females were larger than the males having body length of 0.963 mm and wing expanse of 2.613 mm, whereas in males, it was 0.844 and 2.174 mm, respectively. These observations are in close proximity being bigger to those recorded by Dhillon (1999) who reported the body length of females and males to measure 0.882 and 0.816 mm, with the wing expanse of 2.178 and 1.980 mm, respectively. But it was comparatively smaller to those recorded by Byrne and Bellows (1991) who reported the body length of females and males to be 1.06 and 0.09 mm with the wing expanse of 2.65 and 2.41 mm, respectively.

5.4.2 Annual Life-Cycle of the Whitefly

5.4.2.1 Number of generations

Under laboratory conditions, *T. vaporariorum* completed 13 overlapping generations in a year being more than reported by Isart (1977) who observed 7-8 generations in open and 8-10 generations in greenhouse on different horticultural crops in Spain. The variation in number of generations may be attributed to differences in ecological conditions.

5.4.2.2 Developmental biology

Egg: The incubation period of the eggs was found to vary between 4.7 to 6.7 and 7.3 to 12.7 days during April-May to September-October and October-November to March-April generation signifying the impact of low temperature (the maximum temperature varying between14.5-26.0°C) in prolonging the incubation period in generations occurring in winter months as compared to summer generations where the temperature ranged between 28.0-32.0°C. The results are in proximity to the observations of Hernandez and Hernandez (1972) who reported the incubation period of 8 days at 23°C and 6-7 days at 25-26°C. Also, Hill (1987) reported a longer incubation period of 9 days at lower temperature of 21°C.

The hatchability ranged between 52.8-95.5 per cent and was comparatively more during winter generations. This can be due to better osmotic potential of leaves during winters owing to lower evaporation rate which checks dessication and mortality of eggs leading to higher hatchability as observed by Castane and Save (1993) who reported leaf osmotic potential to affect the survival of the eggs of *T. vaporariorum*. Treifi (1986) also reported the mortality to be high at 22-27°C supporting the present observations.

Nymph: The duration of first, second and third instar was found to vary between 3.7-11.3, 3.3-7.7 and 4.0-8.0 days, respectively with the total nymphal period ranging between 10.0-24.0 days in different generations being more in generations during winter months. Observations of Hussey and Gurney (1957) who reported the nymphal stage to last for 9.3 days at 21.2°C and 7.7 days at 32.2°C on tomato provides partial support to the results. But the findings of Dhillon (1999) are fully supportive of the findings who reported the total nymphal period of 30.2 days at 15 °C which reduced to 9.8 days with an increase in temperature to 30°C.

The first instar nymphs experienced maximum mortality whereas it was minimum in third instar nymphs. This can be attributed to the fact that no waxy covering is laid in first nymphal instar and they have to crawl over the leaf surface for the selection of suitable site for feeding and are therefore prone to more mortality. The nymphal survival was maximum during February-March being statistically on par to April-May generation. Dhillon (1999) also found higher survival (74.6%) at lower temperature of 25±1 °C.

Pupa: The pupal period varied between 3.0-7.7 days being maximum during October-November (X) and minimum during September (VIII) being statistically on par to generations in May (III) and August-September (VII). Hussey and Gurney (1957) also recorded the pupal stage to last for 6 days at 21.2 and 29.4°C which reduced to 5.5 days at 32.2°C on tomato, whereas Kim *et al.* (1986) and Ghahari and Hatami (2000) reported it to last for 7.5 days at 25°C on cucumber and 7.7 days at 24±1°C on brinjal, respectively.

Among the different developmental stages of *T. vaporariorum*, the pupal stage experienced least mortality and resulted in survival varying between 73.9-100.0 per cent in different generations. Treifi (1986) also reported higher survival rate of 88.0-90.4 per cent in the pupal stage at 22-27°C and 79-87 per cent relative humidity. But it was comparatively higher to Dhillon (1999) who reported the pupal survival to vary between 40-74.6 per cent at 15-30°C on tomato. The variations with the present observations can be attributed to varying temperature and relative humidity conditions during the course of studies.

Total developmental period: The total developmental period indicated a pronounced effect of temperature on the rate of development in different generations. It was found to occupy 20.7-27.7 days in generations occurring during summer months of April to October (generation: II-IX) and 33.3-43.3 days in winter generations (October-April). This can be attributed to comparatively low temperature during winter generations (mean minimum and maximum temperature being 19-25 and 22-25°C) as compared to comparatively higher corresponding temperatures (22-29 and 28-32°C) in summer generations. The developmental period observed is in accordance to that reported by Garman and Jewett (1922) who recorded it to last for 21 days in summer and 41 days in winter months. Total developmental period within the summer generations also varied considerably and was of longer duration in the months of April-May (II), June (IV) experiencing comparatively higher temperature as to the minimum recorded in September (VIII) generation (mean temperature: 21.2°C). This is supported from the findings of Yano (1981) who observed the development of *T. vaporariorum* from egg to pupa to be of 22 days at 24°C which got prolonged to 32 days at a higher temperature of 30°C.

Adults: The females of *T. vaporariorum* lived longer than the males and the life span of the adults was influenced greatly by the atmospheric temperature prevailing in different generations and varied between 7.1-42.6 and 5.5-26.7 days, respectively. Longevity was comparatively more in the winter generations than in the summer generations. Hussey and Gurney (1957) had also reported the longevity of females to be more than the males being influenced by the temperature and ranged between 12-57 days in the temperature range of 21.1-26.6°C. Yano (1989) also observed an increase in life span of adults at lower temperatures.

The females out numbered the males and resulted in mean male to female ratio of 1:2.8. In contrary, Dhillon (1999) reported lower male to female ratio of 1:1.4 on tomato at 25-28°C. The variations may be attributed to the smaller sample size used for determining the sex ratio.

Fecundity: The females laid on an average 108-373 eggs during different generations being comparatively more in winter generations and the maximum correspond to the October-November (X) generation. This can be due to longer life span of females during these months. The results find support from the observations of Burnett (1949) who reported the fecundity to be of 319.5 at 18°C which decreased to 5.5 at higher temperature of 33°C.

5.4.3 Life Cycle of the Whitefly on Summer Vegetables

5.4.3.1 Ovipositional preference

The studies on the ovipositional preference of *T. vaporariorum* on different vegetable crops revealed french bean to be the most preferred for deposition of eggs by the females. This was followed by brinjal and cucumber which were on par to each other. The females showed least preference toward capsicum and chilli which can be attributed to abaxial leaf surface of these hosts.

5.4.3.2 Developmental biology

The studies on developmental biology could be initiated only on four hosts namely, brinjal, cucumber, french bean and tomato owing to complete mortality in the first and second instar nymphs on chilli and capsicum, respectively. Although, *T. vaporariorum* has been reported to be a pest of *Capsicum annum* elsewhere but in and around Palampur it was not found to infest capsicum and chilli. The present observations indicate that either the varieties of chilli and capsicum grown were resistant to *T. vaporariorum* or the strain found here was not capable to exploit these crops as its host. This draws support from the findings of Vianen *et al.* (1987) who found capsicum to be a host of *T. vaporariorum* in greenhouses of Hungary and observed no incidence in Netherlands.

The incubation period was significantly minimum on french bean followed by brinjal and cucumber which were on par to each other. The hatchability on the other hand was highest on french bean and minimum on tomato. The total nymphal period varied between 17.6-22.6 days being significantly minimum on brinjal followed by cucumber and tomato being on par to each other and was maximum on french bean. The total nymphal survival was also maximum on brinjal and minimum on french bean.

The pupal period was minimum on cucumber (6.3 days) being on par to other hosts except french bean where it was maximum (8.3 days). Pupal survival differed non-significantly in all the four hosts. The total developmental period was minimum on brinjal (23.7 days) being on par to cucumber (25.0 days) and was maximum on french bean (27.0 days). Total survival as depicted from adult emergence was maximum on brinjal (76.4%) and was on par to cucumber and minimum on tomato (26.7%) being on par to french bean. The differences with regard to male and female longevity and fecundity were non-significant among the four hosts.

On the basis of the growth indices worked out, brinjal was found to be the most suitable host for the development of *T. vaporariorum* followed by cucumber, french bean and tomato.

The observations find support from the findings of Boxtel *et al.* (1978), Marendonk and Lenteren (1978) and Kamp and Lenteren (1981) who reported the lowest mortality, highest fecundity and rapid development on brinjal followed by cucumber, tomato and paprika (*Capsicum annum*).

5.5 BIOEFFICACY OF INSECTICIDES

5.5.1 Intrinsic Toxicity

Bioassay studies carried out to determine the order of toxicity of six insecticides following leaf dip method against the adults of *T. vaporariorum* on the basis of LC_{50} values revealed imidacloprid, acetamiprid, MTI-446, triazophos, dimethoate and acephate to be the decreasing order of toxicity with respective LC_{50} values of 0.0029, 0.0036, 0.0047, 0.0065, 0.0245 and 0.0257 per cent. Taking acephate as unity, the corresponding relative toxicities worked out were 8.86, 7.14, 5.47, 3.95 and 1.05 for imidacloprid, acetamiprid, MTI-446, triazophos, and dimethoate. The neonicotinoids, imidacloprid and acetamiprid were found to be most toxic which can be attributed to their ability to withstand metabolism by esterases.

Information regarding intrinsic toxicity of insecticides to *T. vaporariorum* was scanty threfore toxicity of insecticides to a related species *Bemisia tabaci* is being used to discuss the present findings. Cahill *et al.* (1996) found the LC_{50} value of imidacloprid to be 1.7 ppm against *B. tabaci* in Spain. The LC_{50} values of dimethoate (859 mg/g) recorded by Zheng *et al.* (1997) against *T. vaporariorum* in China was comparatively low to the present observations. Chinnabbai *et al.* (2000) calculated LC_{50} values of triazophos, acephate, acetamiprid and imidacloprid to be 0.02, 0.29, 0.003 and 0.063 per cent against *B. tabaci* being higher to recorded against *T. vaporariorum* in the present studies.

5.5.2 Field Efficacy

5.5.2.1 Efficacy against immature stages

The field efficacy of nine insecticides against *T. vaporariorum* on french bean under protected environment revealed imidacloprid (0.05%) followed by acetamiprid (0.004%), MTI-446 (0.007%) and dimethoate (0.025%) to be the most effective in reducing the population of immature stages (nymph and pupa). One day after treatment (DAT) all the synthetic insecticides except acephate resulted in significantly higher reduction in population of immature stages and maximum (82.58%) coincided with acetamiprid followed by imidacloprid. Almost a similar trend was observed 7 DAT, with MTI-446 being the most effective treatment and on par to imidacloprid and acetamiprid. The effectiveness of the botanical insecticide azadiractin and microbial insecticide *B. bassiana* also increased significantly as compared to 1 DAT. However 14 DAT, buprofezin brought about the highest reduction in population being on par to imidacloprid.

5.5.2.2 Efficacy against adult whiteflies

Efficacy of insecticides evaluated against adults revealed that 1 DAT, MTI-446 showed the maximum reduction in population (91.27%) being on par to imidacloprid, azadiractin and acetamiprid. After 7 DAT also MTI-446 remained the most effective treatment giving the maximum reduction in population over control and was on par to dimethoate and imidacloprid. However 14 DAT, buprofezin became significantly superior treatment giving maximum reduction in adult population (98.06%) over untreated check and was followed by acetamiprid which in turn was on par to dimethoate, imidacloprid and MTI-446. Overall MTI-446 (0.007%) remained the most effective treatment while the microbial formulation of *B.bassiana* was found to be least effective.

Naba *et al.* (1983) also reported 2-3 high volume sprays of buprofezin at weekly intervals to give an effective control of the nymphs of *T. vaporariorum* on beans. Whereas, Cresswell *et al.* (1994) observed a single dose of acephate to be effective against the immature stages. Observations of Orozco *et al.* (1998) and Zhu *et al.* (1998) regarding the effectiveness of imidacloprid in checking the whitefly population are supportive to the present observations. The efficacy of imidacloprid and *B. bassiana* against *T. vaporariorum* was also established in greenhouses (Anon., 2001). But contrary to their findings and the observations of Dirlbeck (1988) who reported *B. bassiana* to be effective against *T. vaporariorum*, the formulation was found to be least effective in present studies which may be attributed to low humidity (relative humidity: 38-45%) during the period of experimentation. The results pertaining to acetamiprid are also supported by the observations of Zabel *et al.* (2001) who reported it to be very effective in controlling *T. vaporariorum* on tomato. Bene *et al.* (2000) has also reported the botanical formulation of Neem to give 69 per cent mortality in nymphs of *T. vaporariorum*.

SUMMARY

SUMMARY

Studies on the 'Bionomics and Management of the Whitefly on Summer Vegetables' were conducted under laboratory and field conditions during 2001-02 at Palampur. The results obtained are summarized in this chapter.

1. The whitefly associated with crops in and around Palampur was identified to be greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae).

2. Host range studies revealed 44 plant species belonging to 20 families to be infested by *T. vaporariorum*, with the major proportion of plant species falling in the family Solanaceae, Compositae and Malvaceae. The host plants comprised of six vegetable crops, two field crops, twenty nine ornamental plants, three medicinal plants and four weed hosts. Under field conditions (open environment), *T. vaporariorum* infested 24 plant species with the abundance being high to very high on 7 host plants namely hydrangea (*Hydrangea microphylla*), primula (*Primula* spp.), hollyhock (*Althea rosea*), flemingo plant (*Jacobina carnea*), tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*) and nasturtium (*Tropoaeolum majus*). Whereas under protected environment, 23 plant species were observed to be the host plants of *T. vaporariorum*, the incidence being high to very high on eight host plants namely abutilon (*Abutilon hybridum*), *Primula* spp., variegated duranta (*Duranta sellowiana*), *J. carnea*, *C. sativus*, *L. esculentum*, fuschia (*Fuschia magellanica*) and patchy-stachys (*Pachystachis lutea*). Salvia and fuschia continuously supported the breeding population of *T. vaporariorum* throughout the year under open as well as protected environment.

Six plant species namely, bougainvillea (*Bougainvillea* spp.), calendula (*Calendula officinalis*), chrysanthemum (*Dendranthema grandiflora*), dahlia (*Dahlia variabilis*), dhatura (*Datura stramonum*) and pansy (*Viola tricolor*) were designated as the hosts for adult feeding only as no developmental stages were encountered on them. Among the host plants of *T. vaporariorum* observed, 39 species are being recorded for the first time from Himachal Pradesh and 37 species seems to be the new record from India.

3. In spring-summer crop of french bean, incidence of the whitefly initiated in the second week of April under field conditions (open environment) whereas under protected environment, the incidence was recorded a week earlier to open environment. Incidence was comparatively more in open environment with the peak of activity in early May whereas under protected environment it occurred in the second fortnight of May. In autumn crop of french bean under protected environment, the infestation was first recorded in the last week of August with peak of infestation occurring in the second week of September whereas in open environment, the incidence initiated in the first week of October with peak activity during last week of October.

   In case of brinjal grown under open environment (field conditions), incidence of *T. vaporariorum* initiated in the first week of May with peak of infestation occurring in the second fortnight of June. Whereas under protected environment, the infestation began only two weeks after transplanting in the third week of April with two peaks of infestation, one during the last week of June and the other during second week of September.

   The infestation index under open as well as protected environment with abiotic factors exerted a non-significant correlation in spring-summer crop of french bean and brinjal. A significant positive relationship with maximum temperature under protected environment in autumn french bean and a negative and significant relationship with the infestation index under open environment was observed. Other factors were related non-significantly.

Significantly higher proportion of nymphs was distributed in the middle canopy of french bean and brinjal whereas the proportion of pupa were found more in lower canopy. In brinjal, the proportion of adult population was significantly higher in the upper canopy whereas in french bean the proportion of adult population though was higher in upper canopy but was on par to that observed in the middle canopy.

The adult activity of *T. vaporariorum* monitored using yellow sticky traps revealed it to begin in third week of March under open environment and in the first fortnight of April under protected environment. Two peaks of trap catches were observed, the first being in May under both conditions and the other was recorded in second week of September in protected environment and second fortnight of November under open environment conditions.

The adult trap catch had a significant positive relationship with maximum temperature and sunshine hours in spring-summer crop of french bean and brinjal Under open environment and a negative correlation was evident with relative humidity. Wind velocity also influenced the trap catch positively in both the crops being significant in brinjal only. Similar but negative trend was observed in case of rainfall. In autumn crop of french bean the trap count exhibited a non-significant correlation with the abiotic factors as well as the population of *T. vaporariorum*.

Under protected environment, trap catch in french bean and brinjal resulted in a non-significant relationship with the abiotic factors. But the catch had a positive correlation with population count in both french bean and brinjal.

4. The females of the greenhouse whitefly deposited eggs singly or in clusters of 5-6 on the underside of leaves whereas on glabrous leaves a circular pattern of egg laying was observed. The eggs were oval and yellow when

laid and turned dark prior to hatching and measured 0.201 mm in length. *T. vaporariorum* passed through three nymphal instars which were oval in shape and light greenish yellow in colour. They possessed functional legs on hatching but remained immobile thereafter except during moulting. The second and third nymphal instars possessed setae like projections of wax with the corresponding average length and breadth of the first, second and third instars being 0.267 & 0.145 mm, 0.370 & 0.217 mm and 0.658 & 0.377 mm. The pupa of *T. vaporariorum* was flattened and oval like a scale initially and became opaque and expanded with submarginal and dorsal setae later. In the last stage, red eyes and yellow body pigment was also visible below the transparent pupal case. The mean length and breadth of the pupa was 0.728 and 0.415 mm, respectively. The adults were the white snowy flies with yellow bodies. The females were larger (0.963 mm) than the males (0.844 mm) and had a wing expanse of 2.613 and 2.174 mm, respectively.

T. vaporariorum completed 13 overlapping generations in a year under laboratory conditions at Palampur. The incubation period varied between 4.7-6.7 and 7.3-12.7 days during summer (April-May to September-October) and winter generations (October-November to March- April), respectively. Hatchability was more in winter generations. The durations of the first, second and third instar varied between 3.7-11.3, 3.3-7.7 and 4.0-8.0 days, respectively, in different generations occupying comparatively more in winter generations. The first instar experienced maximum mortality and the least was observed in third instar nymphs. The pupal stage experienced the least mortality among the different developmental stages. Pupal period varied between 3.0-7.7 days amongst different generations. Total developmental period was of shorter duration (20.7-27.7 days) in summer generations of April to October than in winter generations (33.3-43.3 days). The survival in different generations varied from 36.7-74.2 per cent, being comparatively more in winter generations.

The longevity of adults was influenced by the prevailing atmospheric temperature and a longer life span was observed in the generations through low temperature regime. The females lived longer than the males and the longevity ranged between 7.1-42.6 and 5.5-26.7 days, respectively in different generations. The females outnumbered the males and a mean ratio of 1: 2.8 in respect to male and female was recorded. The females on an average laid 108-373 eggs in different generations, being comparatively more during winter generations.

5. The oviposition preference of *T. vaporariorum* recorded on six summer vegetables in a free choice test revealed the order of preference to be french bean > brinjal ≥ cucumber > tomato > capsicum > chilli. On chilli and capsicum no nymphal survival beyond first and second instar was observed. Among the four vegetable hosts, the incubation period was minimum and hatchability maximum on french bean. The nymphal duration was minimum on brinjal but the pupal duration was minimum on cucumber. The survival to adult emergence was more on brinjal followed by cucumber and was minimum on tomato. Variation in respect to adult longevity and fecundity were non-significant amongst the four hosts. The growth indices calculated on the basis of developmental period and survival suggested brinjal to be the most suitable host followed by cucumber, french bean and tomato.

6. The toxicity of six insecticides to adults of *T. vaporariorum* was evaluated following leaf dip bioassay. Imidacloprid was ranked to be the most toxic insecticide followed by acetamiprid, MTI-446, triazophos, dimethoate and acephate with the corresponding LC_{50} values of 0.0029, 0.0036, 0.0047, 0.0065, 0.0245 and 0.0257 per cent.

The field efficacy of nine insecticides against *T. vaporariorum* on french bean under protected environment revealed the synthetic insecticides namely acetamiprid (0.004%), dimethoate (0.025%), imidacloprid (0.05%), MTI-446 (0.007%) and triazophos (0.03%) except acephate (0.05%) to be most effective after one day of treatment (DAT) against immature stages and the botanical insecticide azadiractin exerting significant influences on adult population. Whereas 7 DAT, the botanical insecticide azadiractin and microbial insecticide *Beauveria bassiana* (7.5×10^6 cfu/ ml) also showed improved efficacy against the population of immature stages and adults. However 14 DAT, the growth regulator, buprofezin (0.02%) proved to be the most effective and resulted in reduction in proportion of immature stages and adults to the extent of 98.01 and 98.06 per cent. Insecticides belonging to neonicotinoid group of insecticides proved to be the most effective in checking the population of *T. vaporariorum* whereas azadiractin was effective only up to 7 DAT suggesting repetitive applications and buprofezin showing a delayed effect on population control.

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* Original seen

APPENDICES

Appendix – I

Weekly Temperature and Relative Humidity Data under Laboratory Conditions during the Study Period

Week	Temperature (°C)		Relative humidity (%)
	Minimum	Maximum	
February 1, 2001	24.3	10.2	40.0
7	24.2	13.4	43.5
14	22.0	13.6	43.0
21	22.2	15.8	50.0
28	23.2	16.4	68.5
March 7	23.0	12.0	69.2
14	23.7	11.8	78.0
21	25.3	13.5	85.5
28	26.4	14.8	85.7
April 4	28.5	15.5	83.6
11	31.8	19.5	86.4
18	29.0	20.5	73.0
25	31.2	22.8	49.5
May 2	33.0	25.0	55.0
9	34.4	24.8	46.3
16	28.8	21.4	62.9
23	32.3	24.8	50.9
30	33.4	24.3	59.6
June 6	30.0	23.0	69.9
13	28.3	24.5	68.4
20	26.3	25.0	62.5
27	27.7	26.1	73.4
July 4	29.1	30.6	77.9
11	29.7	28.7	82.1
18	28.0	26.4	71.2
25	28.0	26.1	66.1
August 1	27.2	26.3	70.8
8	28.7	26.8	78.6
15	29.4	27.7	77.8
22	27.9	25.6	68.8
29	26.7	24.6	64.2
September 5	27.9	25.6	54.0
12	28.4	25.4	50.5
19	28.1	27.5	46.4
26	30.4	28.4	43.9
October 3	28.8	27.6	47.5
10	29.3	27.6	36.2

Continued

Week	Temperature (°C)		Relative humidity (%)
	Minimum	Maximum	
17	28.6	26.1	30.7
October 24	28.1	26.8	31.2
31	27.4	24.9	32.5
November 7	25.7	23.4	27.3
14	27.7	23.6	29.3
21	25.8	20.7	31.6
28	20.9	17.3	31.9
December 5	23.9	18.4	32.4
12	18.9	14.7	42.5
19	24.6	17.8	34.1
26	21.7	15.8	33.9
January 2, 2002	21.7	16.7	31.4
9	21.3	16.4	36.2
16	19.1	13.4	50.2
23	20.0	14.3	35.3
30	18.4	14.4	34.0
February 6	17.4	13.9	45.4
13	18.5	14.1	42.1
20	19.0	14.9	39.3
27	20.3	15.4	37.7
March 6	21.7	16.6	37.9
13	24.3	20.1	42.7
20	24.6	21.7	35.4
27	25.7	21.0	29.4
April 3	27.5	22.5	27.5
10	28.4	24.0	28.5
17	29.6	25.5	31.0
24	31.5	27.5	28.0
May 1	32.0	28.0	23.0
8	35.0	30.0	22.5
15	33.0	30.0	27.5
22	32.5	29.0	42.5
29	30.0	26.0	47.5
June 5	29.0	26.0	47.5
12	31.0	28.0	46.0
19	30.0	28.0	49.0
June 26, 2002	32.0	28.5	51.0

Appendix – II

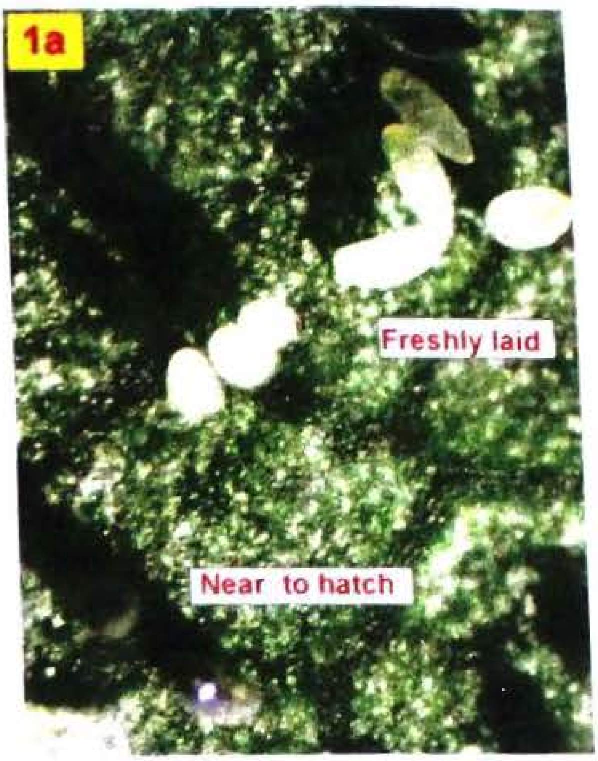
Weekly Weather Data under Open Environment (Field Conditions)

Week	Temperature (°C)		Relative humidity (%)	Rainfall (mm/week)	Sunshine hours	Wind velocity (kmph)
	Minimum	Maximum				
March 18, 2001	10.5	22.9	41.5	2.3	7.5	6.5
25	10.8	22.4	42.0	14.9	5.3	6.3
April 1	11.1	23.8	39.5	36.5	8.1	5.9
8	14.4	29.6	32.0	0.0	9.6	6.2
15	15.9	27.4	41.5	11.4	4.7	6.7
22	11.8	22.4	51.5	52.3	5.4	5.1
29	17.7	29.9	46.5	0.0	9.5	5.3
May 6	18.6	31.6	31.5	0.0	10.6	5.8
13	19.7	32.5	40.5	7.3	9.3	5.8
20	17.0	27.9	58.5	14.2	4.3	4.3
27	18.2	29.4	44.0	7.9	9.4	5.7
June 3	17.6	28.3	60.0	78.6	6.5	4.3
10	17.1	27.5	63.5	25.6	5.8	3.8
17	19.0	28.0	78.0	53.3	3.6	3.4
24	17.4	27.1	70.0	56.2	5.8	3.5
July 1	18.4	28.1	81.0	61.5	5.6	2.5
8	20.0	27.9	82.5	114.1	3.7	2.7
15	19.9	26.9	85.5	247.5	2.1	2.7
22	20.1	26.9	84.5	106.5	3.0	2.5
29	19.5	26.2	84.0	128.8	1.9	2.5
August 5	19.5	26.4	79.0	170.4	4.1	2.5
12	20.2	27.9	79.0	193.1	3.5	1.9
19	19.8	28.6	80.5	168.1	2.9	0.0
26	19.0	27.2	84.0	70.4	4.3	2.9
September 2	19.0	27.3	76.0	52.4	5.8	3.3
9	17.5	27.4	69.5	30.5	7.1	3.9
16	15.6	26.9	61.5	20.1	6.0	4.3
23	16.4	27.4	51.5	0.0	9.8	3.9
30	15.4	28.0	63.0	0.0	9.9	4.4
October 7	12.5	25.1	65.0	1.6	7.9	4.1
14	11.2	26.0	50.0	0.0	9.3	4.5
21	12.9	25.0	45.5	0.0	9.5	4.2
28	14.5	25.9	51.5	0.0	8.6	3.9
November 4	14.2	25.5	53.0	0.1	6.6	5.0
11	9.8	22.5	37.5	1.2	8.6	4.4
18	10.2	22.5	39.0	0.0	9.5	4.5
25	9.3	22.1	46.5	0.0	8.9	4.3
December 2	8.4	20.6	47.0	0.0	7.8	4.2
9	8.6	21.3	39.5	0.0	6.5	3.8
16	7.3	20.4	49.0	17.6	4.8	4.6
23	5.2	17.2	47.5	5.0	6.4	4.0
30	5.3	17.4	52.0	0.0	7.9	4.0
January 6,2002	4.0	18.6	59.0	0.0	8.0	4.4

Appendix – III

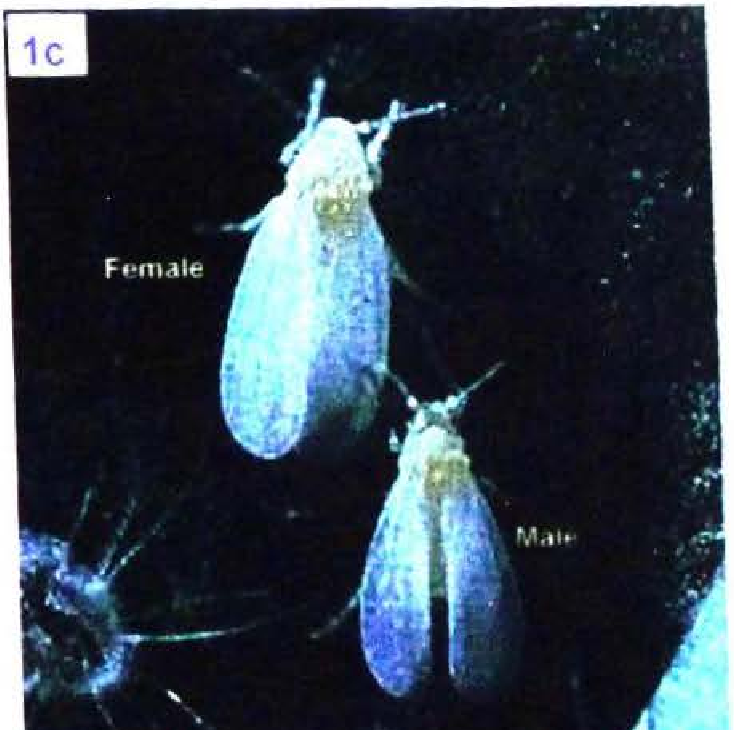
Weekly Weather Data under Protected Environment (Polyhouse) during 2001

Week	Temperature (°C)		Relative humidity (%)
	Minimum	Maximum	
April 1	17.0	33.0	33.0
8	16.0	29.0	54.0
15	17.0	41.0	40.0
22	17.0	41.0	35.0
29	16.3	41.3	28.5
May 6	15.5	16.4	30.9
13	16.6	45.7	46.6
20	21.6	43.6	42.7
27	19.0	44.0	39.0
June 3	18.0	38.0	48.5
10	22.0	34.0	61.5
17	18.0	36.0	66.0
24	20.0	22.0	68.0
July 1	22.0	37.0	76.5
8	23.0	36.0	76.0
15	19.0	35.0	74.5
22	22.0	31.0	79.5
29	22.0	34.0	78.5
August 5	23.0	38.0	77.5
12	22.0	35.0	82.5
19	21.0	35.0	76.5
26	21.0	36.0	71.0
September 2	19.0	39.0	66.5
9	18.0	36.0	63.0
16	19.0	44.0	57.0
23	18.0	43.0	51.0
30	15.0	39.0	51.0
October 7	15.0	39.0	42.5
14	14.0	36.0	35.0
21	15.0	37.0	58.5
28	12.4	27.6	40.0
November 4	12.4	32.7	40.6



Eggs
(L: 0.201+0.014mm; B: 0.096+0.015 mm)

Egg laying pattern on glabrous leaves

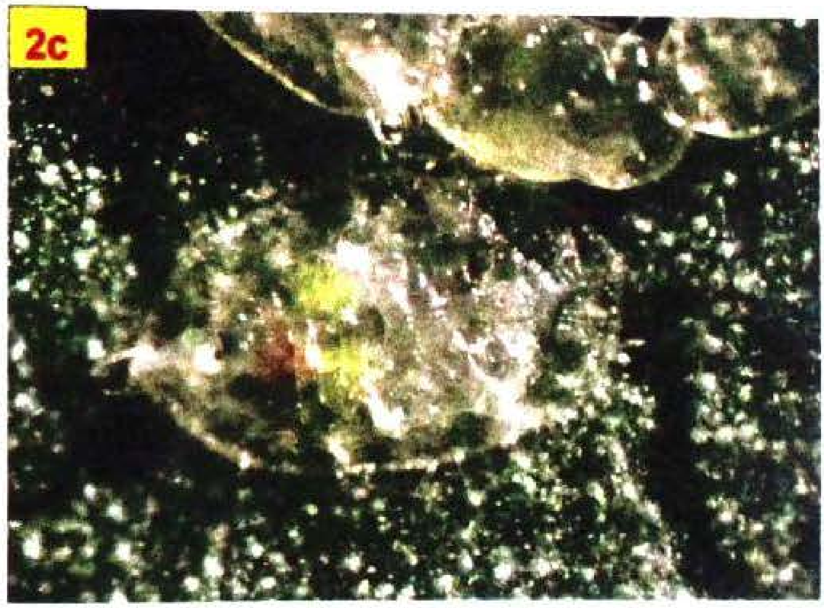


Adults
(Male: 0.844+0.043 mm. Female: 0.963+0.042 mm)

Plate 1. Eggs and Adults of *Trialeurodes vaporariorum*

First Instar Nymphs
(L: 0.267+0.019mm; B: 0.145+0.015 mm)

Second Instar Nymphs
(L: 0.370+0.025mm; B: 0.217+0.020 mm)

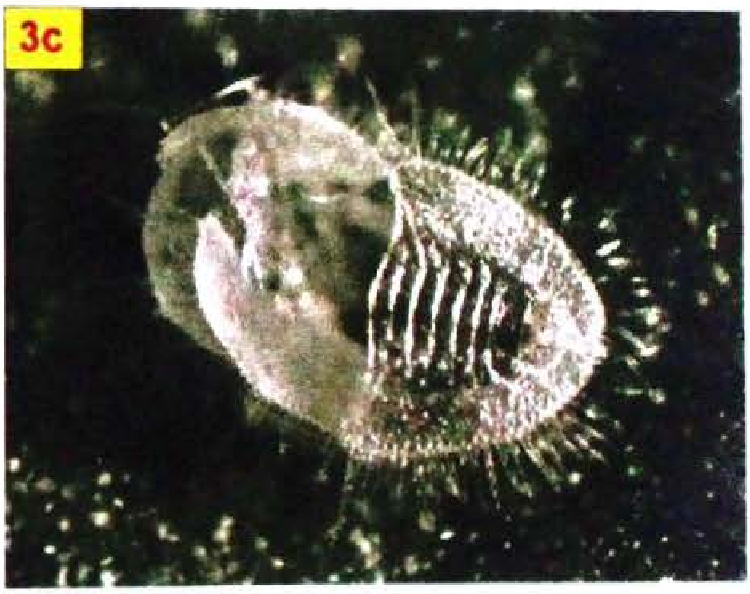


Third Instar Nymph
(L:: 0.658+0.023mm; B: 0.377+0.021 mm)

Plate 2. Different Nymphal Instars of *Trialeurodes vaporariorum*

Lateral View of Pupa

Pupa
(L: 0.728+0.043mm, B: 0.415+0.019 mm)



Pupal Case

Plate 3. Pupa of *Trialeurodes vaporariorum*

Title of the Thesis	:	**Bionomics and Management of the whitefly on summer vegetables**
Name of the Student	:	**Sonika Sood**
Admission No.	:	A-2000-30-21
Major Subject	:	Entomology
Minor Subject	:	Plant Pathology
Degree	:	M.Sc.
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ABSTRACT

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) was found to infest 44 host plants belonging to 20 families in and around Palampur (1290masl). These hosts comprised of 6 vegetable crops, 2 field crops, 29 ornamental plants, 3 medicinal plants and 4 weed hosts. Seasonal abundance of *T. vaporariorum* on french bean and brinjal recorded under open and protected environment revealed it to remain active throughout the cropping season with peak of activity occurring in June and October, the incidence being higher under open environment. The infestation established a positive and significant relationship with maximum temperature prevailing during autumn winter crop in open environment and a negative relationship during summer crop under protected environment. Distribution of different stages of greenhouse whitefly with in plants showed that the proportion of nymphs, pupae and adults was more in middle, lower and upper canopy, respectively, in both french bean and brinjal. Adult activity monitored using yellow sticky traps revealed the activity to begin in March under open and in April under protected environment resulting in two peaks of activity, one during May and the other in September. *T. vaporariorum* completed 13 overlapping generations in a year under laboratory conditions. The total developmental period was comparatively longer in generations occurring during winter months of October-November to March-April (33.3-43.3 days) than during April-May to September-October (20.7-27.3 days) with the survival ranging between 36.7 to 74.2 per cent. The females lived longer (7.1-42.6 days) than males (5.5-26.7 days), the adult longevity being more during winter generations. The females out-numbered the males and laid on an average 108-373 eggs in different generations. Observations recorded on ovipositional preference to different vegetable hosts revealed the females to oviposit more on french bean followed by brinjal, chilli being the least preferred. The growth indices based on developmental period and survival revealed brinjal to be the most suitable host followed by cucumber, french bean and tomato. However, on chilli and capsicum the nymphs could not survive beyond first and second instar. The relative toxicity based on LC_{50} values of different insecticides to adults of *T. vaporariorum* based on leaf dip bioassay revealed the order of toxicity as imidacloprid (0.0029%), acetamiprid (0.0036%), MTI-446 (0.0047%), triazophos (0.0065%), dimethoate (0.0245%) and acephate (0.0257%). The field efficacy of nine insecticides tested against the whitefly on french bean revealed MTI-446 (0.007%), imidacloprid (0.05%) and acetamiprid (0.004%) to be the most effective while azadiractin (0.00045%) was effective only up to 7 days in checking the population of *T. vaporariorum*. Buprofezin (0.02%) showed a delayed effect on population control and resulted in up to 98% reduction in population 14 days after application.

Sonika 5/10/02

(Signature of the student with date)

(Signature of Major Advisor)

Countersigned
Head of Department