Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region

Thesis

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By

Chenesh Patel
Id. No. 48090

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(Chenesh Patel)
Author

March, 2021
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CERTIFICATE - I

This is to certify that the thesis entitled **"Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region"** submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** with major in **Entomology** and minor in **Plant Pathology**, of the College of Post-Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, is a record of bonafide research carried out by **Mr. Chenesh Patel, Id. No. 48090** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

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Pantnagar
March, 2021

(R.M. Srivastava)
Chairman
Advisory Committee

CERTIFICATE - II

We, the undersigned, members of the Advisory Committee of **Mr. Chenesh Patel, Id. No. 48090**, a candidate for the degree of **Doctor of Philosophy** with major in **Entomology** and minor in **Plant Pathology**, agree that the thesis entitled **"Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region"** may be submitted in partial fulfilment of the requirements for the degree.

(R.M. Srivastava)
Chairman
Advisory Committee

(Meena Agnihotri)
Member

(Yogendra Singh)
Member

(J.P. Jaiswal)
Member

(Ex-Officio Member)
Head of the Department

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LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Percent
CD	:	Critical Difference
cm	:	Centimeter
d.f	:	Degree of freedom
et al.	:	Etali (Co-workers)
FS	:	Foliar spray
g	:	Gram
ha	:	Hectare
Ha^{-1}	:	Per hectare
Hr.	:	Hour
Kg	:	Kilogram
Km	:	Kilometer
kmph	:	Kilometer per hour
lit	:	Litre
lits	:	Litres
m	:	Metre
MSE	:	Error mean squares
NS	:	Non-Significant
PTC	:	Pre-treatment count
RBD	:	Randomized Block Design
ROC	:	Reduction over control
SEm	:	Standard Error of Mean
SL	:	Soluble liquid
SS	:	Second spray
ST	:	Seed treatment
viz.,	:	Videlicet (namely)
WG	:	Water dispersible granule
WP	:	Wettable powder

Introduction

Chapter 1 INTRODUCITON

Whitefly (Hemiptera: Aleyrodidae) is a cryptic phloem-feeder and vector of plant viruses with great genetic diversity and has been recognized as a global agricultural pest **(Dinsdale *et al*., 2010; De Barro *et al.,* 2011)**. The word whitefly has been derived from the white, wax-like substance that coats their body, particularly the wings **(Bogran and Heinz, 2000)**. The species shares many characteristics with other homopterans *i.e.,* piercing-sucking mouthparts, opisthognathous, membranous wings, arrhenotokous reproduction system (non-fertilized eggs are haploid males and fertilized eggs are diploid females) and incomplete metamorphosis (**Mahalakshmi *et al*., 2015; Shah *et al*., 2015)**. It is one of the world's worst invasive alien species and is reported from all continents except Antarctica. Approximately, 161 genera containing 1,556 species of whitefly have been described till 2007 **(Martin and Mound, 2007)**. However, in the last 25 years only two whitefly species *viz.,* the sweet potato whitefly, *Bemisia tabaci* (Gennadius) and the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) have been identified as major pests, both under greenhouse and open field conditions **(Nauen *et al*., 2014)**.

Globally, whitefly has become a serious pest due to its polyphagous nature and diverse ways of damaging crops **(Rekha *et al*., 2005; Ramazeame, 2012)**. Whitefly extracts large quantities of sap from plant phloem which results in decreasing plant vigour and growth and cause uneven ripening of fruits **(Perring, 2001; Jones, 2003)**. They excrete sticky honeydew on leaves which induces sooty mould growth and hence reduces the photosynthetic potential of the plant and often causes stunting **(Jones, 2003).** The infected fruits become unsightly and unsalable **(Byrne and Bellows Jr, 1991; Inbar and Gerling, 2008)**. Whitefly serves as vectors for many damaging plant viruses **(Jones, 2003)**. More than 150 plant viruses, responsible for over 40 diseases of important crops plants worldwide resulting in yield loss ranging from 10 to 100 per cent are known to be transmitted by whiteflies **(Singh and Mahant, 1989; Singh *et al*., 1994; Polston and Anderson, 1997; Jones, 2003)**. The damage done by the whitefly is further exacerbated due to its adaptation on wide host range, more than 900 plant species belonging to Asteraceae, Compositae, Cruciferae, Cucurbitaceae, Euphorbiaceae, Fabaceae, Labiatae,

Leguminosae, Malvaceae and Solanaceae plant families **(Mound and Halsey, 1978; Johnson *et al*., 1982; Elsey and Farnham, 1994; Bayhan *et al*., 2006; McKenzie *et al*., 2014).**

The problem is further magnified due to the high reproductive potential, fecundity and shorter life cycle (11-15 generations/year) **(Brown *et al*., 1995)**, of this insect under a wide range of environmental conditions. Their lifecycle varies according to temperature and host plant. The whitefly lifecycle consists of 6 stages (egg, 4 nymphal stages and adult). The adult female inserts a small egg into a slit in leaf made or into a stoma, made by the ovipositor. It then hatches into a mobile-first instar nymph (crawler) **(Byrne and Bellows Jr, 1991)**. Second, third and fourth instar nymphs are stationary, with the fourth instar entering a non-feeding puparial stage which gives rise to adult whitefly via a T-shaped slit in the puparium **(Byrne and Bellows Jr, 1991)**. The life cycle is dependent on the abiotic factor *viz*., temperature and host plant species. It can range between 14-60 days, but normally *Bemisia* spp. completes its life cycle in 20 days at 26.67 °C. The average total developmental period from egg to adult recorded was 20.85±0.90 days for male and 23.14±0.69 days for female **(Chintkuntlawar *et al*., 2016)**. On tomato total life cycle completes in 22.0 days **(Takahashi *et al*., 2008; Ramazeme *et al*., 2014)** and 20.88 on eggplant **(Ghahari and Hatami, 2000)**.

The magnitude of infestation and the nature of extent of damage varies with seasons and localities **(Basu, 1995)**. Adult whitefly population in tomato was present throughout the growing period reaching to the peak during mid-February and the highest infestation level was recorded from mid-February to mid-March in the field and from February to March in the greenhouse **(Lin *et al*., 2007)** while the highest level of infestation in brinjal was recorded during October-November **(Choudhary and Gaur, 2009)** reaching to its peak during January **(Dhatonde and Pandya, 2014)**. Whitefly population showed a positive correlation with all the abiotic factors such as temperature, relative humidity and precipitation **(Purohit *et al*., 2006; Rao and Chari, 1993; Meena *et al*., 2013; Shera *et al*., 2013; Zia *et al*., 2013)**. Temperature is the most crucial abiotic factors influencing the rate of growth and development of this insect. However, relative humidity and temperature are the chief weather parameters that largely affect the activity of whitefly, while heavy and prolonged periods of rain

can substantially reduce the population **(Rafiq *et al.*, 2008)**. In case of tomato and brinjal crop, the peak population of whitefly was observed at a temperature range of 16.8-30.5° C and 26-35° C, the average relative humidity of 61.5 per cent and 84 to 67 per cent and rainfall 162 mm and zero, respectively **(Barde, 2006; Selvaraj and Ramesh, 2012).**

To reduce crop damage, accurate identification of insect-pests/virus vectors is a prerequisite **(Brown, 2000)**. The adult whitefly species can be distinguished on the base of morphological characters *viz.*, structure of the antenna **(Maskell, 1895)**, the number of ommatidia connecting the upper and lower lobes **(Hulden, 1986)**, wing venation and distribution of abdominal wax gland **(Martin and Mound, 2007)**. However, fourth instar nymph, also called puparium stage was considered to be more useful for morphological studies than the adult stage, making the whitefly taxa separation (genera and species) **Hodges and Evans (2005); Suh and Hodges (2008)**. The morphological features *viz*., shape, colours, the wax filaments and their arrangement, spines, hairs, pores and many others are taken into consideration for identification **(Hodges and Evans, 2005)**. Sometimes, phenotypic variability and plasticity nature of whiteflies make the morphological separation of species inconclusive or impossible. The *B. tabaci* complex is an excellent example of a cryptic species for which molecular markers are used to identify and distinguish between the species.

Different molecular markers had been used by several workers to analyze genetic diversity, which amplify various specific fragments linked to genes in the whitefly genome such as RAPD-PCR by **Lima *et al.* (2000); Lima *et al.* (2002); Fontes *et al.* (2010)**, Mitochondrial Cytochrome Oxidase I (mt COI) by **Chu *et al.* (2010); Rocha *et al.*, (2011)**, Internally transcribed spacer 1 sequence (ITS1) by **Boykin *et al.* (2007)** and AFLP markers by **Cervera *et al.* (2000)**. Analysis of the mitochondrial cytochrome oxidase I (mt COI) gene of worldwide collections of the whitefly has greatly improved the understanding of the genetic diversity of the whitefly species complex **(Hebert *et al.*, 2003; Bosco *et al.*, 2006; Dinsdale *et al.*, 2010)**.

Increasing whitefly load over the last few years has led to the upsurge in applications of insecticides as the sprays are introduced early in the season. Chemical control is mostly used for the management of whitefly but chemical applications alone

are not sufficiently effective to suppress all developmental stages of the pest due to the presence of waxy shelters **(James, 2003).** The excessive chemical application has several drawbacks like resistance development in insects against these chemicals, subsequent population outbreaks **(Palumbo *et al*., 2001)** and harmful impact on natural enemies **(Gonzalez-Zamora *et al*., 2004)**.

Therefore, there is an urgent need to develop alternative control methods like the use of reduced-risk sprays (RRSs) *viz*., vegetable oils, insecticidal soaps and plant extracts. These tactics have less health and environmental impacts than conventional pesticides **(Fraser, 2005)**. Several reduced-risk sprays have been tested against *T. vaporariorum* and *B. tabaci* (Gennadius) as toxicants, repellents, deterrents or antifeedants **(Larew and Locke, 1990; Mele *et al.*, 1992; Buta *et al.*, 1993; Simmonds *et al.*, 2002; Choi *et al.*, 2003; Chiasson *et al.*, 2004; Pavela and Herda, 2007; Schuster *et al.*, 2009)**. These essential oils can be effectively incorporated in integrated pest management programs.

Statement of the problem

Globally, 1,556 species of whitefly have been reported to feed over 900 host plant species. Some peculiar properties like high reproductive rate, readily dispersion among host plants, breeding throughout the year and vector of several diseases and biotype makes it one of the most destructive pest. The management of whitefly is a challenging task because very limited data is available regarding the incidence, biotypes and associated hosts of whitefly, under Uttarakhand condition. This situation warrants to search for more effective tactics to manage this pest and overcome the crisis.

Justification

The survey has to be carried out to understand the biology, distribution and biotypes of the vector and its associated hosts throughout Uttarakhand to develop effective management strategies. Sufficient knowledge about the seasonal activity of the pest is also necessary for adopting suitable control measures in a particular region. Molecular and morphological studies are rapid and accurate techniques for whitefly biotype detection and subsequent identification to facilitate studies of whitefly

epidemiology and genetic diversity. Therefore, the present studies have been undertaken with the following objectives:

1. Survey for the identification and diversity of potential reproductive hosts of *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in Uttarakhand.
2. To study the seasonal incidence of *Bemisia tabaci* (Gennadius) on tomato and brinjal crop ecosystem at Pantnagar.
3. Host preference, ovipositional suitability and biotic potential of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in selected vegetable crops.
4. Comparative morphological studies of life stages of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood).
5. Distribution and phylogenetic analysis of whitefly species from North-Western region of Uttarakhand.
6. Repellent and oviposition deterrent effects of selected plant essential oils against *Bemisia tabaci* (Gennadius).

Review of Literature

Literature on different aspects of the present study is surveyed and presented as under:

2.1 Survey for the identification and diversity of potential reproductive hosts of *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in Uttarakhand.

Martinez *et al.* (2000) carried out an extensive survey in Paraná state to identify the available *Bemisia tabaci* (Genn.) biotypes, their host plants and their geographical distribution. About sixty-six per cent of the sampled area shows the presence of whitefly and both biotype A and B in Paraná, however, the B biotype was present only in the north region. Although biotype B possess a wider range of host plants, it was confined only to the northern region of the state and most of the whitefly specimens found were still belong to biotype A.

Matthew and Olalenkan (2005) carried out extensive surveys at Samaru and the north region of Guinea Savanna (Nigeria) and find out that *Bemisia tabaci* (Genn.) hosts 42 species of plants including 32 cultivated and 7 wild species. They presented the first description of different host plants of *B. tabaci* in the Nigerian region. They also found that 29 species in upland region, 2 species in lowland region and 11 species in both upland as well as lowland (Fadama) regions. The heavily whitefly infested plants showed stunted growth, distorted and chlorotic leaves symptoms.

Lin *et al.* (2007) recorded 14 host species on which *B. tabaci* fed during the winter and spring. Among these 14 species, *L. esculentum* (Mill) followed by *B. alboglabra* (Bailey), *F. carica* L., *E. pulcerrima* Wild, and *H. patens* (Haence) were found as the prominent host. Their study also revealed that the population of whitefly was low during winter but slowely increased from the month of February to March until they migrate into field hosts in April month.

Abd-Rabou and Simmons (2010) conducted a field survey throughout Egypt to identify host species of the *Bemisia tabaci* (Gennadius) complex. They reported 118 species of hosts in 79 genuses belonging to twenty-eight families. Major host families

include Asteraceae (23 host plant species) followed by family Fabaceae (17 host plant species). Their study reported 70 per cent new host for Egypt, consisting of 5 species and 1 subspecies belonging to the families Asteraceae, Portulacaceae, Piperaceae, Fabaceae and Plantaginaceae

Li *et al.* (2011) conducted a study on whitefly in China to find its potential hosts and natural enemies. Their study includes 361 plant species belonging to 89 families. The results revealed that the most preferred host species of whitefly belongs to family Leguminosae, Cruciferae, Cucurbitaceae, Compositae and Solanaceae. They also recorded fifty-six parasitoids species, fifty-four arthropod predators and seven species of entomopathogenic fungi. The arthropod predators of whitefly include Aphelinid parasitoids belonging to *Encarsia* and *Eretmocerus* genus, lady beetles and lacewings in Coleoptera and Neuroptera respectively.

Gonsebatt *et al.* (2012) attempted the first intensive survey in Argentina and reported two species of whitefly i.e. *T. vaporariorum* (Westwood) and the *Bemisia tabaci* complex (Gennadius). They reported *T. vaporariorum* to be present on 24 species of plants belonging to 11 families, 12 and 8 of which are new hosts in Argentina and the world, respectively. The *B. tabaci* complex was recorded only on flower production systems, on 19 plant species (11 families), 14 and 7 of which are new hosts in Argentina and in the world, respectively. *Eretmocerus californicus* was the only recorded parasitoid for *T. vaporariorum*.

Kedar *et al.* (2018) performed the surveys to identify host plants of whitefly at Hisar (Haryana). About 114 host plants belonging to 32 families was identified as hosts out of these 114 species, 35 were found as weeds, 25 was found to be ornamentals, 20 were crops, 17 were vegetables, 13 plants were of medicinal importance and 4 were fruit crops. The plnats belonging to family Fabaceae, Malvaceae, Solanaceae, Asteraceae and Cucurbitaceae were found to be most preferred.

McKenzie *et al.* (2020) conducted survey in Georgia on Middle Eastern Asia Minor 1 (MEAM1; biotype B) and MED whiteflies and collected 70 samples from 23 counties. During the year 2011 and 2012, 5 whitefly samples were collected, representing 9 counties and 5 hosts. They also found that MED biotype is expanding its

geographical range in the United States. The MED whitefly was majorly detected on the Lantana and Verbena in 2011 and poinsettia in 2012 at commercial greenhouses. Only MEAM1 whitefly was detected in all the field-grown commodities sampled in Georgia regardless of the year.

2.2 To study the seasonal incidence of *Bemisia tabaci* (Gennadius) on tomato and brinjal crop ecosystem at Pantnagar.

Chaudhuri *et al*. (2001) found highest pest density of 1.68 whiteflies per plant during mid-February and this level of infestation was maintained throughout mid-February to mid-March, with RH (65.29-72.78 %), rainfall (5 mm), temperature (17.07-22.13ºC) and sunshine (7.79- 8.9 hours per day).

Kharpuse (2005) reported that the highest population of whitefly appeared on tomato during the first week of March. **Dahatonde and Pandya (2014)** reported that the incidence of whitefly started from November (7.27 whiteflies/three leaves) and the peak incidence was reached during January (25.73 whiteflies/three leaves). Weather parameters like temperature (maximum, minimum and average) showed a significant negative impact on the pest population.

Patel *et al*. (2015) found that peak incidence of whitefly (15.33 whiteflies per leaf) on brinjal occurred during the April (last week). **Kumar *et al*. (2016)** found that the major outburst of whitefly on brinjal occurred during 2nd SW of January.

Mathur *et al*. (2012S) reported that the peak incidence of whitefly on brinjal during January (2nd SW) and lowest in March (12th SW). Pest population showed negative and significantly association with temperature (maximum and minimum) and wind speed, while a positive association with rainfall amd means relative humidity.

Deole (2015) reported that activity of whitefly was initiated during the 1st week of April with 6.33 whiteflies per plant with maximum and minimum temperature of 35.94 °C and 20.78 °C, and maximum relative humidity of 75%. The peak incidence was observed during the 1st week of May with day and night temperature of 25°C and 40 °C and relative humidity of around 55%. The correlation between pest population and weather parameters showed to had no significant effect of weather parameter on the pest.

Jha and Kumar (2017) recorded the peak population (42.4 per cent) of *Bemisia tabaci* on the 70th day after transplanting of tomato and computed a negative and significant association between temperature max. (-0.481), temperature min. (-0.483), sunshine hrs. (-0.641) and *B. tabaci* population respectively. However morning and evening relative humidity had a positive significant correlation *viz*., (0.514) and (0.483), respectively with *B. tabaci* population. The percentage contribution of all the weather parameters on the population of *B. tabaci* was around 55.70 per cent (R^2 = 0.5570).

Nagamandla *et al*. (2017) observed that the whitefly attacked on tomato crop from November to March in both conditions (open as well as polyhouse) but peak population was found during the last week of February to first week of March. In open condition, the population of whiteflies was more associated with weather parameters in comparison to polyhouse conditions. Similarly, a greater degree of influence of canopy temperature and light intensity were observed on whitefly.

Deb and Bharpoda (2017) reported that whitefly was noticed from 39th SMW and having a maximum population in 45th SMW with 2.72 whiteflies/ 3 leaves. Correlation study revealed that wind speed, evening relative humidity were key abiotic factors influencing significantly.

Kadgonkar *et al*. (2018) reported that maximum incidence of whitefly occurred during January (1st SW) and minimum during February (8th SW), it was significantly and negatively correlated with both maximum and minimum temperature while positively correlated with mean relative humidity.

Pawan *et al*. (2019) found highest maximum infestation of whitefly (15.00 whiteflies/3 leaves) a maximum temperature of 35.0ºC and minimum temperature of 16.9ºC, with max. and min. relative humidity of 55.6 % and 17.7 %, respectively, and rainfall of 0.8 mm. The pest population showed a significant positive correlation with maximum (r = 0.565) and minimum (r = 0.526) temperature, whereas, non- significant negative correlation with maximum relative humidity (r = -0.430) and a significant negative correlation with minimum relative humidity (r = -0.525). A non- significant correlation was observed between pest population and total rainfall (r = -0.087).

Harshita *et al*. (2019) reported that the maximum incidence of whiteflies was recorded during the last week of February 2016 with 6.74 per leaf and the first fortnight of March 2017 with 6.30 per leaf. The whitefly population and average relative humidity showed a significant negative correlation and a positive correlation with maximum temperature.

Mondal *et al*. (2019) reported that the whitefly population against maximum temperature (r = -0.010) and rainfall (r = 0.007) were non-significantly correlated. **Lal *et al*. (2019)** reported that the incidence of whitefly started during 43rd SW and peak incidence occurred during 1st SW. Correlation studies showed that the population of whitefly and morning relative humidity (r = 0.51) are correlated positively significant.

2.3 Host preference, ovipositional suitability and biotic potential of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in selected vegetable crops.

Musa and Ren (2005) conducted experiments on *B. tabaci* B-biotype and studied its development and reproduction. Laboratory studies were conducted at 26±1°C and three bean species were undertaken the developmental period was found to be varied from 27.80 days (garden beans) to 18.20 days (soybeans) while survivorship varied from 77.14, 70.14 and 64.28% for soybeans, cowpeas, and garden beans, respectively. Studies for average longevity of adult female varied between 12.30 days to 9.80 days for soybeans and garden beans, respectively. Also, the oviposition was from 160.85 eggs (soybean) to 98.00 eggs (garden beans). The studies of intrinsic rate (r_m), the finite rate of increase (λ) and net reproductive rate (R_0) described that these were high for B biotype fed on soybean (0.1857, 1.2041 and 82.1576, respectively). Whereas, these values were lower for garden beans (0.1097, 1.1159 and 31.2661, respectively). These parametric values for cowpea lie between soybean and garden beans. From their studies it became imperative that soybean was the preferred host for *B. tabaci* B-biotype.

Lin and Ren (2005) did laboratory (temperature 26 ± 1 °C; relative humidity 75%–90%; L: D 14:10) experiment for whitefly B biotype *B. tabaci* (Gennadius) on various commercial ornamentals for host preference, survivorship, and development. The survivorship rate was maximum for cottonrose hibiscus (*Hibiscus mutabilis* L.) (79.11%) which showed great host preference whereas the lowest for variegated

leafcroton (*Codiaeum variegatum 'Aucubaefolium'*) (29.39%). Even intrinsic rates of natural increase (r_m) were highest for Cottonrose hibiscus. Studies on the developmental period showed variation between 23.12 to 32.13 for cottonrose hibiscus and hibiscus, respectively. Also, average longevity of eggs laid per female was 9.20, 25.13, 54.45, and 26.79 for *Hibiscus rosa-sinensis* L., *Euphorbia pulcherrima* Will, *Hibiscus mutabilis* L., and *Codiaeum variegatum'Aucubaefolium'*, respectively. The whole study on life table analyses culminates with the proposition that cottonrose hibiscus was the most preferred and suitable host.

Omondi *et al.* (2005) studied host preference and suitability of *B. tabaci* biotypes on okra and cassava. It was noted that the Cassava biotype preferred cassava for oviposition over okra while the okra biotype not only preferred okra to oviposit but also chose other crops like brinjal, tomato, cowpea and *Solanum integrifolium* . The only similarity it showed was just like cassava biotype. *B. tabaci* did not choose to oviposit on cassava crop. But again, was able to just marginally able to survive on cabbage, *Brassica oleracea*, and pepper, *Capsicum annum*va *grosum*. On the contrary, cassava biotype was never able to develop on okra, cabbage, and pepper. Authors also suggested that host acceptance of *B. tabaci* has widened as before. It was also documented from the experiment that the first instar showed highest mortality and developmental time was quite long on marginal hosts. Also, it was recorded that cabbage, *Brassica oleracea*, and pepper, *Capsicum annumva grosum* are reservoir hosts.

Zang *et al.* (2006) did comparative experiments for B biotype of whitefly, *B. tabaci* (Gennadius) (Homoptera: Aleyrodidae) and non- B indigenous biotypes (China-ZHJ-1). The experiment was mostly based on the wider host range adaptability and the biology incurred on the five host plants. The crops taken were cotton, tobacco, cabbage, squash, and kidney bean. Host preference was magnificently showed by B biotype over ZHJ-1, as developmental stages *i.e.*, egg to adult was completely successful on tobacco, cabbage, and kidney bean. Squash had experimentally differential behavior over the above mentioned three crops, as B biotype developed prior, survived better and elicit higher fecundity, while this performance was poor for ZHJ-1. When studies on cotton, noticed that both the biotypes performed equally but female of B biotype lived twice longer than on ZHJ-1. It became apt to notice that B

biotype has the ability to admixture itself to the environment of the wide host range. Due to which better survival and reproduction could be established. Also, this behaviour results in invasion and better movement in the field.

Kakimoto *et al*. (2007) worked on the effect of host plant on the development, survivorship, and reproductive biology for *B. argentifolii* Bellows. The experiment was carried with eggplant, cucumber, sweet pepper, and tomato in the laboratory (25 ^{o}C). The observation regarding developmental time showed that tomato (25.6 days) required significantly longer time for development than eggplant (21.8 days), cucumber (22.4 days), and sweet pepper (22.7 days). Studies for mean lifetime fecundity was significantly higher for eggplant (221.3 eggs) in comparison to cucumber (167.6 eggs), sweet pepper (92.3 eggs), and tomato (62.9 eggs). Studies were also performed regarding mean generation time (T), net reproductive rate (R_0), and intrinsic rate of natural increase (r_m) and it was found that on eggplant it was 31.2 days, 185.1, and 0.168 respectively; on cucumber 31.8 days, 130.7, and 0.153 respectively; on sweet pepper 30.0 days, 73.1, and 0.143 respectively, and on tomato 32.7 days, 36.1, and 0.110 respectively. Therefore, for *B. argentifolii*, it was found based on population growth parameters that eggplant was the most suitable host and least was tomato.

Jian-wei *et al*. (2009) did experiments on various biological parameters and studied the host preferences of *B. tabaci* Gennadius B biotype. Experiments were conducted for cucumber, eggplant, pepper, cotton, and sweet potato. The experiments of free diffusion in petri dish and biology expressed that there was no significant difference in the number of individuals in the initial 2 hours of the experiment but the difference was more pronounced between 4-48 hours. The significant difference was documented as the number of individuals of whitefly increased on cucumber but it decreased on pepper. Whereas population were stable on eggplant, cotton, and sweet potato. Host preference was majorly for cucumber but lowest for pepper crop. When the plants were pretreated by starvation and applied sprays of Imidacloprid, no significant effect for selectivity for the host was documented. Though, a significant difference was documented regarding honeydew secretion in the order; cucumber, sweet potato, cotton, eggplant, and pepper. When studies regarding longevity of developmental stage of *B. tabaci* were considered then crops like cucumber, eggplant, sweet potato, and cotton aided in longer longevity of developmental stage over pepper.

Also, the total number of oviposited eggs showed a difference. Highest was on cucumber (224.33) and this was followed by sweet potato (191.73), eggplant (182.33), cotton (172.60). Least was recorded on pepper (47.83). Hatching rate did not show any significant differences, though there was again a difference in the developmental period of nymphs and mortality too; this was 10.60 days and 5.21% (cucumber), 11.11 days and 17.24% (sweet potato), 11.96 days and 27.78% (eggplant), 13.30 days and 37.11% (cotton), respectively. Nymphs on pepper were not able to develop normally.

Oriani *et al.* (2011) did experiment based on antibiosis-based resistance for tomato, developmental biology, and mortality for Whitefly, *B. tabaci* (Genn.) B biotype in the controlled greenhouse laboratory conditions. The experiment was conducted on 30 days old plants which were infested with 20 whitefly pairs for 24 hours. The observation was made on the basis of 30 eggs on three leaflets per plants. Once the adult emerged it was concluded from the experiment PI134418 (20.3 days) took shorter time whereas LA1335, PI365928 and LA722 genotypes took three days longer. Studies also presented that the highest mortality rate was seen on PI365928 (63.8%), LA1335 (54.5%) and LA722 (53.3%) genotypes whereas lowest was from IAC294 (4.9 %) and IAC68F-22-2 (6.2%). For B biotype, antibiosis-based resistance was shown by LA1335, PI365928 and LA722 genotypes.

Xu *et al.* (2012) did experiments on sweet potato whitefly, the B biotype of *B. tabaci.* The authors' results explained that usually most of the mortality is observed in the younger nymphs on the host plant species and also documented that feeding preference does not correlate with oviposition preference. They also documented that the shorted time for development was observed on *Lablab purpureus* and *Helianthus annuus* but highest fecundity and survivorship was observed on *Solanum tuberosum* and *L. purpureus.*

Fekri *et al.* (2013) conducted four green-house experiments on eight tomato varieties for resistance against *B. tabaci.* The experiments basically identify the host preference (varieties) and best oviposition along with the development from egg to adult. One of the experiments was about a free-choice test where attractiveness and preference for oviposition were completely free for whiteflies. It was noted that Variety Rio Grande was most attractive to whiteflies due to which a higher rate of oviposition

resulted whereas Chef-falat variety showed the minimum number of whitefly. CAL-JN3 had lowest oviposition but Ergon showed highest. In the other experiment, which were more dependent on no-choice or no-preference, oviposition was more pronounced, Chef-falat and CAL-JN3 varieties showed resistance mechanism for oviposition. Overall, it was found that the egg to adult development cycle varied alongwith mortality. For Ergon it was 26.02 but CAL-JN3 showed 26.66 days and mortality was lowest in Ergon (20.52) but highest for CAL-JN3 (33.97). Therefore, it was stated in consideration will all the characteristics it was stated that CAL-JN3 was most resistance and Ergon was most susceptible to whitefly.

Prijovic *et al*. (2013) did experiments on five tomato genotypes (cv. Narvik and hybrids NS-6, Tamaris, Alliance and Marko) and studied survival, reproduction, development, and host preferred for greenhouse whitefly *T. vaporariorum.* It was noticed that those females which laid eggs on Marko thrived longer and their younglings took shorter duration to develop than the females which developed on genotype Narvik. Marko genotype aided in highest gross and net fecundity rate; and highest gross and net fertility (36.74 eggs/ female and 27.93 eggs/female; and 31.24 adults/female and 23.73 adults/female, respectively) in comparison to genotype NS-6 (18.55 eggs/female and 15.33 eggs/ female; and 14.85 adults/female and 12.53 adults/female, respectively) which also had lowest fecundity rates. Even on Narvik net fertility rate (13.80adults/female) of the females was significantly lower than Marko. It was observed that the instantaneous rate of increase of females was significantly higher on the genotype Marko over NS-6 and Narvik.

Niu *et al*. (2014) conducted experiments to study host preference and development of *T. vaporariorum*. It was found that cucumber was the most preferred host of adult whiteflies among all the studied hosts. The developmental time for eggs ranges between 9.6 to 10.1 days. Developmental time for the first instar is 7.4 days, 6.1 days, 6.2 days, 6.6 days, and 5.7 days for strawberry, cucumber, lima bean, pepper, and tomato, respectively. For second instar it was 5.4 days, 4.9 days, 4.8 days, 3.6 days, and 3.3 days for pepper, tomato, strawberry, cucumber, and lima bean, respectively. For third instar, an increase of 6.4 days (strawberry), a 36% (cucumber), 35% (pepper), and 31 % (tomato) increase was seen. For fourth instar development time ranged between

7.5 to 8.7 days for cucumber, lima bean, and tomato but for pepper it was 5.4 days. Also, the total developmental time from egg to adults achieved for strawberry, cucumber, lima bean, tomato and pepper was 35.3, 32.7, 31.8, 31.6 and 31.4 days, respectively.

Lorenzo *et al*. (2016) conducted experiments related to host-preference and biotic potential of *T. vaporariorum* and *B. tabaci* (Hemiptera: Aleyrodidae) on tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum* L.) crops. It was seen that these two are the major insect pest in many countries for the above-mentioned. In Uruguay, *B. tabaci* preferred pepper over tomato whereas *T. vaporariorum* showed preferences for tomato. Even their studies were able to show that oviposition preference of *T. vaporariorum* was tomato and for *B. tabaci*, it was pepper. Also, it was documented that pepper would affect the biotic expression of *T. vaporariorum* but such complications were not observed for *B. tabaci* for both the crops. The authors culminate with the ideology that these differences were pronounced due to the biological basis.

Hossain *et al*. (2018) studied host preference, fecundity and longevity of *B. tabaci* on brinjal and tomato. The study observed that brinjal accompanied the highest number of eggs, nymph and adult of whitefly over tomatoes and which was 76.41, 14.5, and 9, respectively. Even it was documented that brinjal was suitable for oviposition and feeding too. Also, the number of adult females (81.32) was significantly higher than tomato (27.50). Even longevity of developmental stage was slightly higher on brinjal over tomato. Though longevity of 2^{nd} and 3^{rd} instar nymphs was greater on tomato than brinjal. But eggs laid on brinjal (142.60 ± 3.01 eggs) were higher than tomato (98.41 ± 1.96 eggs).

2.4 Comparative morphological studies of life stages of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood).

Hill (1969) studied morphological structures of compound eyes and third antennal segments of adult whitefly species *B. tabaci* (Gennadius), *B. argentifolii* Bellows & Perring, *B. tuberculate* (Bondar), *T. vaporariorum* (Westwood), *T. Variablilis* (Quaintance), and *A. socialis* (Bondar) with the help of electron microscopy for identifying adult of whiteflies in cassava and beans in Colombia. The distance between the two species of *Trialeurodes* was greater than expected within the same genus.

Rosell *et al*. (1997) evaluated and compared the variability in the several morphological characters of the 4th instar larva of *Bemisia sp*., from 17 populations from various locations around the world. They had taken different characters in account like anterior submarginal setae, dorsal setae, posterior submarginal setae, caudal setae, anterior and posterior wax fringes, and tracheal folds. In their work they found that anterior submarginal setae 4 (ASMS 4) were usually absent, but with *B. argentifolii* Bellows and Perring and B biotype populations, and in most non-A/non-B biotypes (E, K, L, P, and Q) ASMS 4 were present. However, in A biotype, ASMS 4 were found in N biotype as well as in *B. hancocki*. The dorsal setal pair 4 was absent in the majority of populations, and its lengths with pairs 1, 2, 3, 5, and 6 varied along with different individuals from several populations. In all individuals of the populations, length and width of anterior wax fringes were highly variable. In all individuals except Nepal (P biotype) population the posterior wax fringes extended beyond the borders of caudal setae. Although in most of the individuals of examined specimen's posterior submarginal setal pair 5 (PSMS 5) was found short and was elongated in other few specimens from 5 populations. Findings of the above investigation signify those morphological characters of pupae alone were not sufficient for classifying different individuals from *B. tabaci* or *B. argentifolii* populations.

Whiteflies are unintentionally but frequently transported from one place to another during international plant trade. Quick and precise detection of source of future progenies of these whiteflies must be done at very first step by quarantine authorities, if intercepted during the sampling process. So, for the taxonomical identification the fourth larval instar or puparium should be considered, as their taxonomical characters are very rarely based on their eggs, early larval instars and adults **Malumphy** (**2009)** found and identified four species that are usually detected in plant trade *i.e*., *B. afer* (Priesner and Hosny), *B. tabaci* (Gennadius), *T. ricini* (Misra) and *T. vaporariorum* (Westwood) through morphological study of their egg, first three larval stages and adults. Morphological characteristics of all these four species during early stages of their growth enable to distinguish between them. Identification of fourth larval instars and antennal structure is also a reliable and simple character for separating this from other instars. Phenotypic plasticity that is previously only reported in the pupal stage is, also noticed in second and third-larval instars.

According to **Chaubey *et al*. (2010)** *B. tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is a key pest and well known as vector, for causing plant viral disease through virus transmission. Till now puparia alone has been taken in account for the taxonomic identification and morphological variations while life stages had not been considered towards their field diagnostics. Hence, for easy identification, the salient features of different life stages have been documented. For accounting taxonomic characters at all level illustrated diagnostics had been developed. Comprehensive analysis supports the fact that the marginal setae, antennae and thoracic tracheal fold were the vital characters of utilitarian value in the diagnostics of life stages of *B. tabaci*.

Baig *et al*. (2015) studied the biology and morphology of different life stages of various whiteflies species like *Aleyrodes sp.* on *Oxalis corniculata* Linnaeus (Oxalidaceae), *B. tabaci* (Gennadius) on *Solanum melongena* Linnaeus (Solanaceae), and *Dialeurodes delhiensis* David and Sundararaj, 1992 on *Ficus virens* Ait. (Moraceae). The *Dialeurodes delhiensis* was reported from India as its biology was first time studied in India only. The time period between the egg and adult emergence for males and females of the former three species was 24.2, 28.4, 18.6 and 21.8, 97.5, 100.6 days, respectively. Time duration, with morphometric evaluation and illustrations for each of the developmental stages revealed that males developed more quickly than females and were exceeded by the former three species of females with a ratio of 3.5:1, 4:1 and 3:1, respectively. Nymphal developmental period of whitefly was found in positive correlation with the length and width and was negatively correlated with the length: width ratio. Their sexual variation was estimated by adult morphometric.

Harish *et al*. (2016) found that the silver leaf whitefly, *B. tabaci*, is the main restraining factor in the cultivation of cassava around the world. Whitefly acts as an insect vector and able to convey the cassava mosaic virus, causes cassava mosaic disease which is responsible for approximately 40 per cent reduction in the tuber yield. Therefore, to assess the existence of various genetic groups within the population by morphometric variations, diverse population of whitefly was collected from all of the agro-ecological zones of Kerala, India. But noteworthy variations could not be observed between nine different adult characters and fourteen different pupal characters among these agro- ecological zones. However, the principal component analysis of populations collected from Sulthan Bathery revealed significant degree of variations.

2.5 Distribution and phylogenetic analysis of whitefly species from North-Western region of Uttarakhand.

Xiao-Jun *et al.* (2012) used molecular techniques like mitochondria cytochrome oxidase subunit I (mtCOI) and cDNA-AFLP analysis to estimate diversity at genetic level and differentiation of *B. tabaci* species complex in China. By using sequencing of mtCOI gene, they concluded that the ninety-three samples of *B. tabaci*, collected from twenty-two provinces includes two invasive species i.e. Middle East-Asia Minor 1 (MEAM 1) and Mediterranean species, and four indigenous cryptic species including Asia II 1, Asia II 3, Asia II 7 and China 3. They also studied diversity and genetic differentiation by using cDNA-AFLP in a subset of nineteen populations of *B. tabaci* and concluded that Mediterranean species posses lowest similarity as compared to other species. Their study indicated that both Middle East-Asia Minor 1 and Mediterranean species were rapidly establishing in China.

Mugerwa *et al.* (2012) examined geographic distribution and magnitude of genetic diversity of *B. tabaci* by using partial sequences of the mtCOI DNA in cassava growing areas of Uganda, Tanzania and Kenya. They found that the in East Africa most widely distributed clade was SSA1 sub-clade I and also identified South-West Indian Ocean Islands (SWIO) species and sub-Saharan Africa 1 (SSA1). The SSA1 comprised of two sub-clades I and II. SSA1, sub-clade I sequence posses as genetics similarity of about 97.8-99.7 per cent with Uganda 1 genotypes. The pairwise comparison of the SSA1 sub-clade II sequences revealed a similarity of 97.2-99.5 per cent regarding southern Africa genotypes and diverged by 0.5-2.8 per cent.

Gao *et al*. (2014) worked on population structure, diversity, characteristics and invasion routes, of *T. vaporariorum* by using seven microsatellite loci. The diversity in the 4 provinces of China *i.e*., Qinghai, Guizhou, Jilin and Ningxia was lower than five provinces *i.e*., Gansu, Shanxi, Yunnan, Shandong and Liaoning. On basis of STRUCTURE analysis as two distinct genetic clusters were obtained while using BAPS analysis, 8 clusters were identified. It indicated a strong relationship between genetic distance (Fst) and geographical distance. These results indicated significant genetic diversity of *T. vaporariorum* in China and possibility of multiple introductions of *T. vaporariorum* into China.

Kapantaidaki *et al.* (2015) conducted phylogeographic studies on *T. vaporariorum* collections from 18 countries by using both the mitochondrial genetic diversity and infection status. To study the genetic diversity of *T. vaporariorum* sequence data from the mt cytochrome oxidase I, cytochrome b, and NADH dehydrogenase subunit 5 genes were used. They obtained two clades possessing narrow sequence divergence: one clade consisted of samples collected from Northern hemisphere whereas the other comprised samples from a broader geographical range. In general all male and female individual was detected with at least one secondary endosymbiont (Arsenophonus). The frequency of Wolbachia was very low and only few individuals from Greece were detected with Cardinium. The Fritschea, Rickettsia and Hamiltonella were not found. These results revealed significant low diversity in terms of both mtDNA and symbionts in this worldwide collection.

Tocko-Marabena *et al.* (2017) conducted a study with an objective to identify upsurge of a local population and new invasion of whitefly on cassava and other crops in the Central African Republic (CAR). The use of mtCOI sequences revealed that MEAM1, MED, SSA1 (-SG1, -SG2), SSA3 and Indian Ocean (IO) species occur in CAR. At the majority of site cassava plants had one specific haplotype of SSA1-SG1 (SSA1-SG1-P18F5). It was identical to the SSA1-SG1 Mukono8-4 (KM377961) haplotype from Uganda but that also occurs widely in CMD pandemic-affected areas of East Africa. Thus, the SSA1-SG1-P18F5 haplotype can be considered as a new invasive population in CAR.

Wosula *et al.* (2017) worked on whitefly (*B. tabaci*) samples collected from cassava in eight countries in Africa. They used NextRAD sequencing for genotyping while single nucleotide polymorphism (SNP) markers were used for analysis of phylogeny and population genetics. The results of mtCOI revealed the presence of 8 distinct groups whereas the study of phylogeny using SNPs identified 6 major groups. These results were further confirmed by using PCA technique and multidimensional analyses. Four ancestral *B. tabaci* populations were identified by using STRUCTURE analysis. These 4 population contributed alleles to the six SNP-based groups. Significant gene flows were reported between six SNP-based groups and it was strongest for SNP-based groups occurring in central Africa. The comparison of the

mtCOI and SNP identities of sampled insects indicated that there was an emergence of hybrid populations in some parts of Africa. They suggested that to differentiate cassava-colonizing *B. tabaci* haplogroups, mt COI is not an effective marker and hence robust SNP-based multilocus markers should be developed.

Manani *et al*. (2017) conducted a study in cassava growing area of Kenya areas (Western, Nyanza, Eastern, and Coast regions), to estimate phylogenetic relationships among *Bemisia tabaci* species. The mtCOI-DNA and Bayesian methods was deployed to unrivaled the phylogenetic similarities. It was found that two *B. tabaci* species were present in Kenya; sub-Saharan Africa 1 and 2 consisted of five distinct clades (A–E) with similarity varied from 97.7 to 99.5 %. Clades B, C, D, and E are majorly distributed in western and Nyanza regions of Kenya, whereas in the eastern and Nyanza region, clade B is dominantly found. About 99.5 % similarity was recorded between *B. tabaci* clade A groups and sub-Saharan Africa 2-(SSA2). They also reported the identification of SSA2 after a 15-year absence in Kenya.

Kumar *et al*. (2017) made an attempt to study genetic diversity of *B. tabaci* populations collected from different countries including India, Thailand, Vietnam and Indonesia. The use mitochondrial cytochrome c oxidase I (*coxI*) sequences and found it as a better marker for estimating genetic diversity. The marker distributed the Indian population into three distinct clades i.e. Asia I, Asia II 7, and Asia II 8). The Indonesian populations showed similarity with Asia I population of India. The Vietnam populations align with the MEAM1 clade, while MEAM1 invades northern Vietnam quite recently. Inter stingily, samples from Thailand made a unique clade between the out-group while the remaining *B. tabaci*, representing the possibility of a new subspecies. The ANOVA analysis among populations obtained from Tamil Nadu exhibits significant genetic differences, which represent each district's individuality.

Li *et al*. (2018) collected samples from twenty three provincial-level administrative and tried to estimate the level of genetic diversity among the mitochondrial haplotypes of *B. tabaci* Q by deployment of mtCOI markers. On basis of 773-bp mtCOI fragment analysis, five haplotypes (abbreviated as Q1H1-Q1H5) was obtained in the Q1 sub clade based. These results indicated that *B. tabaci* Q populations

were derived from multiple invasion sources originating from the western Mediterranean region. The Q1H1 was found as the most dominant haplotype followed by Q1H2. The study of 773-bp mtCOI fragment indicated that whitefly populations were generally characterized by low levels of genetic diversity.

Paredes-Montero *et al*. (2020) conducted extensive studies on population complexity and genetic diversity of endosymbiont communities of *B. tabaci* under different micro-environments of Pakistan. Mitotypes of *B. tabaci* belonging to the Asia II-1, Asia II -5, and Asia II -7 mitotypes of the Asia II major clade by using mt*COI* gene sequence. The whitefly endosymbiont communities were differentiated in 43 OTUs on basis of 16S ribosomal RNA operational taxonomic unit (OTU) assignments. Most OTUs belons to Asia II-1 and II-7 mitotypes, while the Asia II-5 microbiome was less complex. The *Portiera* (primary endosymbiont) was represented by a single, highly homologous OTU. Two out of six *Arsenophonus* OTUs were distinctly associated with Asia II-5 and -7, and one occurred exclusively in Asia II-1, two only in Asia II-5, and one in both Asia II-1 and -7. Rest of secondary endosymbionts, *Cardinium, Hemipteriphilus, Rickettsia,* and *Wolbachia* OTUs, were found at ≤ 29% frequencies. The most prevalent *Arsenophonus* OTU was found in all three Asia II mitotypes (55% frequency), whereas the same strain of *Cardinium* and *Wolbachia* was found in both Asia II-1 and Asia II-5, and a single *Hemipteriphilus* OTU occurred in Asia II-1 and -7.

Shah *et al.* (2020) conducted a study in eight district of Pakistan to find the *B. tabaci* mitotypes associated with cotton using mitochondrial cytochrome oxidase I. Phylogenetic analysis revealed that the predominant haplotypes belonged to the Asia II-1 mitotype (0.15 to 3). The Asia II-1 mitotype group was found as the most predominant whitefly vector species and it indicated a continuous genetic expansion of *B. tabaci* populations in Punjab.

Acharya *et al*. (2020) conducted experiments in Nepal to find genetic diversity of whitefly by using nucleotide sequences of COI gene to estimate genetic diversity. The results revealed the presence of three cryptic species (Asia I, Asia II 1, and Asia II 5). Asia II 1 was found as more genetically diversified as compared to other two cryptic species.

2.6 Repellent and oviposition deterrent effects of selected plant essential oils against *Bemisia tabaci* (Gennadius)

Yang *et al*. (2010) studied the effects of essential oils derived from garden thyme, *Thymus vulgaris* L., patchouli, *P. cablin* and *Corymbia citriodora* against *Bemisia tabaci* biotype B. Three concentrations of essential oils, 0.125%, 0.25% and 0.5% (v/v), were applied in contact toxicity experiments. In separate experiments, 0.5% essential oil treatment was tested for repellency. The greatest effect was found with essential oil extracted from *T. vulgaris*, which reduced the survival rate of *B. tabaci* by 73.4%, 79.0% and 58.2% after treatment of eggs, nymphs and pupae, respectively, as compared with controls. In no-choice tests, the cumulative survival rates of *B. tabaci* females treated with *T. vulgaris*, *P. cablin* and *C. citriodora* were 46.4%, 38.8% and 26.8% respectively lower, as compared with controls. In choice tests, the mean numbers of eggs laid on *P. cablin*, *T. vulgaris* and *C. citriodora* oil-treated plants were 74.5%, 59.0% and 48.0% respectively fewer, than on control plants. Result reavealed that *P. cablin* oil exerted the strongest repellency to *B. tabaci*.

De Carvalho *et al*. (2010) studied the fumigant action of essential oils from the peel of *Citrus sinensis* var. pear and *C. aurantium* evaluated against *Bemisia tabaci* biotype B and compared against eugenol as control. The concentration of oil in the Pear orange at 8.5 µL/L of air responsible for 97% mortality, while the concentration of oil Bitter orange at 9.5 µL/L of air responsible for 99% mortality. The minimum concentrations of the oils that reduce the fecundity significantly were 3.5 and 7.0 µL/L of air for BO and PO, respectively.

Zandi Sohani (2011) studied the toxicity of essential oil vapours distilled from thyme (*Zataria multiflora* Boiss.), rosemary (*Rosmarinus officinalis* L.), savory (*Satureja hortensis* L.), penny royal (*Mentha pulegium* L.) and spearmint (*Mentha viridis* L.) against adults of cotton whitefly. Amounts of the essential oils were 2, 4, 6 and 8 µl. The essential oil vapors of all five species caused the highest mortality in 2 µl/l air doses and 24hr of exposure time in this species. The results showed that the essential oil of five aromatic plants have the potential to be used for management of *B. tabaci* in greenhouse conditions. *M. pulegium* and *M. viridis* essential oils caused the highest mortality of *B. tabaci* adults (78.75 and 78.19%), respectively. The mean

mortality caused by essential oils of *Z. multiflora*, *R. officinalis* and *S. hortensis* were 69.02, 54.3 and 53.47% respectively.

Baldin *et al*. (2013) studied the management of whitefly *B. tabaci* (Genn.) biotype B (Hemiptera: Aleyrodidae), by using essential oils from the leaves of *Artemisia camphorata* Vill., *Ageratum conyzoides* L., *Foeniculum vulgare* Mill., *Lippia alba* Mill., *Plectranthus neochilus* Schltr., and *Tagetes erecta* L. for their possible repellent and oviposition-deterrent effects and finally the result revealed that *P. neochilus* essential oil was the most active repellent and oviposition deterrent. Essential oils of *A. conyzoides* and *T. erecta* deterred the female of *B. tabaci* biotype B.

Dehghani and Ahmadi (2013) examined the repellence and anti-oviposition activities of essential oils against *T. vaporariorum*. Cucumber plants were treated with essential oils or aqueous extracts (40 µL/ mL) to evaluate repellent and anti-oviposition effect. The highest anti-oviposition was observed in *Achillea millefolium* EO and greatest repellent effect was found in *Cuminum cyminum* L. and *Thymus vulgaris* L. EO, respectively.

Saad *et al*. (2017) conducted an experiment on *B. tabaci* (Gennadius), where essential oil of citronella (*Cymbopogon nardus* L.) leaves was assessed for contact-toxicity, repellency and ovipositional deterrence against *B. tabaci*. Mortality of *B. tabaci* exposed to the essential oil increased with the concentration of the essential oil, with the greatest mortality being observed at the highest concentration (6.66 µl/L air) tested (survival was reduced 94.3% in comparison to control treatments). The median lethal concentration was 1.028 µl/L air.

Wagan *et al*. (2017) studied the effect of essential oils for repelling and oviposition deterrent action against whitefly, *B. tabaci* (Gennadius). Four tested plants: *Curcuma longa* (Zingiberaceae), *Litsea cubeba* (Lauraceae), *Piper nigrum* (Piperaceae) and *Zanthoxylum bungeanum* (Rutaceae) were investigated under laboratory and glasshouse conditions. Result showed that Oils from *L. cubeba* repelled adult females (69.14% and 62.49% repellency at 24 and 48 hr. respectively), and oils from *C. longa* deterred oviposition (68.46% and 65.94% at 24 and 48 hr. exposures, respectively). Essential oils from *L. cubeba* repelled females by 54.77 per cent at 24 hr. and *P. nigrum* by 44.37 per cent at 48 hr. whereas oils from *P. nigrum* reduced oviposition by 43.35

per cent at 24 hr. and *Z. bungeanum* by 21.08 per cent at 48 hr. under glasshouse conditions.

De Carvalho *et al*. (2020) *B. tabaci* is a wide-spread pest and major reason for accountable impairment to crops in the agricultural hub of Petrolina in the state of Pernambuco, Brazil. They examined the lethal and sub lethal property of essential oils by means of hydro distillation of the Citrus peels of four species and the latex from *Mangifera indica* (var. "rosa" and "espada") against *B. tabaci*. The chemical analysis done by gas chromatography coupled with mass spectrometry led them to recognize 71 constituents of the oils, with limonene as the major constituent of the citrus oils and terpinolene as the chief constituent of the *M. indica* oils. *B. tabaci* was found more vulnerable towards *Citrus aurantiifolia* (LC_{50} = 0.70 μL L^{-1} air) and C. *limon* (LC_{50} = 1.77 μL L^{-1} air) oils, which offered the same level of toxicity. Citrus and *M. indica* oils also found responsible for reduction in the egg laying capability of the pest. The lethal and sub lethal action of the components like linalool, α-terpineol, α-pinene, β-pinene, terpinolene and limonene was also investigated. The lethal effect of the oils explored here in relation with the reduction in fecundity is a noteworthy advantage in the successful management of *B. tabaci*. However, for convenient use of these oils as a novel insecticide for further investigation is required to deal with safety issues for human health and resolving formulation to further develop the insecticidal effectiveness, stability and cost-benefit ratio.

Materials and Methods

Chapter 3 MATERIALS AND METHODS

The field and laboratory experiments on **"Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region"** were conducted during the year 2017-18 and 2018-19 at Vegetable Research Centre and Molecular laboratory of Department of Entomology, G. B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand. The present investigations were carried out to achieve the following objectives:

1. Survey for the identification and diversity of potential reproductive hosts of *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in Uttarakhand.
2. To study the seasonal incidence of *Bemisia tabaci* (Gennadius) on tomato and brinjal crop ecosystem at Pantnagar.
3. Host preference, ovipositional suitability and biotic potential of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in selected vegetable crops.
4. Comparative morphological studies of life stages of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood).
5. Distribution and phylogenetic analysis of whitefly species from North-Western region of Uttarakhand.
6. Repellent and oviposition deterrent effects of selected plant essential oils against *Bemisia tabaci* (Gennadius).

3.1 Survey for the identification and diversity of potential reproductive hosts of *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in Uttarakhand.

The potential reproductive host plants of whitefly *Bemisia tabaci* (Gennadius) and *Trialeurodes vaprariorum* (Westwood) in Uttarakhand were monitored during 2017-18 and 2018-2019. Based on altitude, the surveyed areas were divided into three zones *viz*., low, mid, and high. Potential host plants such as agricultural, vegetable,

ornamental, medicinal, and fruit trees as well as surrounding weeds on the farmland and along the roadside, were examined for the presence of whiteflies at each survey location. A plant was considered as the host of *B. tabaci* and *T. vaporariorum* when all development stages were found on that plant.

The assessment of the population level of whitefly was carried out using a qualitative scale suggested by **Qiu *et al*. (2001)**

Grade 1	less than10 nymphs and puparia / 10 cm^2 leaf area
Grade 2	11 to 30 nymphs and puparia / 10 cm^2 leaf area
Grade 3	31- 50 nymphs and puparia / 10 cm^2 leaf area
Grade 4	more than 50 nymphs and puparia / 10 cm^2 leaf area

Field-collected leaves samples bearing the pupae were preserved in 70% alcohol for taxonomic identification of whitefly species. Slides of pupae from several hosts/locations were prepared by following the methodology given by **Dubey and Ramamurthy (2013)**. Correct taxonomic identification of the slide-mounted specimens was done by using keys provided by European and Mediterranean Plant Protection Organization.

3.2 To study the seasonal incidence of *Bemisia tabaci* (Gennadius) on tomato and brinjal crop ecosystem at Pantnagar.

3.2.1 Experimental site

The field experiment was conducted at Vegetable Research Centre of GB Pant University of Agriculture and Technology, Pantnagar (Uttarakhand) during *kharif* season of 2017-18 and 2018-2019. The soil of the experimental plot had fairly uniform topography with deep and well-drained silty clay.

3.2.2 Geographical Location and Climate

The Pantnagar is situated in the *Tarai* region of Uttarakhand, south of the foothills of the Shivalik range, Himalayas. Geographically it is located between 29.5ºN latitude and 79.3ºE at an altitude of 243.84 meters above the mean sea level. The climate of the region is typically sub-humid, subtropical with hot dry summers and cool winters. The mean annual rainfall is nearly 2382 mm and relative humidity fluctuates

Plate 1: Experimental field for study of seasonal incidence of whitefly on Tomato and Brinjal

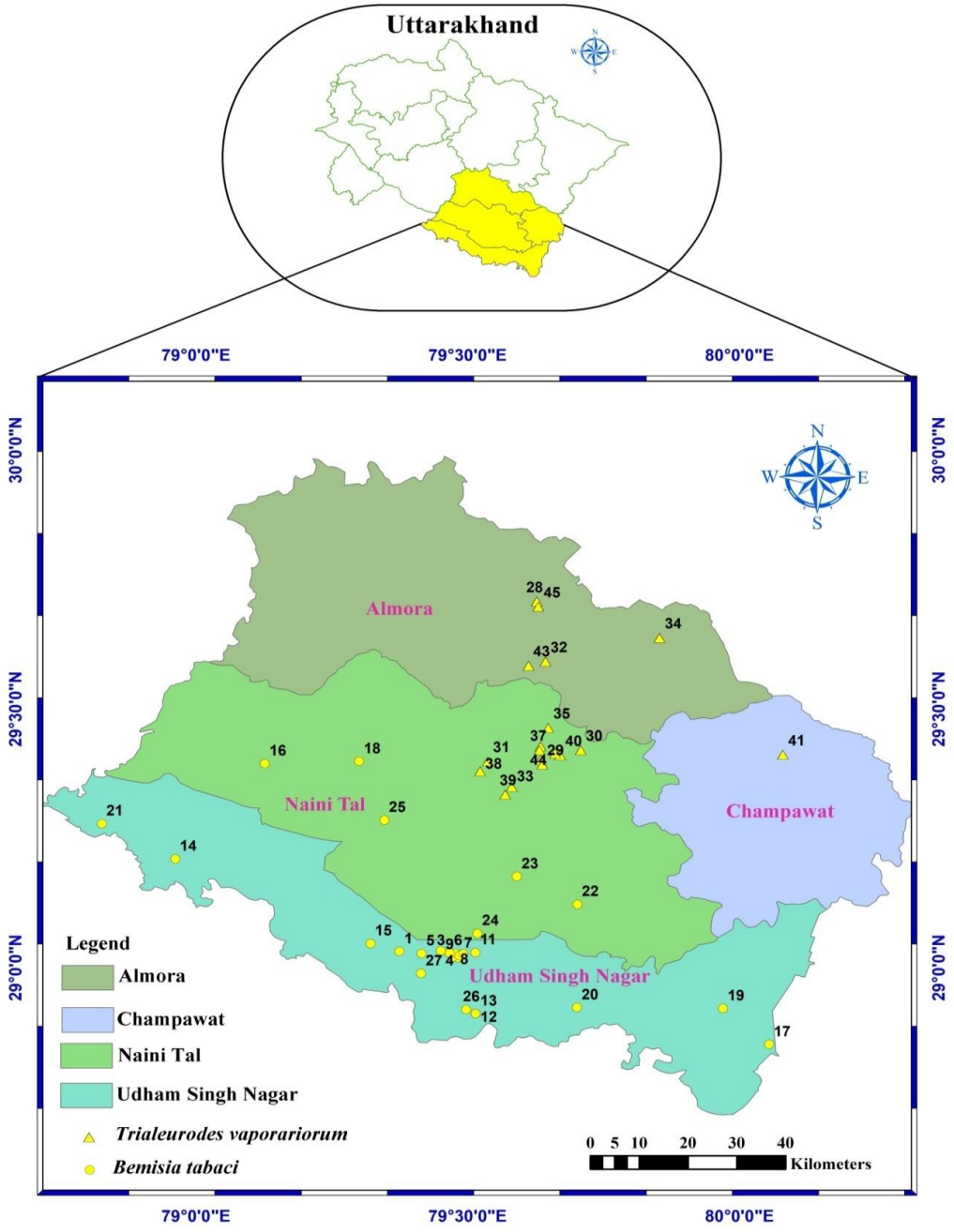


Plate 2: Geographical distribution of *B. tabaci* and *T. vaporariorum in* North- western Himalayan Region

around 98 per cent to 85 per cent. The summer temperature rises to 46 ºC while the winter temperature falls to 2 ºC.

3.2. 3 Physical properties of soil of experimental field

The soil of the experimental field is Sandy loam in nature with a pH of 6.8. The soil comes under mollisols at Pantnagar. The soils appear light brown color and have adequate drainage and optimum water holding capacity.

3.2.4 Experimental details:

Location: Vegetable Research Centre, GBPUA&T, Pantnagar

Season: *Kharif* 2017-18 and 2018-19

Varieties:

Tomato: Heem Sonha (Syngenta, India Pvt. Ltd.)

Brinjal: Pant Rituraj (GBPUA&T, Pantnagar)

Plot size: 12 m^2 (4.0m×3.0m)

Date of sowing:

Tomato: 7-09-2017 and 9-09-2018

Brinjal: 10-09-2017 and 11-09-2018

3.2.5 Observations:

The crop was under constant observation for the appearance of pests just after transplanting. The number of whiteflies was recorded on five randomly selected and tagged plants on three leaves *i.e.,* (upper, middle, and lower) during the early morning when insects have minimum activity.

3.2.6 Data analysis

The data was analyzed by using SPSS software (Version 20, SPSS, Inc. Chicago, II, USA) and correlation was worked out between environmental parameters *i.e*., minimum and maximum temperature (ºC), relative humidity (%), rainfall (mm), wind velocity (kmph), sunshine (hrs.), and whiteflies population, under field conditions.

3.3 Host preference, ovipositional suitability and biotic potential of two whitefly *species, Bemisia tabaci (Gennadius) and Trialeurodes vaporariorum* (Westwood) in selected vegetable crops.

3.3.1 Collection, mass rearing, and maintenance of whitefly pure culture

Adult whiteflies were collected with the help of an aspirator, from vegetable crops grown in polyhouse at Vegetable Research Centre, Pantnagar, and various locations from Padampuri (natural) area. These whiteflies were released on 30 days old brinjal plants. Infested plants were kept in aluminum-framed rearing cages ($60\times60\times60cm^3$) under controlled conditions (temperature: 27±2 ºC, humidity: 60±5%, photoperiod of light to darkness 16:8) in the glasshouse of Department of Entomology, GBPUA&T, Pantnagar. Old plants (severely damaged by whiteflies) were replaced with new ones.

3.3.2 Raising of Host Plants

Five test plants, *viz*., eggplant (Pant Rituraj), tomato (Pant Tomato-3), chilli (Pant C-1), bottle gourd (Pant Lauki-3), and cabbage (Golden Acre) which were to be used for the host preference and oviposition assays, were grown in plastic pots (15 cm dia., 20 cm height), filled with a mixture of soil and compost in the proportion of 2:1 and maintained in whitefly-tight screen cages up to 3–4 true leaves stage.

3.3.3 Experiment layout and observation of host preference

Free choice- In the free-choice assay, the test plants (five plants comprising a treatment) were arranged randomly in a circular manner inside a $60\times60\times60$ cm^3 screen cage. Each treatment was replicated three times. About 100 adult whiteflies of the same age, taken from laboratory-maintained stock culture were released at the center of the screen cage.

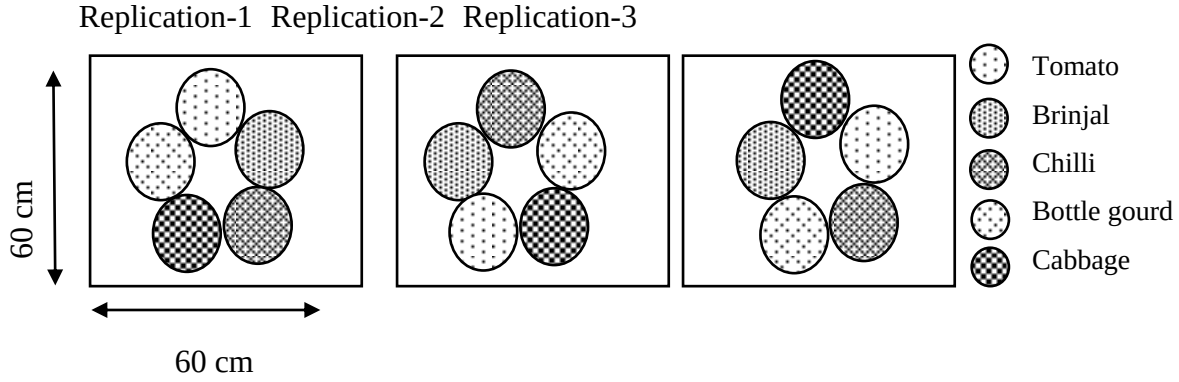


Fig. 1: Layout of the experimental designs for free-choice test

No- choice- All the test plants were kept separately for no-choice test and covered with cylindrical mylin plastic sheet cage. In each cylindrical cage 10 pairs adult of the same age, whiteflies were released. The experiment was carried out in three replications under ambient environmental conditions (25±2 °C, and 50–80% RH). To determine host feeding preference whiteflies were counted after 24, 48, and 72 hours in both the experiments, while in case of oviposition preference adult whiteflies were removed from plants after 72 hours then the eggs per unit of leaf area were counted with the help of hand lens (20X). The leaf area was measured by a leaf area meter.

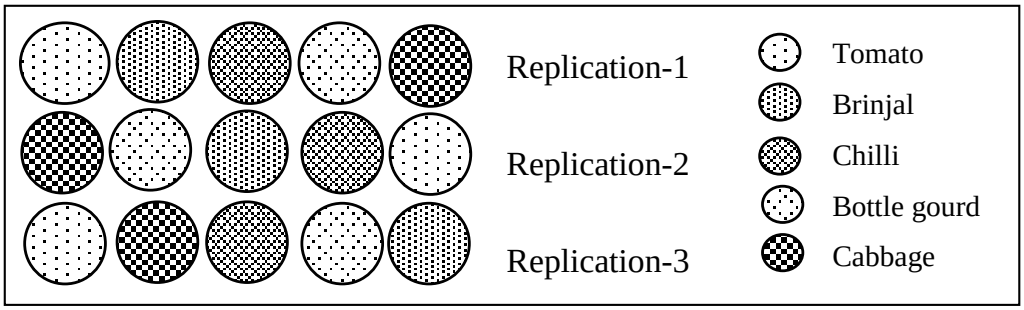


Fig. 2: Layout of the experimental designs for No-choice test

3.3.4 Experiment and observation of biotic potential

Two host plants, tomato (Pant Tomato-3) and brinjal (Pant Rituraj) were grown in a glasshouse having controlled temperature, humidity, and light condition and after 5-6 weeks, plants were used for the biological trait of whiteflies. Unsexed newly emerged 10 pairs of adult whiteflies were collected from laboratory-maintained stock culture. For oviposition whiteflies were introduced in a self-fabricated leaf clip cage **(Gill and Rataul, 1994)** located on the lower side of a leaflet with the help of an aspirator. After introducing whiteflies, the pots were transferred to the Insect Growth Chamber (Rescholar, Ambala) for proper growth and development of whiteflies. Leaf clip cage and adult whiteflies were removed from the plant after oviposition. Leaf was examined under the microscope and only five eggs were kept per leaf (excess eggs were removed by brush). The insects were monitored daily under the trinocular microscope (Magnus MSZ-TR) to record the developmental changes till nymphs reached the 4^{th} instar. The assessed biological parameters were nymphal stage (duration, number of instars); adult stage (longevity of males and females, pre-oviposition, and oviposition, number of eggs per female); egg stage (duration, hatching percent), and total life cycle (time extant from egg to adult emergence and survival rate).

3.3.5 Data analysis

The observed data of host preference for feeding and oviposition in free choice and no choice methods were analyzed using one-way ANOVA. Student Newman Keuls (SNK Test) was used for comparing the means and data obtained from the biological parameter were analyzed by SPSS software (Version 20, SPSS, Inc. Chicago, II, USA).

3.4 Comparative morphological studies of life stages of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood).

3.4.1 Morphological study

Whitefly species to be used for the morphological study were collected from the experimental trail under the glass house of Dept. of Entomology, GB Pant University of Agriculture and Technology. Eggs, immature stages, and emerging adults were preserved in glass vials containing 70% alcohol and stored at 20 °C till ready for use.

3.4.2 Slide preparation

Permanent slides were prepared by following a method described by **Mound (1963), Mohanty and Basu (1986), and Jesudasan and David (1991)** with some modification.

Steps:

1. Preserved specimens in 70% alcohol were placed in 10% potassium hydroxide (KOH) and allow remaining in KOH solution for 12-14 hrs. to macerate the musculature and fat till it looked rather translucent.
2. Specimens were removed from KOH and placed in glacial acetic acid at room temperature for 15 minutes.
3. Specimens were then stained in acid fuchsin (overnight).
4. Specimens were removed from the stain and placed in 75% ethyl alcohol (EtOH) for 10-15 min. for distaining all non-sclerotized areas.
5. Specimens were placed in 95% alcohol from 75% alcohol for 10-15 min. this will complete the de-staining process.
6. After that, the specimens were kept in clove oil for 30 min. until the cloudiness get reduced.
7. The Specimens were then mounted in DPX. After mounting, slides were placed in a dryer oven for three weeks at 35 °C.

3.4.3 Observation and measurements

Slide mounted specimens were observed taxonomically for morphological characters *viz*., wing venation, antennae, ommatidia arrangement, legs, wax plate, genitalia, vasiform orifice, and setae. The species identification was confirmed using the standardized identification keys. Photographs of egg, adults, and immature stages were taken by Leica stereo zoom microscope attached with MC170 HD digital camera and digital measurements were done using Magnus (MSZ-TR) Microscope with Mag cam DC-14 digital camera attached.

3.4.4 Drawing

Drawings of the various structures were made under Camera Lucida (Olympus CX 41 equipped with a drawing tube). The drawings were made on A4 paper by pencil then inked on tracing paper. Standard scales were drawn adjacent to the object using stage and ocular micrometer. Drawings were scanned and the size was reduced as appropriate for printing.

3.5 Distribution and phylogenetic analysis of whitefly species from the North-Western region of Uttarakhand.

3.5.1 Site of collection

A large-scale survey and collection of adult whiteflies were carried out from 30 different diverse locations of Uttarakhand on various crops *viz*., field crops, vegetable crops, ornamental crops, and weeds during two consecutive years (2017-18 and 2018-19). Collection details, geographical locations, host plants, and dates of the collection were summarized in **Table 1**.

3.5.2 Method of sample collection

In every location, fields were randomly selected approximately 10 km apart from each other. In all the location surveyed, adult whiteflies (80 to 100) were collected from the topmost leaves of plants by using an aspirator then preserved the adult whiteflies in absolute ethanol and stored at -20 ^{o}C in sampling bottles until the DNA extraction process **(Sseruwagi *et al*., 2005; Mware *et al*., 2009)**.

Table 3.1 Collection areas of whiteflies from different regions of Uttarakhand

Sample No.	Collection site	Host plant	Geographical location	Altitude
1.	VRC, Pantnagar	Brinjal	29°01′53″N79°22′27″E	232m
2.	CRC, Pantnagar	Brinjal	29°01′10″N 79°28′57″E	230m
3.	SPC, Pantnagar	Cowpea	29°01′42″N79°27′58″E	231m
4.	MRDC, Pantnagar	Tulsi	29°01′58″N79°27′01″E	231m
5.	Shantipuri	Brinjal	28°58′13″N79°32′41″E	210m
6.	Kichha	Brinjal	28°54′41″N79°30′51″E	211m
7.	Rudrapur	Bitter gourd	28°98′75″N 79°41′41″E	249
8.	Haldwani	Okra	29°13′21″ N79°31′42″E	432m
9.	Kashipur	Brinjal	29°12′37″N78°57′42″E	234m
10.	Dineshpur	Brinjal	29°02′46″N79°19′17″E	221m
11.	Ramnagar	Brinjal	29°23′39″N79°07′35″E	362m
12.	Kotabagh	Brinjal	29°23′56″N79°18′00″E	673m
13.	Chorgallia	Tomato	29°07′21″N79°42′05″E	315m
14.	Gaulapar	Soybean	29°10′35″N79°35′25″E	361m
15.	Melaghat	Brinjal	28°51′07″N80°03′16″E	191m
16.	Khatima	Potato	28°92′09″N79°96′96″E	299 m
17.	Haridwar	Potato	29°57′00″N78°09′49″E	283m
18.	CRC, Pantnagar (Pigeonpea)	Pigeonpea	29°01′10″N 79°28′57″E	230m
19.	Lalkuan	Brinjal	29°06′76″N79°51′82″E	371m
20.	College of Agriculture, Pantnagar	Soybean	29°02′36″N79°48′45″E	230m
21.	Dhari	Cucurbit	29°21′03″N79°49′40″E	1315m
22.	Dharimkhol	Common Bean	29°41′53″N79°37′48″E	1268m
23.	Mukteshwar	Common Bean	29°35′21″N79°38′38″E	1610m
24.	Bhimtal	Cucurbit	29°20′41″N79°33′06″E	1545m
25.	Bhowali	Tomato	29°22′55″N79°31′10″E	1711m
26.	Pithoragarh	Soybean	29°34′56″N80°12′59″E	1568m
27.	Jgeshwar Dham	Cabbage	29°63′84″N79°85′28″E	1870m
28.	Almora	Tomato	29°35′21″N79°39′05″E	1648m
29.	Pokrad	Potato	29°40′52″N79°64′74″E	2300m
30.	Lohaghat	Cauliflower	29°24′15″N80°05′05″E	1659m
31.	Chaffi	Potato	29°22′06″N79°34′53″E	1350m
32	Padampuri	Tomato	29°38′04″N79°61′94″E	1560m

3.5.3 Chemical reagents

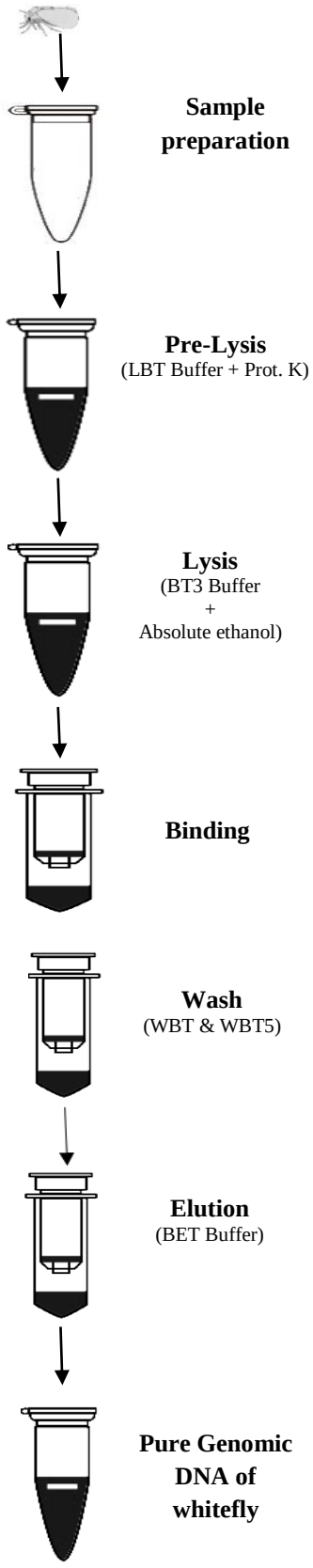
The DNA was extracted by using the DNA extraction kit developed by Genetix Biotech Asia Pvt. Ltd. and the chemicals used for running PCR reaction were obtained from Bangalore, Genei (India).

3.5.4 DNA extraction protocol

DNA was extracted from single adult whitefly with the help of a Nucleo-pore® Insect DNA Extraction Mini kit provided by Genetix Biotech Asia Pvt. Ltd. Extractions were carried out essentially following the manufacturer's instructions with slight modifications.

The procedure of DNA extraction

1. Single preserved adult whitefly was taken from each vial for DNA extraction. The whitefly was washed in distilled water and dried on filter paper. It was then transferred to a 1.5 ml micro centrifuge tube having 180µl LBT buffer and ground thoroughly with a micro pestle. After complete homozinization, 25µl Proteinase K solution (20 mg/ml) was added and it was incubated at 56 ^{o}C until the insect is completely digested (**Optional RNase A Treatment**- for RNA- free genomic DNA add 20µl RNase A (20 mg/ml).
2. After incubation, 200µl BT3 buffer was added and mixed thoroughly by vortexing. The tube was then incubated at 70 ^{o}C for 10 min. (**Note**: If insoluble particles are still visible, centrifuge for 5 more min at high speed (e.g., 11,000Xg) and transfer the supernatant to a fresh micro centrifuge tube).
3. Absolute ethanol (210µl) was added to the sample and vortex vigorously. The mixture was transferred to a DNASure Tissue Mini Kit Column for centrifugation (1 minute at 11,000Xg). It was made sure that all of the precipitate is loaded onto the column. The flow-through was discarded and the column was placed back into the collection tube.
4. The spin column was added with WBT buffer (500µl) and centrifuged at 11,000Xg for 1 minute the filtrate was discarded.
5. Again the spin column was added with WBT5 buffer (600µl) and the above procedure was repeated. (**Note**: for removal of residual ethanol centrifugation was done @ 11,000Xg for 1 minute).
6. The spin column was added with **30µl** pre-warmed BET buffer (70 ^{o}C). This mixture was transferred to a new 1.5 ml micro centrifuge tube, incubated at room temperature for 1 minute and centrifuged (11,000Xg for 1 min).
7. The DNA was collected in 1.5 ml micro centrifuge tube and stored at -20 ^{o}C for further experimentation.



3.5.5 Purity of DNA

The purity of the DNA was checked by using UV Spectrophotometer (Eppendorf Biospectrometer® Basic). A cuvette tube having 1ml TE buffer was taken as blank and used to calibrate the UV Spectrophotometer at 260 nm as well as 280 nm wavelength. Further, 2µl of DNA were added to 998µl of TE buffer, mixed properly and the optical density (O.D.) was measured. The samples which had the O.D. ratio between 1.7-1.9 **(Maniatis *et al.*, 1982)** were used in subsequent experiments. The DNA samples showing a ratio beyond this range were purified again.

3.5.6 Quantification of DNA

The isolated DNA was quantified by measuring the absorbance at 260 nm and 280 nm on a UV-spectrophotometer. Double-stranded DNA at 50µl/ml concentration showed an absorbance of 1 at 260 nm. The concentration of the DNA sample was calculated by using the following formula:

$$\frac{\text{O.D. 260 nm} \times 50\mu\text{l DNA/ml} \times \text{Dilution factor}}{1000}$$

3.5.7 PCR amplification of DNA

A total of 32 DNA samples were subjected to PCR analysis by using three primer pairs. C1-J-2195-F and TL2-N-3014-R were used to identify the whitefly species. The samples which did not show amplification with C1-J-2195-F and TL2-N-3014-R were screened with the generic insect primers LCO-1490-F and HCO-2198-R. A Specific primer Tvap-F and Wf-R was used for the identification of *T. vaporariorum*. All three primers were used to amplify the mt COI region. Hereunder is the list **(Table- 3.2**) of primers used, their components, and concentration used in the PCR reaction:

Table 3.2 List of Primers used for PCR

SI. No.	Targeted Gene	Primer	Primer Sequence(5'>3 ')	Reference
1.	mtCOI region	**C1-J-2195F**	TTGATTTTTTGGTCATCCAGAAGT	**Himler *et al.*, 2011**
		TL2-N-3014R	TCCAATGCACTAAT-CTGCCATATTA	
2.	mtCOI region	**LCO-1490-F**	GGTCAACAAATCATAAAGATATTGG	**Hebert *et al.*, 2003**
		HCO-2198-R	TAAACTTCAGGGTGACCAAAAAATCA	
3.	mtCOI region	**TvapF**	GGCATTATTTCTCATCTTATTAGTGCT	**De Barro *et al.*, 2011**
		WfR	GTGAYTAAGRGMTGGYTTATT	

Table 3.3 List of components with their concentrations used for PCR analysis

SI. No.	Components		Volume	Stock concentration
1.	Reaction buffer 10X		2.5µl	1X
2.	$MgCl_2$		0.5µl	25Mm
3.	dNTPs (Mixture of dATP, dCTP, dGTP and dTTP)		1.0µl	250mM of each DNTPs
4.	Primer	Forward	1.0µl	10µM
		Reverse		
5.	*Taq* polymerase		0.5µl	1.5 unit
6.	Template DNA		3.0µl	50ng/ µl
7.	Nuclease free water		16.5µl	As required to make up to 25ml
	Total volume		**25µl**	-

3.5.8 PCR condition for primers

The DNA amplification was done in the Prima-96 (Himedia) thermal cycler. The temperature profile, duration, and cycles used to run each PCR primer was given in the **Table 3.4.**

Table 3.4 Temperature profile used in PCR Amplification

Steps	Activity	Temperature (^oC)			Duration	Cycles
		Primer				
		Bem23F & Bem23R	**C1-J-2195F & TL2-N-3014R**	**TvapF & WfR**		
1.	Initial Denaturation	94	94	94	5min	1
2.	Denaturation	94	94	94	30 sec	30
3.	Annealing	**60**	**45**	**45**	45 sec	
4.	Extension	72	72	72	1 min	
5.	Final extension	72	72	72	10 min	1
6.	Storage	4	4	4	∞	-

3.5.9 Gel electrophoresis and DNA sequencing

Aliquots of 4µl PCR products were electrophoresed on 1% agarose gel stained in ethidium bromide (Himedia, India) in 1X TBE (Tris-borate-EDTA) buffer. The resultant bands were visualized under the gel documentation system (UVTEC, Cambridge). Later, the PCR products of the expected size were excised from the agarose gel with the help of the Gel Purification kit as per the manufacturer guideline and sequencing was outsourced.

3.5.10 Sequence Analysis

Homology search was carried out using Blast (http://www.ncbi.nlm.nlh.gov) and the difference in COI sequences of *B. tabaci* was determined using the sequence alignment editor Bio Edit version (10.7) and compared against the consensus sequences of **Dinsdale *et al*., (2010)**. The alignment was further analyzed using the MEGA 6.0 program, using the Neighbor-joining method with a "bootstrap" value of 1000.

3.6 Repellent and oviposition deterrent effects of selected plant essential oils against *Bemisia tabaci* (Gennadius).

3.6.1 Plant and Insect Material

Thirty days old chilli seedlings were obtained from Vegetable Research Centre, Pantnagar, and transferred to the glasshouse of the Department of Entomology, GBPUA&T. Whiteflies (*B. tabaci*) reared on brinjal under glasshouse conditions were used in the present experiment.

3.6.2 Tested oil

The oils of Ocimum (*Ocimum tenuiflorum*), Mint (*Mentha spicata*), Citronella (*Cymbopogon schoenanthus*) and Lemongrass (*Cymbopogon citratus*) were obtained from Medicinal Plants Research and Development Centre (MRDC), GBPUA&T.

3.6.3 Bioassays

3.6.3.1 Repellency effect of tested oil against *B. tabaci*

Repellency was assessed in a free-choice bioassay method using a transparent Plexiglas container (25-cm diam., 40 cm high) arena. Four excised chilli leaves (similar size and age) were immersed in the plant extract solution (0.5% v/v in 0.5 % Tween 20) for five seconds alternated with four leaves immersed in 0.5 % Tween 20 (control),

each kept in a vial of distilled water, were arranged inside the arena in completely randomized design **(Wang *et al*., 2003; Zhang *et al*., 2004 and Yang *et al*., 2010)**. The experiment was replicated five times and eighty adult whiteflies, starved for 2 hours, were introduced into each replication, through the bottom of the arena. Observations on repellency were recorded at 3, 6, 12, and 24 h after introduction.

Data analysis: The repellency test was analyzed using Student's t-test to compare the response between the treatment and control groups by using SPSS software (Version 20, SPSS, Inc. Chicago, II, USA). The essential oil repellent index (RI) was calculated using the **Kogan and Goeden (1970)** formula:

$$RI = 2G/ (G + P)$$

Where, G is the number of adult insects in the treatment area, and P is the number of adult insects in the control area.

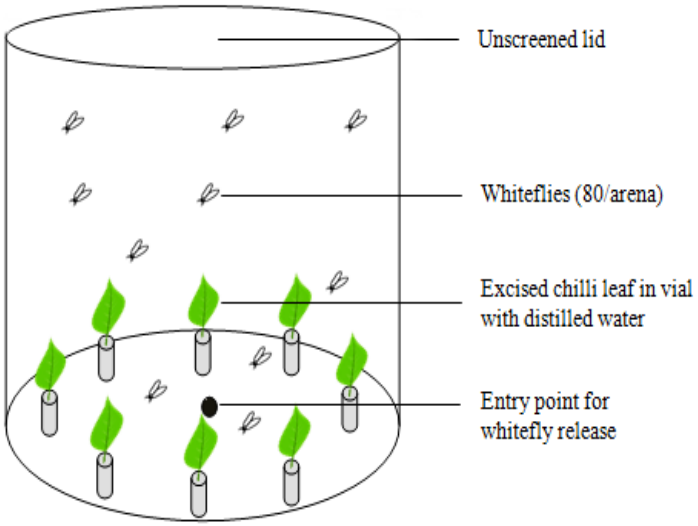


Fig. 3 Diagrammatic view of free-choice method for repellency bioassay against *B. tabaci*

3.6.3.2 Ovipositional deterrence of tested oil against *B. tabaci*

Ovipositional deterrence was assessed in dual-choice and no-choice bioassay methods. In free-choice bioassay, two fully expanded and intact leaves, one immersed in the plant extract solution (0.5%) and another immersed in the control solution, were kept in a vial inside the test arena facing opposite to each other. The experiment was replicated five times and twenty whitefly adults were used in each replication. Leaves

in the no-choice bioassay were kept singly in vials inside the arena. The experiment consisted of five replications with each replication having 10 adults.

Data analysis: In the ovipositional deterrence assay, the number of eggs laid by *B. tabaci* on treated versus control leaves was also compared using the paired t-test by using SPSS software (Version 20, SPSS, Inc. Chicago, II, USA). An oviposition deterrent index (ODI) was calculated using the **Huang *et al.* (1994)** formula:

$$ODI= 100 (C -T)/(C + T)$$

Where, C is the total number of eggs was laid on control leaves, and T is the total number of eggs on treated leaves.

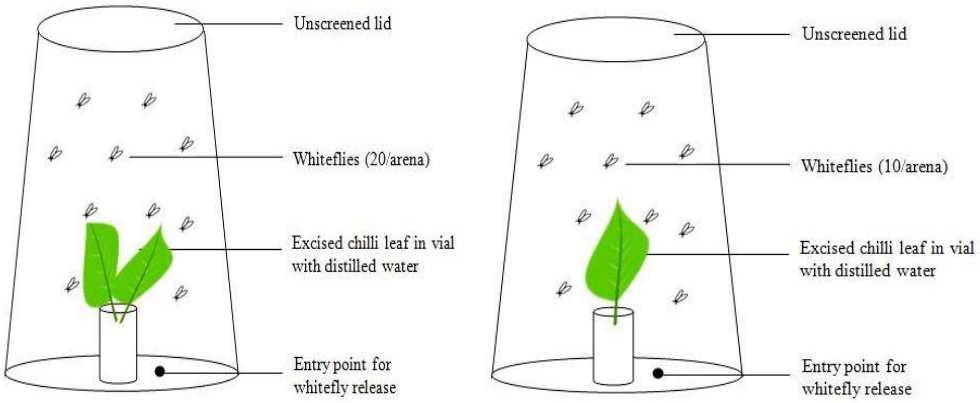


Fig. 4 Diagrammatic view of dual-choice and no-choice method for ovipositional deterrence bioassay against *B. tabaci*

3.6.3.4 *B. tabaci* trapping on treated and untreated yellow sticky traps

To compare whitefly entrapment on treated and untreated yellow sticky traps in an experiment, traps were cut to 100 cm^2 and sprayed with extract solutions, and put at a height of 45 cm. All extracts were mixed with 1% Tween 20-distilled water solution to obtain a 50% concentration. The front and back of each trap were evenly sprayed with 0.5 ml of these, air-dried for 20 minutes, and placed in the polyhouse. Ten paired (treated and untreated yellow sticky traps) combinations were arranged for each day. The number of whiteflies per trap was recorded after 24 h.

Data analysis: The mean number of whitefly adults on treated and untreated sticky traps after 24 h was calculated and analyzed as a two-sample paired t-test by using SPSS software (Version 20, SPSS, Inc. Chicago, II, USA).

Results and Discussion

4.1 Survey for the identification and diversity of potential reproductive hosts of *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in Uttarakhand.

4.1.1 Identification and diversity of host plants of *B. tabaci* in Uttarakhand (2017-2019)

Extensive surveys were conducted in 27 locations of four district of Uttarakhand from 2017 to 2019 to record the potential reproductive host associated with *B. tabaci*. The results of the survey revealed that a wide range of reproductive host plant species of *B. tabaci* was present in the Uttarakhand. In total, 69 host plant species from 29 different plant families were recorded during this survey **(Table 4.1)**. From a total of 27 locations, maximum numbers of host plants were identified from vegetable research center with 19 species followed by 10 species from the crop research center, Pantnagar, and 7 species from Kichha **(Fig. 4.6)**. On the basis of the number of host species, family Asteraceae and Fabaceae showed highest number of species (10 species), followed by Solanaceae (6 species), Cucurbitaceae (6 species) and Malvaceae (4 species) **(Table 4.2 and Fig. 4.2)**. As far as host plants type was concerned, out of the 70 species, 26 species (37%) were weeds, 16 species (22%) were economic crops, 15 species (22%) were vegetables, 11 species (16%) were ornamental and flowers and 2 species (3%) were fruit crop **(Fig. 4.1)**. In terms of crop system and ecology *B. tabaci* was most prominent in lowland (≥300 meter above from the sea level) and open condition as compared to polyhouse conditions **(Fig. 4.5)**. According to the grade of infestation out of 29 host families, nineteen families were categorized under 1st grade of infestation and five families were categorized under 2nd grade of infestation (top 5 families were excluded).

From the top 5 host families, a total 37 species were subjected under 4th grade of infestation (>50 nymphs and pupae in 10 cm^2/leaf area). Out of these 37 host species, 22 species were recorded under the 1st grade of infestation (<10 nymphs and pupae in 10 cm^2/leaf area) of which 10 belonged to Fabaceae, 5 to the Solanaceae, 4 to the Asteraceae and 2 each for Cucurbitaceae and Malvaceae **(Table 4.2)** and the remaining nine, one and four host species were recorded under 2nd, 3rd, and 4th grade of infestation, respectively **(Table 4.2)**. Thus the result revealed that host plants belonging

Table 4.1 The host plants of *Bemisia tabaci* in Uttarakhand (2017-2019)

SI No.	Family	Scientific Name	Location	Crop System	Host type	Sampling date	Ecology	Grade of infection rates
1.	Acanthaceae	*Dicliptera chinensis*	VRC, Pantnagar	O	W	Oct.-2018	Lowland	1
			Kichha	O	W	Nov.-2019	Lowland	1
2.	Aizoaceae	*Trianthema portulacastrum*	VRC, Pantnagar	O/Ph	W	Jun.-2019	Lowland	1
3.	Amaranthaceae	*Amaranthus viridis*	Melaghat	O	W	Nov.-2019	Lowland	2
4.	Apiaceae	*Coriandrum sativum*	CRC, Pantnagar	O	E	Dec.-2019	Lowland	1
5.	Apocynaceae	*Abernaemontana sp.*	VRC, Pantnagar	O	O	Oct.-2019	Lowland	1
6.	Asteraceae	*Eclipta alba*	VRC, Pantnagar	O	W	Sep.-2018	Lowland	2
		Ageratum conyzoides	Kichha	O	W	Oct.-2019	Lowland	1
		Chrysanthemum indicum	MFC, Pantnagar	O	O	Oct.-2019	Lowland	1
		Bidsen Pilosa	VRC, Pantnagar	O	W	Jun.-2019	Lowland	1
		Xanthium strumariam	Kichha	O	W	Jun.-2018	Lowland	1
		Cosmos caudatus	MFC, Pantnagar	O	O	Oct.-2019	Lowland	1
		Tagetes erecta	VRC, Pantnagar	O	O	Jan.-2018	Lowland	2
		Parthenium hysterophorus	Kichha	O	W	Jun.-2019	Lowland	2
		Sonchus oleraceus	SPC, Pantnagar	Ph	W	Feb.-2019	Lowland	2
7.	Brassicaceae	*Raphanus sativus*	CRC, Pantnagar	O	V	Dec.-2018	Lowland	2
		Brassica oleracea var. capitata.	VRC, Pantnagar	O	V	Oct.-2019	Lowland	1
		Brassica sp.	CRC, Pantnagar	O	V	Dec.-2019	Lowland	2
8.	Cannabaceae	*Cannabis sativa*	Kichha	O	W	Jun.-2018	Lowland	1
9.	Commelinaceae	*Commelina benghalensis*	Kichha	O	W	Jun.-2018	Lowland	1

10.	Convolvulaceae	*Ipomoea lacunose*	VRC, Pantnagar	O	W	Jun.-2019	Lowland	1
		Ipomoea pes-tigridis	VRC, Pantnagar	O/Ph	W	Jun.-2019	Lowland	1
		Convolvulus arvensis	VRC, Pantnagar	O	W	Jun.-2019	Lowland	1
			Khurpia, Kichha	O	W	Jun.-2018	Lowland	1
11.	Cucurbitaceae	*Cucumis sativus*	VRC, Pantnagar	O/Ph	V	Dec.-2019	Lowland	4
		Cucurbita pepo	VRC, Pantnagar	O/Ph	V	Jul.-2018	Lowland	4
			Kashipur	O	V	May-2019	Lowland	1
		Trichosanthes dioica	VRC, Pantnagar	O	V	Jun.-2018	Lowland	4
		Lagenaria siceraria	VRC, Pantnagar	O	V	May-2019	Lowland	1
		Momordica charantia	VRC, Pantnagar	O	V	May-2018	Lowland	1
		Coccinia grandis	VRC, Pantnagar	O	V	Nov.-2019	Lowland	2
12.	Elaeocarpaceae	*Elaeocarpus ganitrus*	MRDC, Pantnagar	Ph	E	Dec.-2019	Lowland	1
13.	Euphorbiaceae	*Euphorbia hirta*	Kichha	O	W	Jun.-2017	Lowland	1
		Acalypha sp.	VRC, Pantnagar	O	O	Oct.-2018	Lowland	1
14.	Fabaceae	*Phaseolus vulgaris*	VRC, Pantnagar	O	E	Oct.-2019	Lowland	1
		Vigna radiate	CRC, Pantnagar	O	E	Oct.-2019	Lowland	1
			SPC, Pantnagar	O	E	Sep.-2018	Lowland	2
		Vigna mungo	CRC, Pantnagar	O	E	Oct.-2019	Lowland	1
			SPC, Pantnagar	O	E	Sep.-2019	Lowland	2
		Cajanus cajan	CRC, Pantnagar	Ph	E	Oct.-2019	Lowland	1
		Cajanus scarabaeoides	CRC, Pantnagar	Ph	E	Aug.-2018	Lowland	2
		Vigna unguiculata	SPC, Pantnagar	O	E	Oct.-2019	Lowland	1
		Cassia tora	SPC, Pantnagar	O	W	Jun.-2019	Lowland	1
		Arachis hypogaea	CRC, Pantnagar	O	E	Sep.-2019	Lowland	1
		Bauhinia sp.	MRDC, Pantnagar	Ph	O	Dec.-2019	Lowland	1
		Glycine max	CRC, Pantnagar	O	E	Sep.-2018	Lowland	2
			Lalkuan	O	E	Oct.-2019	Lowland	1
			Kaladhungi	O	E	Sep.-2018	Midland	1

15.	Lamiaceae	*Ocimum tenuiflorum*	MRDC, Pantnagar	Ph	E	Dec.-2019	Lowland	2
		Ocimum sanctum	MRDC, Pantnagar	Ph	E	Dec.-2019	Lowland	2
16.	Lythraceae	*Lawsonia inermis*	MRDC, Pantnagar	O	E	Aug.-2019	Lowland	1
17.	Malvaceae	*Abelmoschus esculentus*	VRC, Pantnagar	O	V	Mar.-2017	Lowland	1
			Dineshpur	O	V	Apr.-2017	Lowland	1
			Khatima	O	V	Mar.-2017	Lowland	1
		Gossypium hirsutum	Phoolbagh, Pantnagar	O	E	Jul.-2019	Lowland	3
		Hibiscus rosa-sinensis	Badimarket, Pantnagar	O	O	Dec.-2019	Lowland	1
		Sida acuta	VRC, Pantnagar	O	W	Nov.-2018		2
18.	Moracae	*Ficus sp.*	Khurpia, Kichha	O	O	Jun.-2019	Lowland	3
		Ficus religiosa	VRC, Pantnagar	O	O	Sep.-2019	Lowland	2
19.	Moringaceae	*Moringa oleifera*	Rudrapur	O	V	Aug.-2019	Lowland	1
20.	Myrtaceae	*Psidium guajava*	HRC, Pantnagar	O	F	Sep.-2019	Lowland	1
21.	Oleaceae	*Jasminum sambac*	MFC, Pantnagar	O	O	Sep.-2018	Lowland	1
22.	Phyllanthaceae	*Phyllanthus niruri*	Agriculture College, Pantnagar	O	W	Nov.-2018	Lowland	1
23.	Poaceae	*Oryza sativa*	Gaulapar	O	E	Jul.-2017	Midland	1
		Cynodon dactylon	Agriculture College,Pantnagar	O	W	Oct.-2018	Lowland	1
24.	Polygonaceae	*Rumex crispus*	VRC, Pantnagar	O	W	Nov.-2018	Lowland	2
25.	Portulacaceae	*Portulaca oleracea*	VRC, Pantnagar	Ph	W	Nov.-2019	Lowland	1
26.	Rutaceae	*Ruta graveolens*	SPC, Pantnagar	Ph	O	Jan.-2019	Lowland	1
		Aegle marmelos	HRC, Pantnagar	O	F	Oct.-2019	Lowland	1

27.	Solanaceae	*Solanum melongena*	VRC, Pantnagar	O	V	Nov.-2018	Lowland	1
			CRC, Pantnagar	O/Ph	V	Dec.-2019	Lowland	4
			Melaghat	O	V	Aug.-2018	Lowland	2
			Ramnagar	O	V	Aug.-2018	Midland	1
			Kishanpur	O	V	Sep.-2018	Lowland	4
			Kotabagh	O	V	Aug.-2018	Midland	1
			Khatima	O	V	Aug.-2018	Lowland	1
			Sitarganz	O	V	Aug.-2018	Lowland	1
		Solanum lycopersicum	VRC, Pantnagar	O	V	Oct.-2017	Lowland	1
			Chorgallia	O	V	Nov.-2018	Midland	2
			Gaulapar	O	V	Dec.-2018	Midland	2
		Capsicum annum	VRC, Pantnagar	O/Ph	V	Mar.-2018	Lowland	2
		Solanum tuberosum	VRC, Pantnagar	O	V	Nov.-2018	Lowland	1
			Jaspur	O	V	Nov.-2018	Lowland	1
		Physalis longifolia	VRC, Pantnagar	O	W	Oct.-2019	Lowland	1
		Solanum nigrum	VRC, Pantnagar	O	W	Oct.-2019	Lowland	1
28.	Urticaceae	*Parietaria officinalis*	Agriculture College Pantnagar	Ph	W	Jun.-2019	Lowland	1
29.	Verbenaceae	*Duranta erecta*	Shastri Bhawan, Pantnagar	O	W	Oct.-2019	Lowland	1
		Lantana camara	VRC, Pantnagar	O	W	Oct.-2019	Lowland	1

Infestation grade 1–4 represent the populations of *B. tabaci* <10, 11–30, 31–50 and >50 nymphs and pupae in 10 cm^2 / leaf area, respectively.

Table 4.2 The top five families based on the number of host species and their infestation grade by *B. tabaci*

Rank	Family	No. of species	No. of host plant species in infestation grade			
			1	2	3	4
1.	Asteraceae	10	04	06	00	00
2.	Fabaceae	10	10	00	00	00
3.	Solanaceae	06	05	01	00	01
4.	Cucurbitaceae	06	02	01	00	03
5.	Malvaceae	04	02	01	01	00

Infestation grade 1–4 represent the populations of *B. tabaci* <10, 11–30, 31–50 and >50 nymphs and pupae in 10 cm^2 /leaf area, respectively.

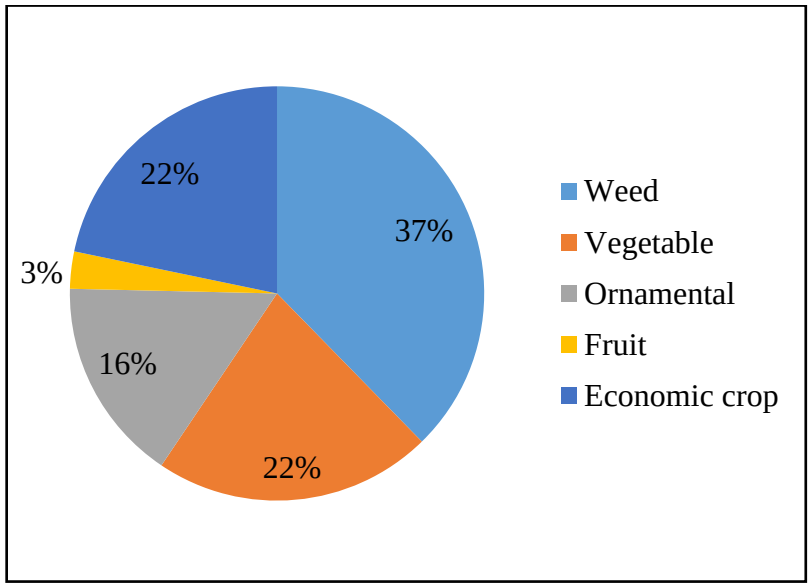


Fig. 4.1: Categories of host type infested by *B. tabaci*

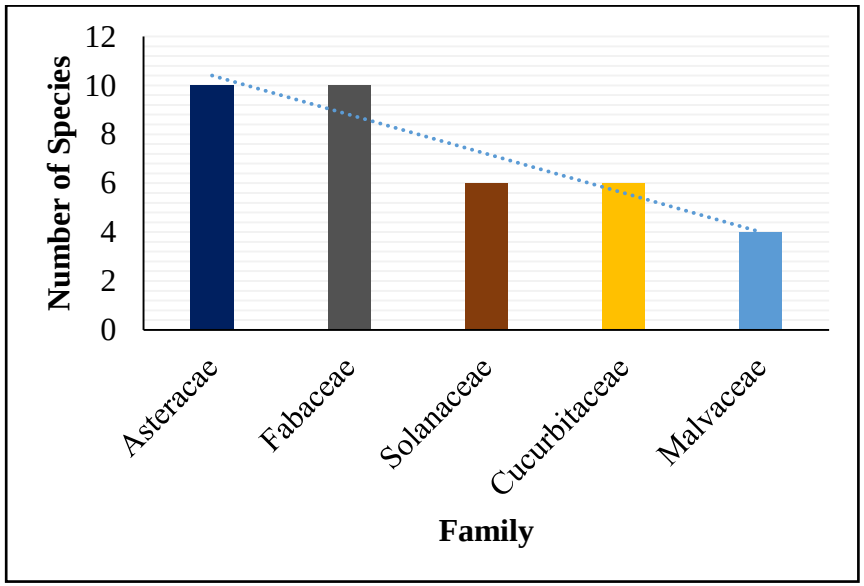
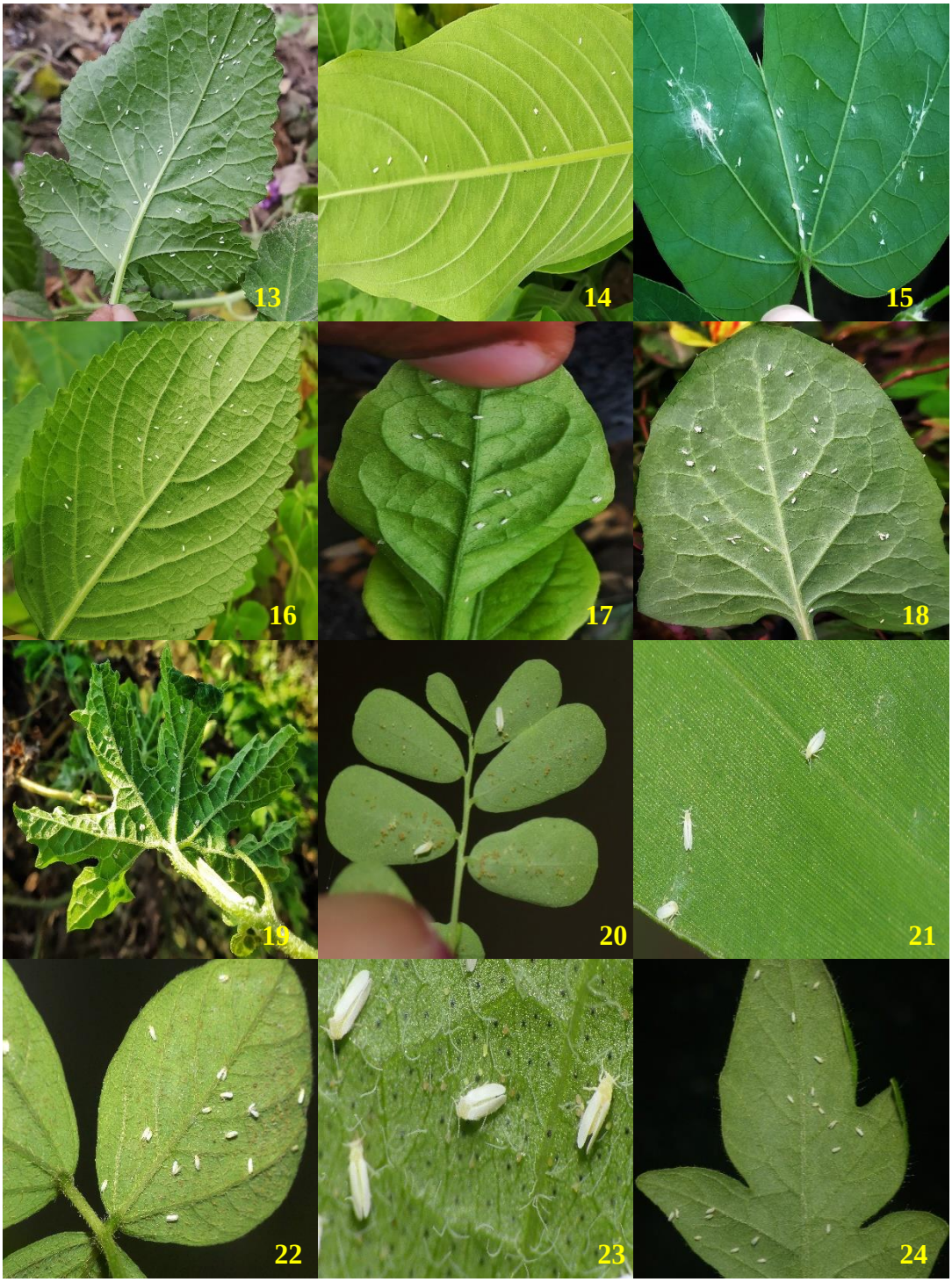
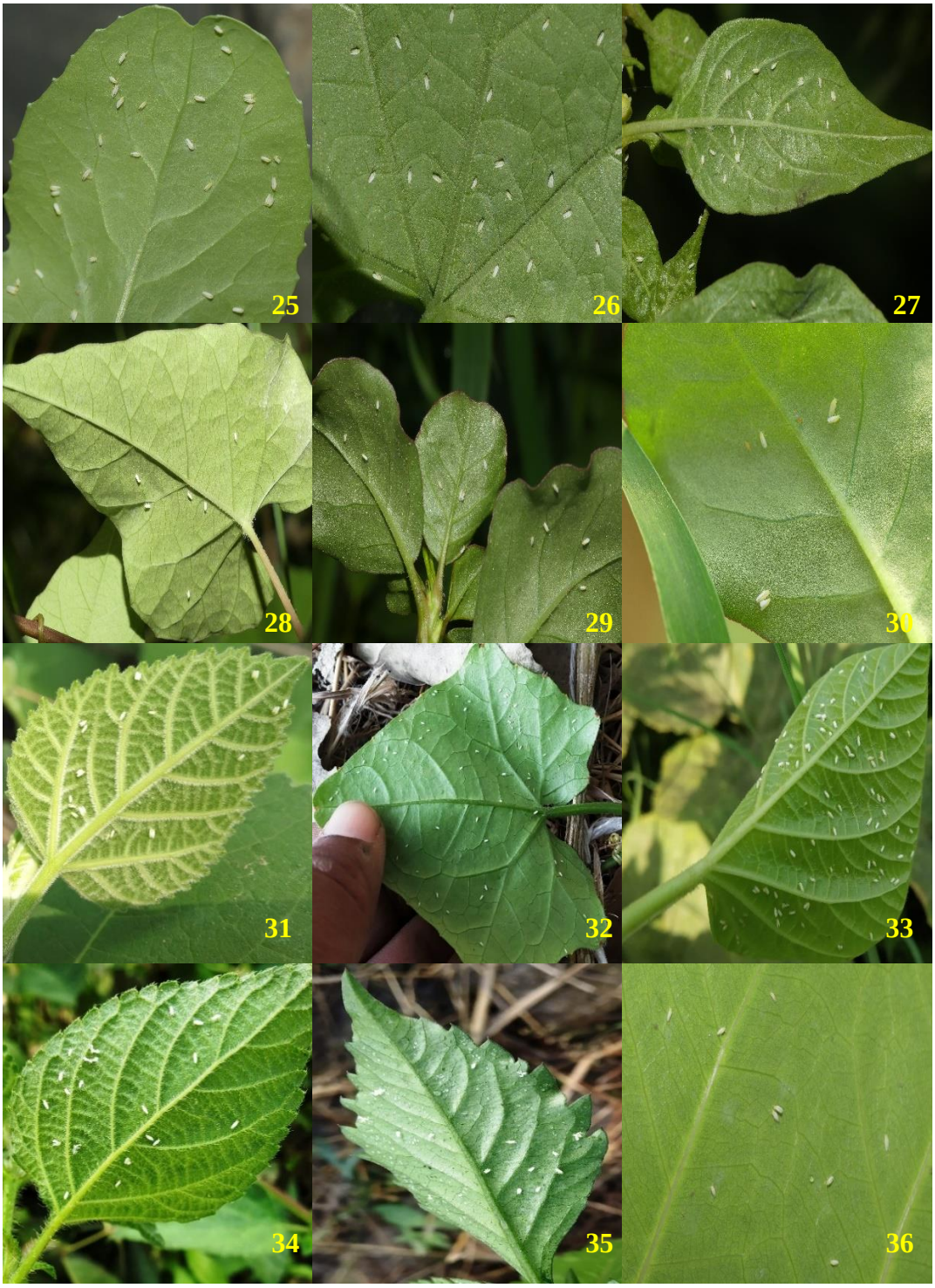


Fig. 4.2: Plant families infested by *B. tabaci*

1.*Moringa oleifera* 2. *Chrysanthemum indicum* 3. *Coriandrum sativum* 4. *Parthenium hysterophorus* 5. *Ocimum sanctum* 6. *Ruta graveolens* 7. *Solanum tuberosum* 8. *Ageratum conyzoides* 9. *Trichosanthes dioica* 10. *Dicliptera chinensis*11. *Rumex crispus* 12. *Solanum nigrum*



13. Raphanus sativus 14. Elaeocarpus ganitrus 15. Bauhinia sp. 16. Ocimum tenuiflorum 17. Aegle marmelos 18. Sonchus oleraceus19. Momordica charantia 20. Phyllanthus niruri 21. Cynodon dactylon 22. Glycine max 23. Gossypium hirsutum 24. Solanum lycopersicum



25. Brassica oleracea var. capitata. 26. Lagenaria siceraria 27. Parietaria officinalis 28. Ipomoea lacunose 29. Trianthema portulacastrum 30. Portulaca oleracea 31. Ficus sp. 32. Coccinia grandis 33. Convolvulus arvensis 34. Lantana camara 35. Sida acuta 36. Ficus religiosa

37. *Tagetes erecta* 38. *Euphorbia hirta* 39. *Cucurbita pepo 40. Acalypha sp. 41 Vigna unguiculata 42. Abernaemontana sp.43. Solanum melongena 44. Cannabis sativa 45. Hibiscus rosa-sinensis 46. Commelina benghalensis 47. Phaseolus vulgaris 48. Arachis hypogaea*

49. Cassia tora 50. Physalis longifolia 51. Cajanus cajan 52. Amaranthus viridis 53. Cajanus scarabaeoides 54. Xanthium strumariam 55. Abelmoschus esculentus 56. Lawsonia inermis 57. Cosmos caudatus 58. Capsicum annum 59. Cucumis sativus 60. Vigna mungo

61. Ipomoea pes-tigridis 62. Psidium guajava 63. Eclipta alba 64.Oryza sativa 65. Jasminum sambac 66. Vigna radiate 67. Brassica sp.68. Duranta erecta 69. Vigna unguiculata

Plate 3: List of Host plant species of *B. tabaci*

to family Asteraceae, Fabaceae, Solanaceae, Cucurbitaceae, and Malvaceae seemed to be more preferred. The maximum hosts of *B. tabaci* were weeds followed by economic crops and vegetables and *B. tabaci* was widely distributed in lowland and open field condition.

4.1.2 Identification and diversity of host plants of *Trialeurodes vaporariorum* in Uttarakhand (2017-2019)

Analogous surveys were carried out at 18 different locations of 6 districts of Uttarakhand (2017 to 19) in order to document potential reproductive host plants for *Trialeurodes vaporariorum*. The results revealed a wide range of potential reproductive host plants associated with *T. vaporariorum* in Uttrakhand. There were 47 host plant species recorded from 19 different families of plants **(Table 4.3)**. Out of 18 different locations, the maximum number of host plants was recorded from Gwala Kote with 12 species followed by North Gola range with 10 species and South Gola range and Bhowali range with 8 species **(Fig. 4.6)**. From a total of 47 species of host plants, the maximum number of host plants species were recorded from Asteraceae with 11 species followed by Solanaceae with 6 species and Fabaceae with 5 species, Cucurbitaceae with 4 species and Brassicaceae with 3 species **(Table 4.4 and Fig. 4.4)**. In terms of host plant type, 21 species (45%) were weeds, 10 species (21%) were ornamental, 8 species (17%) were vegetables, 6 species (13%) were economic crops and 2 species (4%) were fruit crops **(Fig. 4.3)**. On the basis of crop system and ecology, *T. vaporariorum* was most prominent in upland and open conditions as compared to polyhouse conditions **(Fig. 4.5)**. Out of 19 host families, 9 were categorized under 1st grade (<10 nymphs and pupae in 10 cm^2 /leaf area) of infestation and 5 families were categorized under 2nd grade (11–30 and pupae in 10 cm^2 /leaf area) of infestation (excluding the top five families). However, the top five host families were categorized under four grade of infestation in which, 13 species were recorded in the 1st grade of infestation among them 7 species were recorded from Asteraceae, 2 species from each Fabaceae and Solanaceae, 1 species from both Cucurbitaceae and Brassicaceae **(Table 4.4)**. 2nd, 3rd, and 4th grade of infestation was recorded in 9, 3 and 3 species of hosts respectively **(Table 4.4)**. Thus, the results revealed that the most preferred hosts were recorded from the families Asteraceae, Fabaceae, Solanaceae, Cucurbitaceae, and Brassicaceae which were widely distributed in upland and open field conditions with a maximum number of weed plants followed by ornamentals and vegetables.

Table 4. 3 The host plants of *Trialeurodes vaporariorum* in Uttarakhand (2017-2019)

No.	Family	Scientific Name	Location	Crop System	Host type	Sampling Date	Ecology	Grade of infestation
1.	Alstroemeriaceae	*Alstromeria sp.*	North Gola Range	O	O	Oct.-2019	Upland	1
2.	Amaranthaceae	*Amaranthus sp.*	South Gola Range	O	W	Aug.-2018	Upland	2
			North Gola range	O	W	Oct.-2019	Upland	2
3.	Apiaceae	*Mentha sp.*	Gwala Kote	O	E	Oct.-2018	Upland	2
4.	Asteraceae	*Tagetes sp.*	Almora	O	O	Mar.-2018	Upland	1
		Parthenium hysterophorus	Sagurigaon	O	W	May-2019	Upland	2
		Eclipta alba	Sagurigaon	O	W	May-2019	Upland	1
		Xanthium strumariam	Bhowali Range	O	W	Aug.-2019	Upland	2
		Ageratum conyzoides	Gwala Kote	O	W	Oct.-2018	Upland	3
		Bidsen pilosa	North Gola Range	O	W	Oct.-2019	Upland	1
		Galinsoga parviflora	South Gola Range	O	W	Aug.-2019	Upland	2
			North Gola Range	O	W	Oct.-2019	Upland	2
		Sonchus oleraceus	Darima	O	W	Oct.-2019	Upland	1
		Sonchus arevense	Bhowali	O	W	Oct.-2019	Upland	1
		Ageratina adenophora	Bhowali Range	O	W	May-2019	Upland	1
		Helianthus sp.	Gajar	O	O	Oct-2018	Upland	1
5.	Brassicaceae	*Brassica oleracea*	Boranshi	Ph	E	Oct.-2019	Upland	2
			Jageshwar Dham	O	E	Oct.-2018	Upland	2
			Kal Chaura, Lohaghat	O	E	Jan.-2019	Upland	2
		Raphanus sativus	Gwala Kote	O	E	Oct.-2018	Upland	1
		Tropaeolum majus	Darima	O	O	Aug.-2018	Upland	2
			South Gola Range	O	O	Aug.-2016	Upland	3
			Gwala Kote	O	O	Oct.-2018	Upland	3
6.	Cannabaceae	*Cannabis sativa*	North Gola Range	O	W	Oct.-2019	Upland	1
7.	Cucurbitaceae	*Cucurbita pepo*	South Gola Range	O	V	Aug.-2017	Upland	4
			Jageshwar Dham	O	V	Oct.-2018	Upland	1
		Lagenaria siceraria	Parwara	O	V	Oct.-2019	Upland	4
		Gerbera jamesonii	Majhra	O/Ph	O	Oct.-2018	Upland	1
			Mukteshwar	O	O	Oct.2018	Upland	1
		Momordica charantia	South Gola Range	O	V	Aug.-2018	Upland	2
8.	Geraniaceae	*Paleragonium sp.*	Darima	O	O	Oct.2019	Upland	1

9.	Fabaceae	*Euphorbia heterophylla*	Gwala Kote	O	W	Oct.-2018	Upland	2
		Erigeron sp.	Jageshwar Dham	O	W	Jan.-2018	Upland	2
		Stellaria media	Boranshi	O	W	Oct.-2019	Upland	1
			Gwala Kote	O	W	Jan.-2019	Upland	1
		Pisum sativum	Gwala Kote	O	V	Oct.-2018	Upland	2
			Jageshwar Dham	O	V	Oct.-2018	Upland	2
		Phaseolus vulgaris	Bhowali Range	O	E	May-2019	Upland	4
10.	Lamiaceae	*Ocimum tenuiflorum*	Bhowali Range	Ph	E	May-2019	Upland	4
		Lactuca sativa	Gwala Kote	Ph	V	Oct.-2018	Upland	2
11.	Malvaceae	*Malva sp.*	Kasiyalekh,	O	W	Oct.-2018	Upland	4
		Alcea rosea	Mukteshwar	O	O	Oct.-2019	Upland	1
12.	Moraceae	*Papaver sp.*	South Gola Range	O	E	Aug.-2018	Upland	1
		Ficus palmata	Darimkhol	O	F	Oct.-2018	Upland	1
13.	Onagraceae	*Fuchsia sp.*	North Gola Range	O	O	Oct.-2019	Upland	1
14.	Polygonaceae	*Rumex crispus*	North Gola range	O	W	Oct.-2019	Upland	2
15.	Rosaceae	*Rosa sp.*	Gajar	O	O	Oct.-2018	Upland	1
16.	Rutaceae	*Citrus lemon*	South Gola Range	O	F	Aug.-2019	Upland	2
17.	Solanaceae	*Solanum melongena*	Gwala Kote	O	V	Oct.-2018	Upland	2
			Pandey	O	V	May.-2019	Upland	3
		Solanum lycopersicum	Boranshi	Ph	V	Aug.-2018	Upland	2
			Gwala Kote	O	V	Oct.-2018	Upland	2
		Solanum tuberosum	Bhowali Range	O	V	Oct.-2019	Upland	4
			Gwala Kote	O	V	Oct.-2018	Upland	2
		Solanum nigrum	North Gola Range	O	W	Oct.-2019	Upland	1
		Physalis longifolia	North Gola Range	O	W	Oct.-2019	Upland	1
		Nicandra physalodes	North Gola Range	O	W	Oct.-2019	Upland	2
18.	Urticaceae	*Urtica dioica*	Gwala Kote	O	W	Oct.2019	Upland	1
			South Gola Range	O	W	Aug.-2018	Upland	4
19.	Verbenaceae	*Golden duranta*	Bhowali Range	O	O	Aug.-2019	Upland	1
		Lantana camara	Sagurigaon	O	W	18-May-19	Upland	1

Infestation grade 1–4 represent the populations of *B. tabaci*<10, 11–30, 31–50 and >50 nymphs and pupae in 10 cm^2/leaf area, respectively.

Table 4.4 The top five families based on the number of host species and their infestation by *T. vaporariorum*

Rank	Family	No. of species	No. of host plant species in infestation grade			
			1	2	3	4
1.	Asteraceae	11	07	02	01	00
2.	Solanaceae	06	02	03	00	01
3.	Fabaceae	05	02	02	00	01
4.	Cucurbitaceae	04	01	01	00	02
5.	Brassicaceae	03	01	01	01	00

Infestation grade 1–4 represent the populations of *T. vaporariorum* <10, 11–30, 31–50 and >50 nymphs and pupae in 10 cm^2/leaf area, respectively.

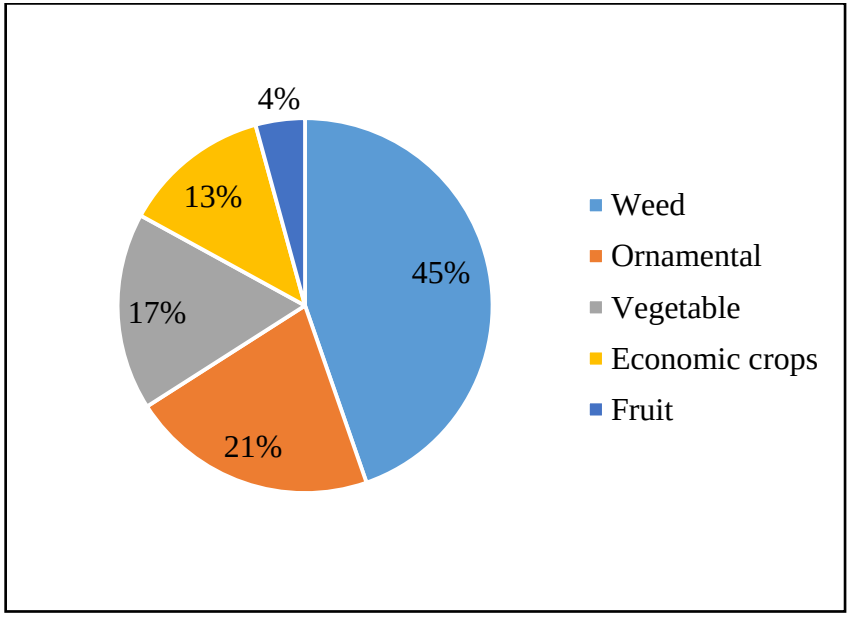


Fig. 4.3: Categories of host type infested by *T. vaporariorum*

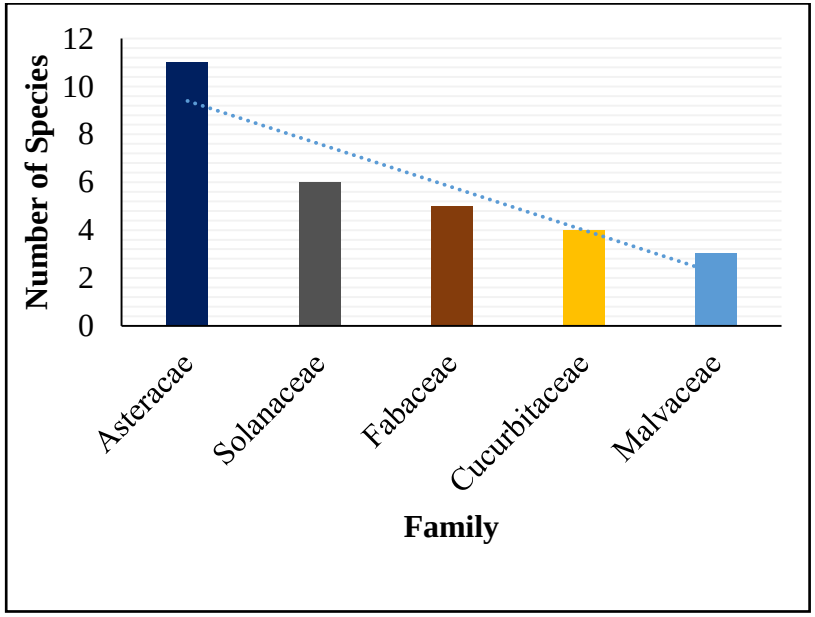
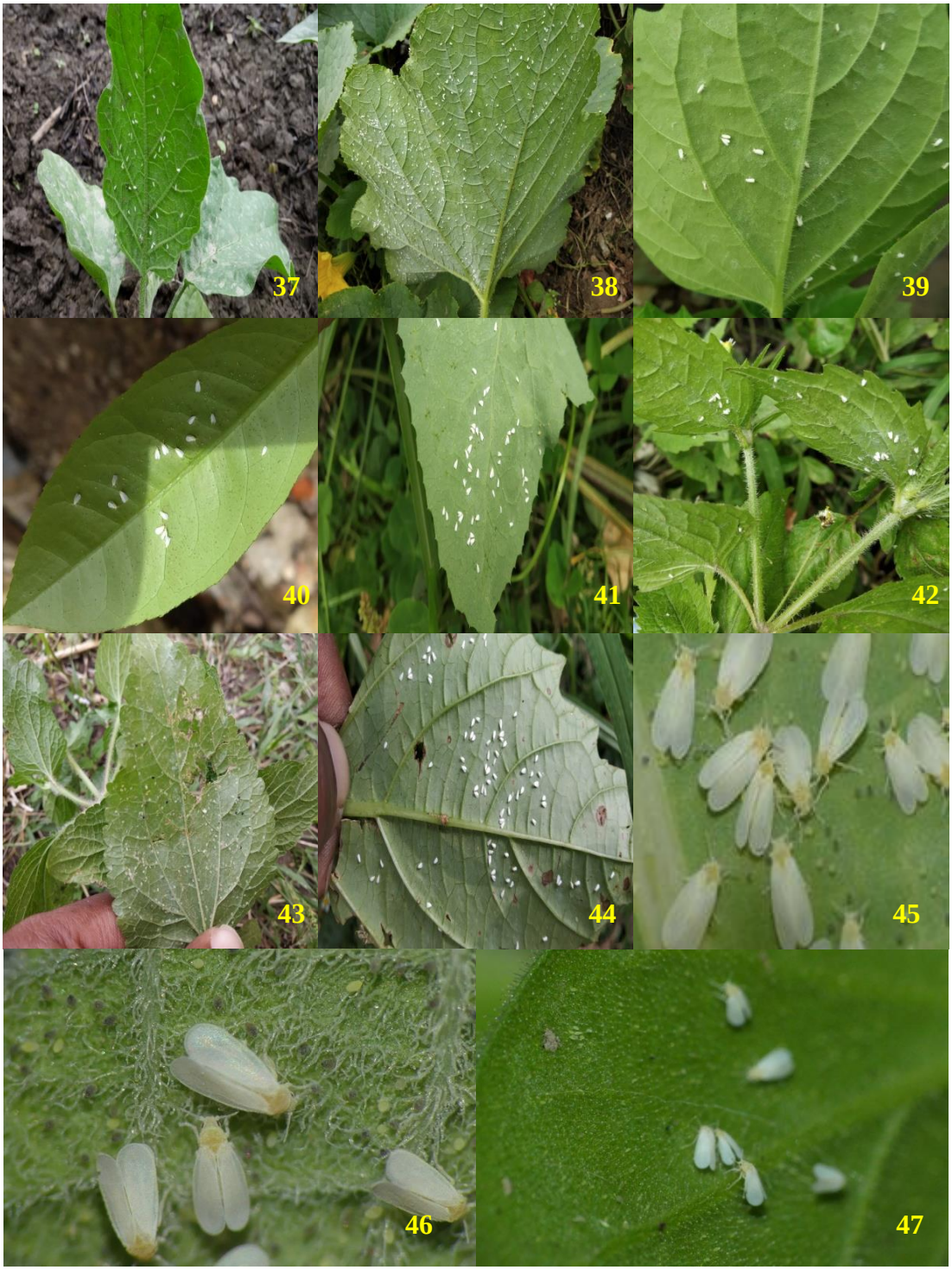


Fig. 4.4: Plant families infested by *T. vaporariorum*

1. Amaranthus sp. 2. Phaseolus vulgaris 3.Cannabis sativa 4. Urtica dioica 5. Lagenaria siceraria 6. Brassica oleracea 7. Stellaria media 8. Erigeron sp. 9. Euphorbia heterophylla 10. Tagetes sp. 11. Fuchsia sp. 12. Gerbera jamesonii

13.Golden duranta 14. Alcea rosea 15. Bidsen pilosa 16. Raphanus sativus 17. Eclipta alba 18. Lantana camara 19. Ageratina adenophora 20. Lactuca sativa 21. Alstromeria sp. 22. Malva sp. 23. Mentha sp. 24. Tropaeolum majus

25. Parthenium 26. Pisum sativum 27. Paleragonium sp. 28. Solanum tuberosum 29. Rosa sp. 30. Solanum nigrum 31. Ficus sp. 32. Helianthus sp. 33. Solanum lycopersicum 34. Papaver sp.35. Xanthium strumariam 36. Rumex crispus



37. *Solanum melongena* 38.*Cucurbita pepo* 39. *Physalis longifolia* 40. *Citrus lemon* 41. *Sonchus oleraceus* 42. *Bidsen pilosa* 43. *Ageratum conyzoides* 44. *Nicandra physalodes* 45. *Sonchus arevense* 46. *Ocimum tenuiflorum* 47. *Erigeron sp.*

Plate 4: List of host plant species of *T. vaporariorum*

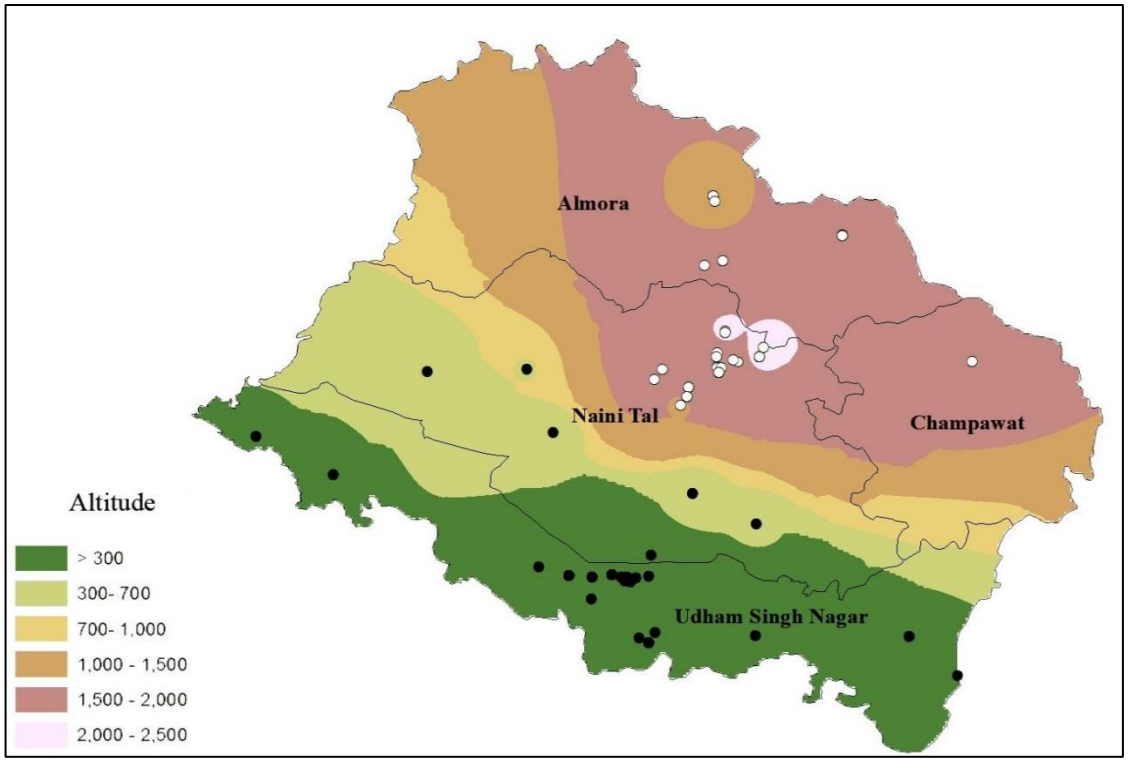


Fig. 4.5: Altitudinal (m) gradient wise distribution of whitefly species *B. tabaci* and *T. vaporariorum* in Uttarakhand

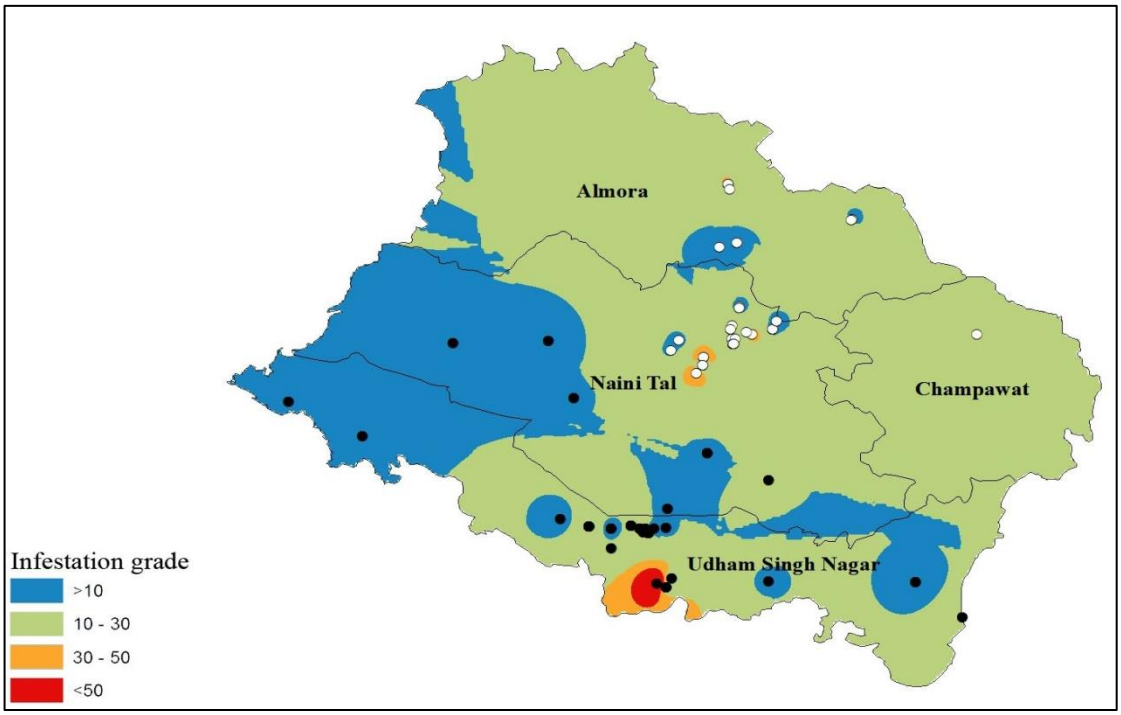


Fig. 4.6: Infestation grade (no. /cm^2) of *B. tabaci* and *T. vaporariorum* in different localities of Uttarakhand

A full understanding of host plant range of *B. tabaci* and *T. vaporariorum* through a systematic sampling process is the basis for developing integrated pest management strategies. In the present investigations, 69 and 47 host species were reported for *Bemisia tabaci* and *Trialeurodes vaporaiorum* respectively. Such a wide host range had earlier been reported by many workers for *Bemisia tabaci*, 44 **(Hussain and Trehan, 1933)**; 160 **(Attique *et al*., 2003)**; 118 **(Abd-Rabou and Simmons, 2010)** and 361 **(Li *et al*., 2011)** and 249 **(Russell, 1977)**; 24 **(Mohan *et al*., 1988)**; 44 **(Sood and Sood, 2002)** and 27 **(Bakshi *et al*., 2003)**. The more abundance of host plants of *B. tabaci* and *T. vaporariorum* were recorded in Vegetable Research Center and Gwala Kote, respectively due to higher temperature which leads to greater richness of the plant biodiversity. In the present investigations, Asteraceae, Fabaceae, Solanaceae and Cucurbitaceae were the most preferred host families for *B. tabaci* and *T. vaporariorum* as large numbers of host plant species were frequently documented from these families. Our results are much similar to earlier reports of **Attique *et al*. (2003); Zhou *et al*. (2003); Abd-Rabou and Simmons, (2010) and Zarei and Asgari (2013)**. However, the maximum number of hosts of *B. tabaci* and *T. vaporariorum* were weeds followed by economic crops and vegetables, a similar finding was reported by **Attique *et al*. (2003); Alegbejo and Banwo, (2005) and Li *et al*. (2011)**. Throughout the year some weeds and ornamental plants *viz*., *Parthenium hysterophorus, Solanum nigrum, Sonchus oleraceus, Duranta erecta, Lantana camara* and *Ficus religiosa* were served as a reservoir of the whitefly and present investigations were found on par with the findings of the observation conducted at Punjab by **Singh *et al*. (1994)**. Extensive survey conducted in a comprehensive pattern for *B. tabaci* and *T. vaporariorum* and their host plants, provided an inventory, a sound knowledge on the distribution of the whitefly species as well as their host range and infestation rate. The result provides a basic platform to formulate Integrated Pest Management modules for tackling sudden outbreaks, host shifting and invasive species in the region.

4.2. To study the seasonal incidence of *Bemisia tabaci* (Gennadius) on tomato and brinjal crop ecosystem at Pantnagar.

4.2.1. Seasonal incidence of whitefly on tomato and brinjal during 2017-18

The compiled data on the seasonal incidence of *Bemisia tabaci* was studied on tomato and brinjal in relation to weather parameters at VRC Pantnagar during *Kharif* crop season 2017-18. The seasonal incidence of whitefly, *B. tabaci* was observed on

tomato and brinjal when the crop age was about 30 days old (after transplanting) and the whitefly was available on the crop till its maturity **(Table 4.5 and Fig. 4.7)**. Whitefly was initially observed on tomato and brinjal crop after 30 days of transplanting with a population density of 0.20 (38^{th} standard week) and 1.40 (39^{th} standard week) adults per three leaves, respectively. The whitefly population was increased with the advancement of crop growth and reached a peak on the 48^{th} SW on tomato (5.40 adults per three leaves) and 51^{th} SW on brinjal crop (7.79 adults per three leaves).

B. tabaci population showed variation in peaks on tomato (4 peaks) and brinjal (5 peaks). The first peak of the population was observed during 40^{th} SW on tomato (1.00 adult per three leaves) and on brinjal during 39^{th} SW (1.40 adults per three leaves). Throughout this period, the maximum temperature and minimum temperature were 33.10, 32.30 °C and 23.80, 23.40 °C, respectively. Whereas, the morning relative humidity was 88% and evening relative humidity were 61, 65%. While, the sunshine recorded was 05.2, 05.4 hrs., wind velocity was 2.50, 3.50 km/hr.; evaporation was 2.60, 3.20 mm and rainfall were 000.00, 007.20 mm. Similarly, second peak was observed on tomato and brinjal during 48^{th} SW and 49^{th} SW (5.40 and 7.40 adults per three leaves, respectively). At this time, the maximum and minimum temperature (24.70, 23.30 °C and 7.80, 10.90 °C), maximum and minimum relative humidity (92, 93% and 48, 60%), the sunshine hour (07.10 and 03.70 hrs.), wind velocity (1.80, 2.50 km/hr.), evaporation (1.80, 2.50 mm) and rainfall (0.00 mm) were recorded.

The third peaks of *B. tabaci* on tomato and brinjal were recorded on 3^{rd} SW and 51^{st} SW with population (2.80 and 7.79 adults per three leaves) and fourth peak was attained during 5^{th} SW and 3^{rd} SW (3.40 and 4.19 adults per three leaves). For both peaks the abiotic parameters were maximum temperature (20.20, 21.30 °C and 20.60, 20.20 °C) and minimum temperature (4.20, 8.30 °C and 5.60, 4.20 °C), morning relative humidity (93, 95% and 94, 93%) and evening relative humidity (65, 64% and 60, 65%) sunshine (05.50, 05.60 hrs. and 05.80, 05.50 hrs.), wind velocity (2.70, 3.00 km/hr. and 3.90, 2.70 km/hr.), evaporation (1.20, 1.40 hrs. and 1.20, 1.20 hrs.) and nil rainfall.

Only brinjal showed the fifth peak during 5th SW when the temperature (maximum and minimum) was 20.60 and 6.90 °C, respectively. The morning and evening relative humidity were 94 and 60% respectively. Further, sunshine, wind velocity, and evaporation were 05.80 hrs. 3.90 km/hr. and 1.20 mm, respectively. There was no rainfall recorded during this period.

4.2.1.1 Correlation coefficient

The Correlation coefficient studies **(Table 4.6 and Fig. 4.8)** between whitefly population and weather parameters during 2017-18 indicated that whitefly population on tomato and brinjal had significantly negative correlation with max. temperature (r= -0.50** and r= -0.53**), min. temperature (r= -0.61** and r= -0.57**) and evaporation (r= -0.64** and r= -0.66**) whereas significantly positive correlation was observed with morning relative humidity on tomato (r= 0.56**) and brinjal (r= 0.55**). A non-significant correlation was observed between brinjal and tomato whitefly population with evening relative humidity, rainfall, sun shine hour and wind velocity.

Following regression equation was developed to predict the incidence of whitefly (*B. tabaci*) on brinjal and tomato

The regression equation **(Table 4.7)** revealed that various weather factors *viz*., temperature (max. and min.), relative humidity (morning and evening), rainfall, wind velocity, sun shine hours and evaporation had influencing effect on population of *B. tabaci* on brinjal and tomato with reasonable accuracy (R^2= 0.66 and R^2= 0.75).

Brinjal = 2.367 + 0.0418 T (max.) – 0.0798 T (min.) + 0.123 RH (mor.) – 0.0978 RH (eve.) – 0.0023 (Rf) – 0.284 (SS) – 0.369 (WV) – 0.720 (Evap.)

The regression equation fitted to study the effect of weather parameters on brinjal whitefly indicates that with every 1°C increase in maximum temperature and every 1 per cent increase in relative humidity (morning) there would be an increase of 0.0418 and 0.123 numbers of whitefly, while for every 1°C increase in minimum temperature, every 1 per cent increase in relative humidity (evening) and 1 mm increase in rainfall and evaporation there would be decrease of 0.0798, 0.0978, 0.0023 and 0.720 numbers of whitefly.

Tomato = 3.171 – 0.019 T (max.) – 0.009 T (min.) + 0.079 RH (mor.) – 0.090 RH (eve.) – 0.002 (Rf) – 0.050 (SS) – 0.098 (WV) – 0.747 (Evap.)

Table 4.5 Seasonal Incidence of whitefly on tomato and brinjal during the year 2017-18

Standard Weeks	Mean adult whitefly counts/3 leaves		Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Sun-Shine (hrs.)	Wind Velocity (km/hr.)	Evap. (mm)
	Tomato	Brinjal	Max.	Min.	Morning	Evening				
37	**0.00**	**0.00**	34.00	25.20	86	64	000.00	08.50	3.00	4.20
38	**0.20**	**0.00**	32.60	24.60	92	74	168.00	05.90	4.00	3.20
39	**0.59**	**1.40**	32.30	23.40	88	65	007.20	05.40	3.50	3.20
40	**1.00**	**1.20**	33.10	23.80	88	61	000.00	05.20	2.50	2.60
41	**0.79**	**1.40**	33.60	20.30	78	48	000.00	08.30	2.40	3.20
42	**1.82**	**2.00**	33.50	18.00	86	50	000.00	09.00	2.10	3.10
43	**2.20**	**4.00**	30.80	14.50	87	46	000.00	07.90	2.50	2.70
44	**2.60**	**4.40**	28.40	14.70	90	53	000.00	04.40	1.90	2.30
45	**3.20**	**5.20**	28.70	12.80	94	52	000.00	04.80	1.30	2.00
46	**3.80**	**5.60**	27.90	11.30	86	40	000.00	06.90	2.50	2.00
47	**4.60**	**5.80**	26.10	8.60	93	43	000.00	07.30	4.20	2.50
48	**5.40**	**6.60**	24.70	7.80	92	48	000.00	07.10	1.80	1.90
49	**4.20**	**7.40**	23.30	10.90	93	60	000.00	03.70	2.50	1.60
50	**3.40**	**5.40**	23.10	11.40	94	66	002.80	05.00	5.50	1.60
51	**3.00**	**7.79**	21.30	8.30	95	64	000.00	05.60	3.00	1.40
52	**2.40**	**4.00**	22.50	7.20	96	66	000.00	06.20	1.80	1.00
01	**1.82**	**3.22**	15.20	6.00	95	81	000.00	02.50	3.00	0.80
02	**1.40**	**2.80**	12.90	5.30	95	79	000.00	01.20	2.60	0.80
03	**2.80**	**4.19**	20.20	4.20	93	65	000.00	05.50	2.70	1.20
04	**2.60**	**2.20**	18.60	6.40	94	70	006.80	03.60	4.20	1.10
05	**3.40**	**4.40**	20.60	6.90	94	60	000.00	05.80	3.90	1.20
06	**3.20**	**3.80**	23.20	5.60	95	50	000.00	06.40	5.40	1.80
07	**2.60**	**2.60**	23.00	9.20	93	61	004.00	06.10	5.30	1.90
08	**2.20**	**2.00**	26.90	11.50	89	51	000.00	07.70	3.00	2.30
09	**1.60**	**1.60**	28.70	11.50	91	44	000.00	07.50	5.60	3.10
10	**1.40**	**1.40**	29.50	10.70	92	39	000.00	08.80	5.50	4.00
11	**1.00**	**1.19**	31.10	11.80	81	44	000.00	08.50	4.90	4.30
12	**0.40**	**1.00**	31.90	12.70	83	40	000.00	09.00	4.60	4.30
13	**0.00**	**0.50**	33.60	14.50	78	47	000.00	08.20	5.30	5.80

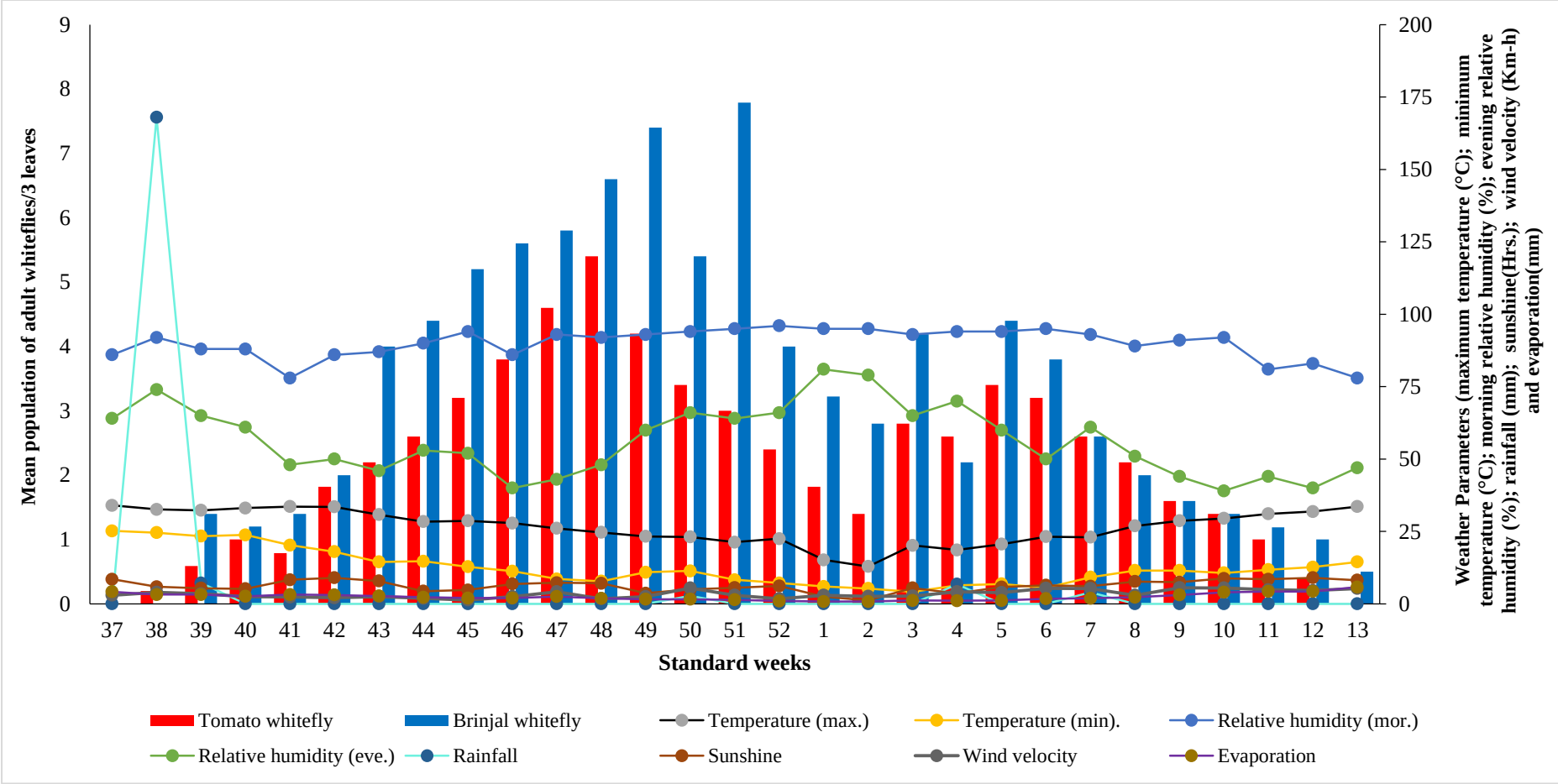


Fig. 4.7: Seasonal Incidence of whitefly on tomato and brinjal during the year 2017-18

The regression equation fitted to study the effect of weather parameters on tomato whitefly indicates that with every 1°C increase in maximum temperature, minimum temperature, and every 1 per cent increase in evening relative humidity there would be decrease of 0.019, 0.009 and 0.090 numbers of whitefly, while for every 1 per cent increase in morning relative humidity, 1 mm increase in rainfall and evaporation there would be decrease of 0.079, 0.002 and 0.747 numbers of whitefly.

Table 4.6 Correlation matrix (Pearson's) for weather-based observations with *B. tabaci* population on tomato and brinjal during 2017-2018

Variables	**TWf**	**BWf**	Tmax.	Tmin.	RHmor.	RHeve.	Rf	SS	WV
Tmax.	**-0.50****	**-0.53****							
Tmin.	**-0.61****	**-0.57****	0.82**						
RHmax.	**0.56****	**0.55****	-0.75**	-0.55**					
RHmin.	**NS**	**NS**	-0.57**	NS	0.52**				
Rf	**NS**	**NS**	NS	0.391*	NS	NS			
SS	**NS**	**-0.38***	0.74**	NS	-0.64**	-0.77**	NS		
WV	**NS**	**NS**	NS	NS	NS	NS	NS	NS	
Evap.	**-0.64****	**-0.66****	0.84**	0.59**	-0.80**	-0.55**	NS	0.74**	0.37*

TWf: whitefly adult population / 3 leaves on tomato; BWf: whitefly adult population / 3 leaves on brinjal; Tmax.: maximum temperature (°C); Tmin.: minimum temperature (°C); RHeve.: minimum relative humidity (%); RHmor.: maximum relative humidity (%); Rf: rainfall (mm); SS: sunshine(Hrs.); WV: wind velocity (Km-h) and Evap.: evaporation(mm). Bold digits in the table indicate the "–" correlation data; data followed by '*' indicates their significant correlation at $P < 0.05$ and data followed by '**' indicate their significant correlation at $P < 0.01$; NS: not significant

Table 4.7 Regression between weather parameters and population of *B. tabaci* on brinjal and tomato during 2017-18

S.I. No.	Year	Regression equation	R^2 value	Predicted value (%)
1.	2017-18	**Brinjal** = 2.367 + 0.0418 T (max.) – 0.0798 T (min.) + 0.123 RH (mor.) – 0.0978 RH (eve.) – 0.0023 (Rf) – 0.284 (SS) – 0.369 (WV) – 0.720 (Evap.)	0.66	66
2.	2017-18	**Tomato** = 3.171 – 0.019 T (max.) – 0.009 T (min.) + 0.079 RH (mor.) – 0.090 RH (eve.) – 0.002 (Rf) – 0.050 (SS) – 0.098 (WV) – 0.747 (Evap.)	0.75	75

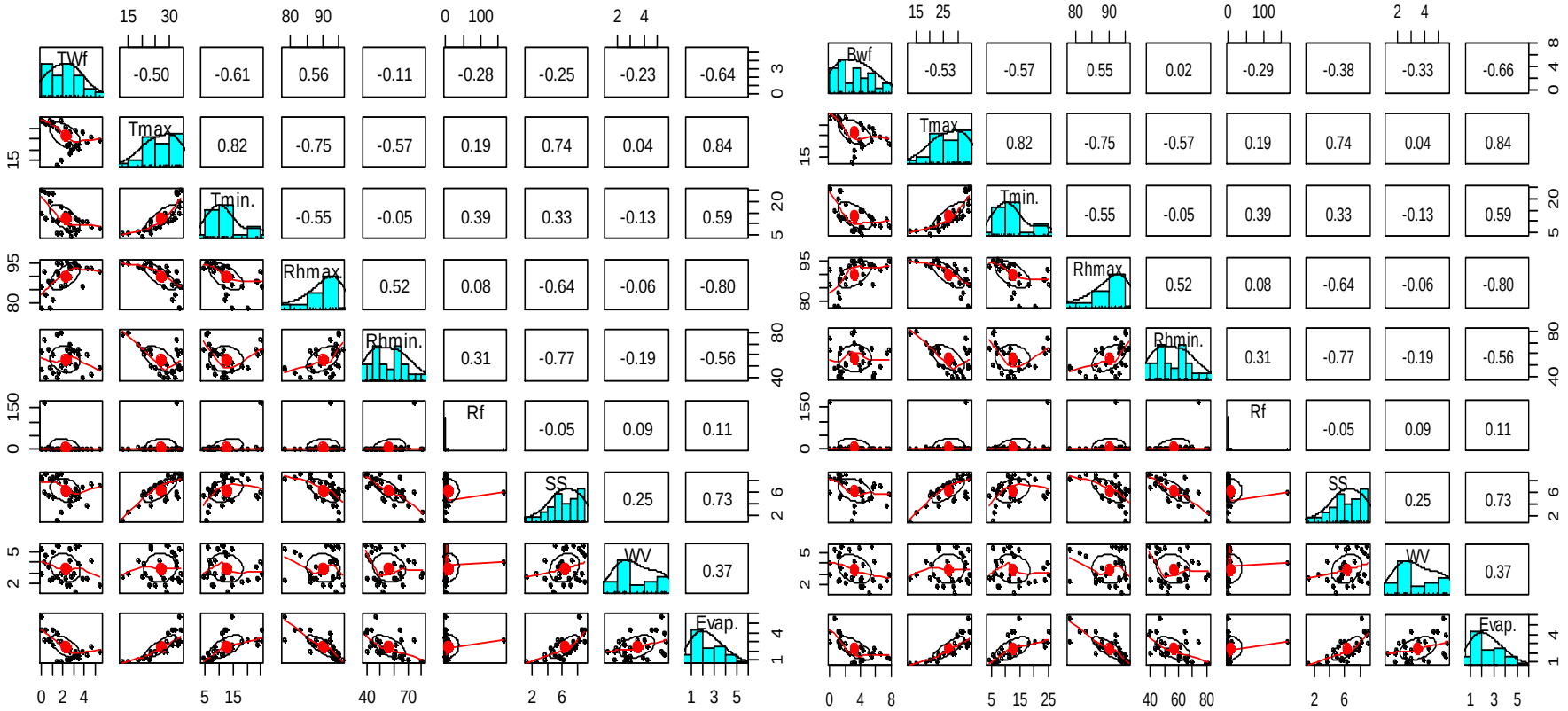


Fig. 4.8: Correlation matrix (Pearson's) for weather-based observations with *B. tabaci* population on tomato and brinjal during 2017-2018

4.2.2 Seasonal Incidence of whitefly on tomato and brinjal during 2018-19

Similar experiment was conducted at VRC, Pantnagar during *Kharif* crop season 2018-19. The first appearance of whitefly was recorded on tomato and brinjal crop just after transplanting with a population density of 0.79 (39^{th} SW) and 0.80 (38^{th} SW) adults per three leaves, respectively **(Table 4.8 and Fig. 4.9)**. With crop growth, the population of whitefly also increased and attained its peak on tomato and brinjal during 49^{th} (6.20 adults per three leaves) and 50^{th} SW (8 adults per three leaves).

On tomato, whitefly attained four distinctive peaks during the crop season. The first peak was found during 43^{rd} SW (2.80 adults per three leaves) when the temperature (maximum and minimum) was 29.60 and 12.00 °C respectively. Whereas, morning and evening relative humidity were 90 and 51 per cent, respectively. Further, sunshine, wind velocity, and evaporation were 8.30 hrs., 3.40 km/hr., and 3.10 mm, respectively. No rainfall was recorded during this period. The second peak was observed during 49^{th} SW (6.20 adults per three leaves) with the maximum and minimum temperature of 23.90 and 7.80 °C, respectively. Whereas, the morning and evening relative humidity were 93 and 61 per cent, respectively. Further, sunshine, wind velocity, and evaporation were 6.20 hrs., 1.80 km/hr., and 1.90 mm, respectively. There was no rainfall during this period. The third and fourth peaks were recorded during 2^{nd} and 7^{th} SW (3.40 and 4.60 adults per three leaves) during this period the maximum and minimum temperature were 21.70, 22.70 °C and 5.70, 10.80 °C, respectively. The morning and evening relative humidity were 94, 94 per cent and 57, 64 per cent, respectively. Also, the sunshine, wind velocity, and evaporation were 5.80, 4.80 hrs., 2.10, 2.80 km/hr., and 1.70, 1.90 mm, respectively. In addition to this, 000.00 and 012.00 mm rainfall was received.

On brinjal, whitefly population accomplished three peaks during 50^{th}, 5^{th}, and 8^{th} SW with population density 8.00, 4.81 and 6.00 adults per three leaves, respectively. The weather parameters taken into consideration were maximum temperature (22.60, 20.90 and 24.30 °C) and minimum temperature (6.60, 7.00 and 11.40 °C), morning relative humidity (95, 93 and 92 per cent) and evening relative humidity (60, 63 and 64 per cent), sunshine (6.30, 6.10 and 4.60 hrs.), wind velocity (1.90, 1.60 and 2.80 km/hr.), evaporation (2.00, 1.80 and 2.40 mm.) and rainfall (008.00, 000.00 and 003.20 mm.).

Table 4.8 Seasonal incidence of whitefly on tomato and brinjal during the year 2018-19

Standard Weeks	Mean adult whitefly counts/3 leaves		Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
	Tomato	Brinjal	Max.	Min.	Morning	Evening				
37	**0.00**	**0.00**	31.90	24.30	93.00	78.00	15.60	5.60	6.00	3.90
38	**0.00**	**0.80**	32.10	22.60	90.00	73.00	49.20	6.80	6.60	4.00
39	**0.79**	**1.20**	30.40	22.00	91.00	70.00	80.60	4.60	5.40	3.10
40	**1.00**	**1.40**	32.30	18.50	84.00	60.00	0.00	9.10	4.60	4.00
41	**1.40**	**1.60**	30.90	17.10	83.00	61.00	2.60	7.30	4.70	3.50
42	**1.20**	**2.00**	30.70	14.30	87.00	59.00	0.00	7.80	3.50	3.30
43	**2.80**	**3.20**	29.60	12.00	90.00	51.00	0.00	8.30	3.40	3.10
44	**2.40**	**3.80**	29.90	13.70	87.00	54.00	4.20	7.10	3.20	2.70
45	**3.60**	**4.60**	27.50	11.70	94.00	54.00	0.00	7.70	2.80	2.40
46	**3.80**	**5.40**	26.50	11.80	92.00	63.00	0.00	6.50	2.10	2.20
47	**4.40**	**6.00**	26.30	10.50	93.00	53.00	0.00	7.70	1.80	2.60
48	**4.79**	**7.00**	25.80	10.70	95.00	61.00	0.00	6.40	1.90	2.30
49	**6.20**	**7.60**	23.90	7.80	93.00	61.00	0.00	6.20	1.80	1.90
50	**4.00**	**8.00**	22.60	6.60	95.00	60.00	0.80	6.30	1.90	2.00
51	**3.60**	**7.20**	22.50	5.00	97.00	51.00	0.00	6.80	2.00	1.90
52	**3.20**	**6.00**	20.30	3.90	97.00	52.00	0.00	6.70	2.00	1.50
01	**3.00**	**5.01**	21.30	6.00	91.00	60.00	0.00	6.00	2.00	1.60
02	**3.40**	**4.60**	21.70	5.70	94.00	57.00	0.00	5.80	2.10	1.70
03	**3.20**	**4.39**	21.70	5.70	93.00	53.00	0.00	6.10	2.10	1.80
04	**3.00**	**4.00**	20.50	8.60	88.00	57.00	14.20	3.80	3.80	2.10
05	**2.80**	**4.81**	20.90	7.00	93.00	63.00	0.00	6.10	1.60	1.80
06	**2.60**	**5.00**	21.30	9.10	95.00	66.00	15.00	4.70	3.40	2.00
07	**4.60**	**5.41**	22.70	10.80	94.00	64.00	12.00	4.80	2.80	1.90
08	**3.20**	**6.00**	24.30	11.40	92.00	64.00	3.20	4.60	2.80	2.40
09	**2.60**	**3.60**	21.50	9.00	92.00	69.00	6.80	5.70	2.20	2.60
10	**1.60**	**2.60**	26.00	8.90	85.00	50.00	0.00	9.40	2.20	3.60
11	**1.20**	**1.60**	27.80	11.90	90.00	47.00	2.60	6.40	1.80	3.20
12	**0.59**	**1.19**	30.70	11.70	85.00	41.00	0.00	9.10	1.20	4.80
13	**0.00**	**0.60**	32.30	15.50	85.00	50.00	0.00	7.70	1.60	4.50

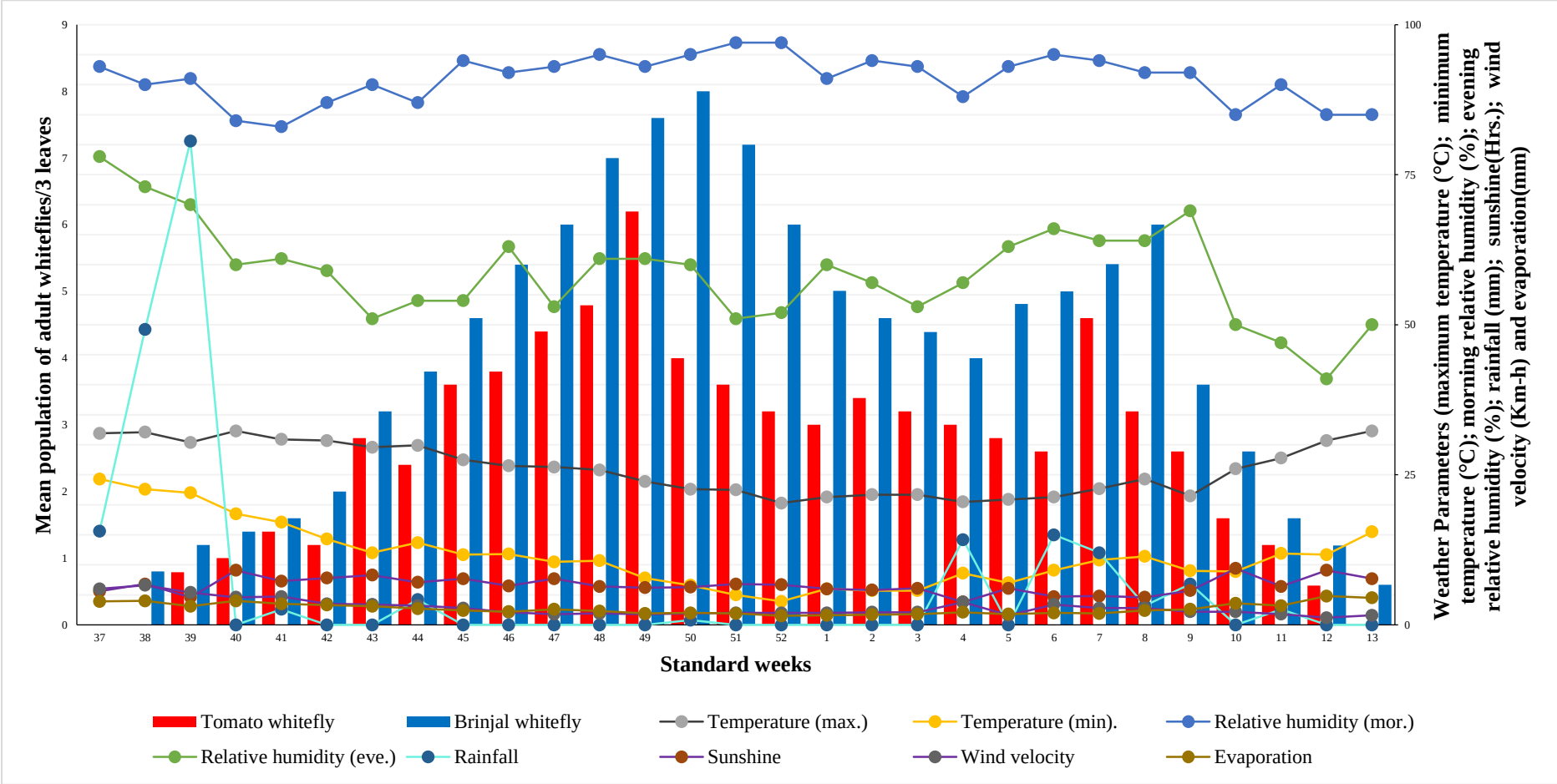


Fig. 4.9: Seasonal incidence of whitefly on tomato and brinjal during the year 2018-19

4.2.2.1 Correlation coefficient

The Correlation coefficient studies (**Table 4.9 and Fig. 4.10**) between the population of whitefly and weather parameters during 2018-19 indicated that the population whitefly on tomato and brinjal had significantly negative correlation with all the weather parameters *viz*., max. temperature (r= -0.63** and r= -0.87**), min. temperature (r= -0.74** and r= -0.90**), morning relative humidity (r= -0.53* and r= -0.57*), rainfall (r= -0.54* and r= -0.51*) and evaporation (r= -0.71** and r= -0.89**) while the population positively correlated significantly positive with morning relative humidity on brinjal (r= 0.67**). A non-significant correlation was observed between the population of brinjal and tomato whitefly with sun shine hour.

Following regression equation was developed to predict the incidence of whitefly on brinjal and tomato

The regression equation **(Table 4.10)** depicted that various weather factors *viz*., temperature (max. and min.), relative humidity (morning and evening), rainfall, wind velocity, sun shine hours and evaporation influence the population of *B. tabaci* on brinjal and tomato with reasonable accuracy (R^2= 0.82 and R^2= 0.70).

Brinjal = -15.728 + 0.418 T (max.) – 0.399 T (min.) + 0.137 RH (mor.) + 0.95 RH (eve.) + 0.000 (Rf) - 0.25 (SS) – 0.255 (WV) – 1.376 (Evap.)

The regression equation fitted to study the effect of weather parameters on brinjal whitefly indicated that with every 1°C increase in maximum temperature, every 1 per cent increase in morning and evening relative humidity and 1 mm increase in rainfall there would be an increase of 0.0418, 0.137, 0.95 and 0.00 numbers of whitefly respectively while for every 1°C increase in minimum temperature and 1 mm increase in evaporation there would be decrease of 0.399 and 1.376 numbers of whitefly respectively.

Tomato = -9.060 + 0.504 T (max.) – 0.362 T (min.) + 0.024 RH (mor.) – 0.101 RH (eve.) – 0.007 (Rf) – 0.215 (SS) – 0.274 (WV) – 1.184 (Evap.)

The regression equation fitted to study the effect of weather parameters on tomato whitefly indicated that every 1°C increase in maximum temperature and 1 per cent increase in morning relative humidity the number of whitefly would be increased

to 0.504 and 0.024 respectively, while with every 1°C increase in minimum temperature and 1 per cent increase in evening relative humidity, 1 mm increase in rainfall and evaporation there would be decrease of 0.362, 0.101, 0.007 and 1.184 in the numbers of whitefly.

Table 4.9 Correlation matrix (Pearson's) for weather-based observations with *B. tabaci* population on tomato and brinjal during 2018-2019

Variables	TWf	BWf	Tmax.	Tmin.	RHmor.	RHeve.	Rf	SS	WV
Tmax.	**-0.63****	**-0.87****							
Tmin.	**-0.74****	**-0.90****	0.92**						
RHmax.	**NS**	**0.67****	-0.72**	-0.54*					
RHmin.	**-0.53***	**-0.57***	NS	0.76**	NS				
Rf	**-0.54***	**-0.51***	NS	0.63**	NS	0.62**			
SS	**NS**	**NS**	NS	NS	NS	-0.55*	-0.55*		
WV	**-0.87****	**-0.93****	0.83**	0.94**	-0.510*	0.72*	0.67**	NS	
Evap.	**-0.71****	**-0.89****	0.95**	0.91**	-0.67**	0.54*	NS	NS	0.89**

TWf: whitefly adult population / 3 leaves on tomato; BWf: whitefly adult population / 3 leaves on brinjal; Tmax.: maximum temperature (°C); Tmin.: minimum temperature (°C); RHeve.: minimum relative humidity (%); RHmor.: maximum relative humidity (%); Rf: rainfall (mm); SS: sunshine(Hrs.); WV: wind velocity (Km-h) and Evap.: evaporation(mm). Bold digits in the table indicate the "–" correlation data; data followed by '*' indicates their significant correlation at $P < 0.05$ and data followed by '**' indicate their significant correlation at $P < 0.01$; NS: not significant

Table 4.10 Regression between weather parameters and population of *B. tabaci* on brinjal and tomato during 2018-19

S.I. No.	Year	Regression equation	R^2 value	Predicted value (%)
1.	2018-19	**Brinjal** = -15.728 + 0.418 T (max.) – 0.399 T (min.) + 0.137 RH (mor.) + 0.95 RH (eve.) + 0.000 (Rf) - 0.25 (SS) – 0.255 (WV) – 1.376 (Evap.)	0.82	82
2.	2018-19	**Tomato** = -9.060 + 0.504 T (max.) – 0.362 + 0.024 RH (mor.) – 0.101 RH (eve.) – 0.007 (Rf) – 0.215 (SS) – 0.274 (WV) – 1.184 (Evap.)	0.70	70

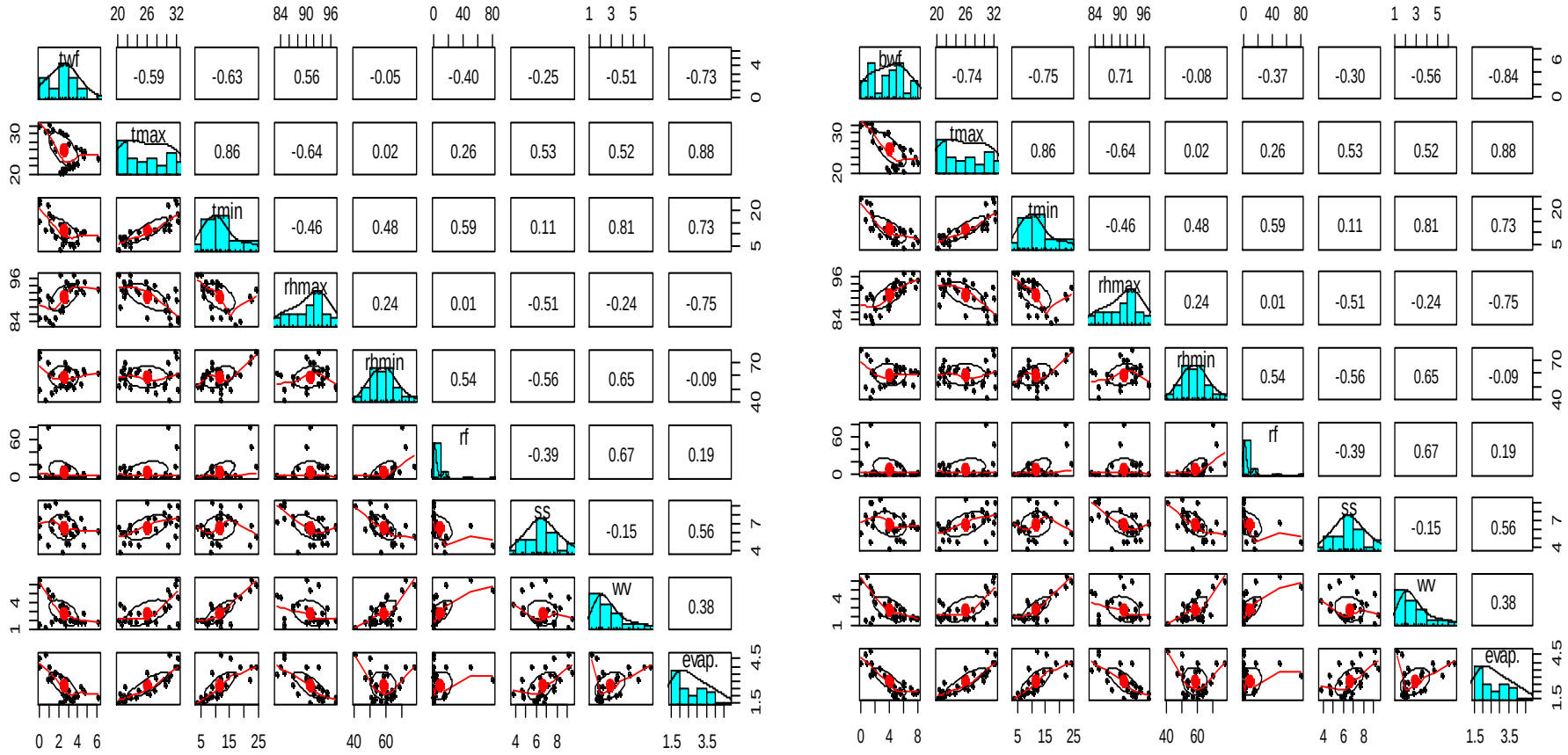


Fig. 4.10: Correlation matrix (Pearson's) for weather-based observations with *B. tabaci* population on tomato and brinjal during 2018-2019

B. tabaci is a thermophilic insect and depends upon weather parameters like temperature, relative humidity, rainfall, sunshine hour, wind velocity and evaporation therefore these parameters play a vital role in initial infestation and further flareup **(Avidov, 1956; Tomar, 2010 and Pathania *et al*., 2019)**. *B. tabaci* is polyphagous in nature and remains active in low to high numbers throughout the year on alternate and collateral host plants **(Melamed-Madjar and Raccah, 1979; Gerling, 1984 and Gerling, 1996)**. Our studies indicate that whitefly appeared on tomato and brinjal immediately after transplanting during mid-September and establishes itself in-between the end of November and first week of December. Maximum incidence of whiteflies was recorded during November and December these findings are also supported by the findings of **Prasad *et al*. (2008); Meena and Bairwa, (2014)**. During this period Maximum temperature (range: 21 to 26 °C) and minimum temperature (range: 6.60 to 10.90 °C), morning relative humidity (range: 92 to 95 per cent) and evening relative humidity (range: 48 to 64 per cent) is favorable for multiplication of *B. tabaci* in tomato and brinjal. The present results are also in conformity with the findings of **Sharma (2008)** where maximum and minimum temperature, 28.0 °C and 8.7 °C respectively and morning and evening relative humidity were 92 and 26 per cent, respectively. The weather parameter (temperature and relative humidity) of 2017-18 and 2018-19 may be similar and therefore, the population build-up of whitefly was similar. Biology and population build- up of insect- pests are greatly influenced by prevailing weather conditions **(Bale *et al*., 2002 and Tomar, 2010)**. During the study, a significant negative correlation was observed between *B. tabaci* population in tomato and brinjal with maximum temperature and minimum temperature, while brinjal whitefly population showed positive correlation with morning relative humidity and tomato whitefly population was negatively correlated with morning relative humidity which is in accordance with the findings of **Mathur *et al*. (2012) and Indirakumar *et al*. (2016)**.

The regular monitoring and surveillance play a significant role for timely management of *B. tabaci* on tomato and brinjal **(Aslam *et al*., 2001)**. To achieve this, basic knowledge of the influence of abiotic factor on the seasonal incidence of *B.*

tabaci on tomato and brinjal is must, which was well furnished in this study **(Rasdi, *et al*., 2009; Ramos *et al*., 2019; Sushmetha and Hariprasad, 2020)**. Thus this study throw light on the consequences of weather parameter on the population dynamics of the *B. tabaci* on tomato and brinjal, also how these abiotic factors can be utilized further in order to manage the pest when the vegetables are grown under controlled condition in the future.

4.3 Host preference, ovipositional suitability, and biotic potential of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) in selected vegetable crops

4.3.1 Feeding preference of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

Brinjal was the most preferred host plant by adult *Bemisia tabaci* and *Trialeurodes vaporariorum* among the five hosts at different interval of the investigation by free choice method and study of ANOVA disclosed the fact that the population of *B. tabaci* and *T. vaporariorum* varied significantly at 24 hours (F= 05.801; p= 00.011 and F= 09.766; p= 00.002), 48 hours (F= 07.704; p= 00.004 and F= 05.270; p= 00.015) and 72 hours (F= 8.075; p=00.004 and F=18.898; p=00.000), respectively **(Table 4.11 and Fig. 4.11)**. After 24 hours of observation, the mean population of *B. tabaci* found on the brinjal was 40.00 followed by tomato, chilli, cabbage, and bottle gourd having an adult population of 30.67, 12.00, 11.67, and 5.67, respectively. A similar trend was also recorded in the case of *T. vaporariorum* where brinjal was the favorite host with the highest (42.00) numbers of individuals followed by tomato (37.00), cabbage (10.67), bottle gourd (07.00), and in contrast to *B. tabaci* least population was found on chilli. After 48 hours of observation, it was evident that maximum numbers of *B. tabaci* and *T. vaporariorum* were found on the brinjal plant with population 37.67 and 41.33, respectively. However, least preferred host varied in the case of both the whitefly genera even after 48 hours which was bottle gourd (6.33) and chilli (3.67), respectively. After 72 hours also, a maximum number of adults of both genus found on brinjal *B. tabaci* (36.33) and *T. vaporariorum* (42.33), whereas the least chosen host plant by *B. tabaci* was bottle gourd (4.33) and by *T. vaporariorum* (2.67) least preferred was chilli. The overall mean population of *T. vaporariorum* was found greater as compared to *B. tabaci* on tomato, brinjal, cabbage, and bottle gourd while chilli was mostly preferred by *B. tabaci.*

Table 4.11 Feeding preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

Host plant	*Bemisia tabaci*			*Trialeurodes vaporariorum*		
	24hrs	**48hrs**	**72hrs**	**24hrs**	**48hrs**	**72hrs**
Tomato	33.22^{bc} (30.67)	33.56^{bc} (31.00)	34.15^{c} (31.67)	37.16^{b} (37.00)	34.50^{b} (33.67)	29.53^{c} (32.00)
Brinjal	38.90^{c} (40.00)	37.61^{c} (37.67)	36.75^{c} (36.33)	40.07^{b} (42.00)	39.68^{b} (41.33)	44.23^{d} (42.33)
Cabbage	19.31^{ab} (11.67)	17.63^{a} (09.33)	16.08^{a} (08.00)	18.78^{a} (10.67)	19.48^{ab} (11.33)	22.53^{bc} (13.33)
Bottle gourd	13.63^{a} (05.67)	14.51^{a} (06.33)	11.67^{a} (04.33)	15.26^{a} (07.00)	17.93^{ab} (10.00)	16.03^{ab} (09.67)
Chilli	20.12^{ab} (12.00)	22.97^{ab} (15.67)	25.71^{ab} (199.67)	10.40^{a} (03.33)	10.86^{a} (03.67)	09.77^{a} (02.67)
F value	05.801	07.704	08.075	09.766	05.270	18.898
p value	00.011	00.004	00.004	00.002	00.015	00.000

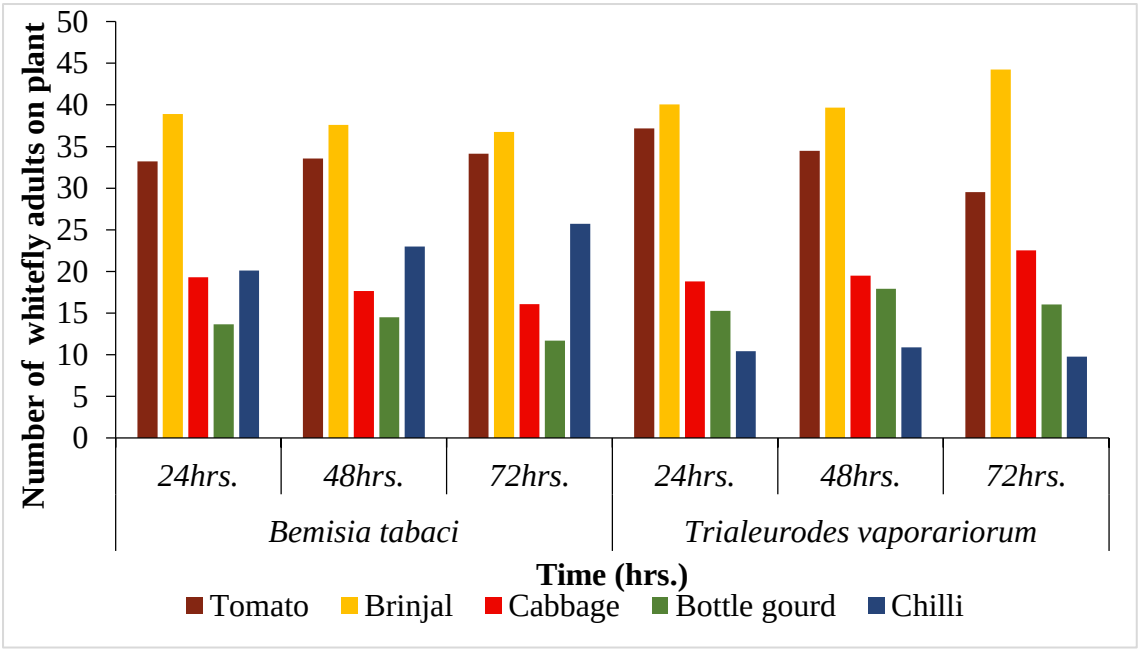


Fig. 4.11: Feeding preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

4.3.2 Feeding preferences of *B. tabaci* and *T. vaporariorum* on different host plants under no choice condition

Data embodied in **Table 4.12** revealed that when adult whiteflies released on the host plant under no-choice method the most favored host was brinjal with the highest number of individuals of *B. tabaci* and *T. vaporariorum* (11.67, 7.67) followed by tomato (7.67, 9.33) at 24 hours of observation, respectively. ANOVA study of the population of both genera on separate host plants indicated that there was a significant variation between different hours of observation of *B. tabaci i.e*., 24h (*F*= 04.157; *p*= 00.031), 48h (*F*= 05.058; *p*= 00.017), 72h (*F*= 04.167; *p*= 00.031) and *T. vaporariorum* 24h (*F*= 05.885; *p*= 00.011), 48h (*F*= 04.121; *p*= 00.032), 72h (*F*=06.362; *p*= 00.008). However, a different pattern was found in both the genus where after brinjal and tomato, maximum population of *B. tabaci* was found in cabbage (11.67) followed by chilli (05.33) and bottle gourd (4.67) whereas, in the case of *T. vaporariorum* number of individuals were 07.00, 03.33 and 2.33 on bottle gourd, cabbage, and chilli, respectively. When observation was taken at 48 hours alike trend was recorded where brinjal put up with highest individuals of *B. tabaci* (10.33) and *T. vaporariorum* (13.67) and least number of individuals found in bottle gourd (3.67) and chilli (1.67) of *B. tabaci* and *T. vaporariorum*, respectively **(Fig. 4.12)**. Even after the 72 hours there was no change in trend, here also it can be easily noticed that most of the individual of *B. tabaci* and *T. vaporariorum* preferred brinjal as a host and the count was found to be 11.00 and 13.00, respectively whereas, the host bears least individuals was bottle gourd and chilli with count 03.00 and 02.67, respectively of *B. tabaci* and *T. vaporariorum.* Here also the overall mean population of *T. vaporariorum* on every host was higher than *B. tabaci* whereas this rule was not followed in the case of cabbage.

4.3.3 Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

The preferred egg-laying host of *B. tabaci* and *T. vaporariorum* on is enlisted in **Table 4.13** where the data varied significantly with the different host according to ANOVA study as *B. tabaci* (*F*= 17.154; *p*= 00.000)and *T. vaporariorum* (*F*= 29.193; *p*= 00.000). The mean egg deposited by adults of *B. tabaci* under *the* free choice method was highest in brinjal (212.00) followed by tomato (153.67), cabbage (45.00), chilli (35.67), and least egg deposited on bottle gourd (17.67). Similarly, the brinjal was

Table 4.12 Feeding preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the no-choice condition

Host plant	*Bemisia tabaci*			*Trialeurodes vaporariorum*		
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
Tomato	15.88^{ab} (07.67)	15.32^{ab} (07.00)	14.90^{ab} (06.67)	17.59^{ab} (09.33)	16.47^{ab} (08.67)	15.93^{ab} (07.67)
Brinjal	19.95^{b} (11.67)	18.72^{b} (10.33)	19.26^{b} (11.00)	21.27^{b} (13.33)	21.32^{b} (13.67)	21.05^{b} (13.00)
Cabbage	13.63^{a} (05.67)	12.65^{a} (05.00)	12.28^{ab} (04.67)	09.96^{a} (03.33)	09.54^{ab} (03.00)	09.96^{a} (03.33)
Bottle gourd	12.36^{a} (04.67)	10.76^{a} (03.67)	9.54^{a} (03.00)	14.90^{ab} (07.00)	13.89^{ab} (06.33)	13.45^{a} (05.67)
Chilli	13.11^{a} (05.33)	12.36^{a} (04.67)	11.51^{ab} (04.33)	08.47^{a} (02.33)	07.33^{a} (01.67)	09.08^{a} (02.67)
F value	04.157	05.058	04.167	05.885	04.121	06.362
p value	00.031	00.017	00.031	00.011	00.032	00.008

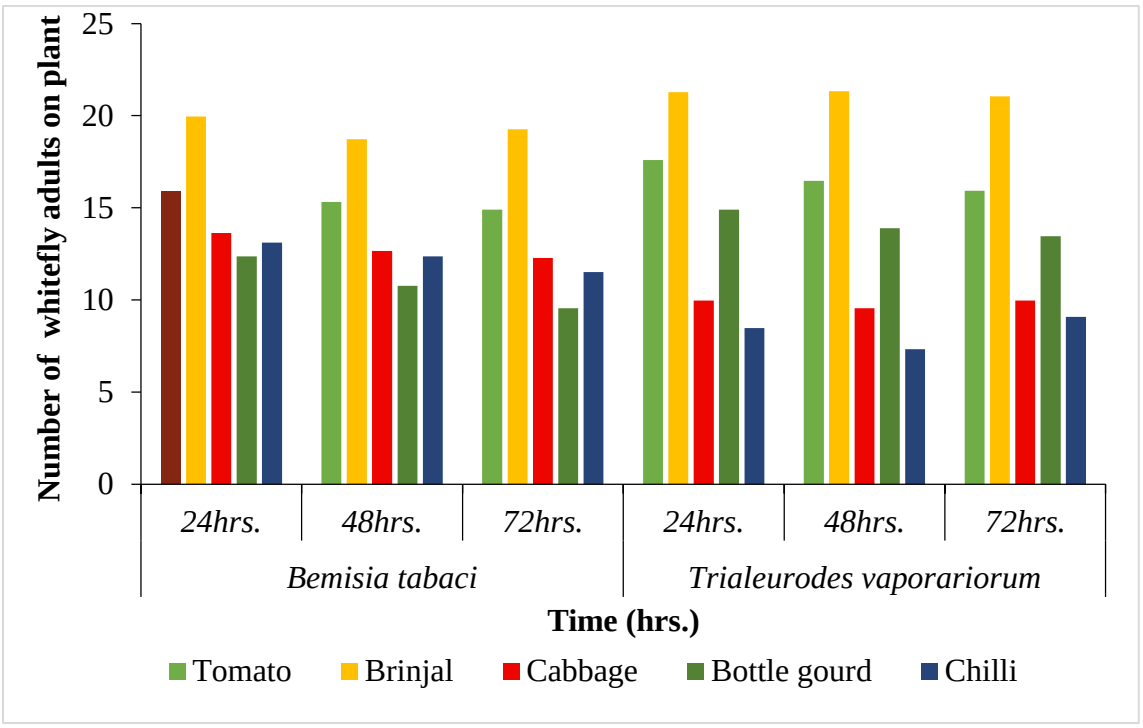


Fig. 4.12: Feeding preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the no-choice condition

Table 4.13 Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

Host plant	*Bemisia tabaci*	*Trialeurodes vaporariorum*
Tomato	153.67±32.77[b]	171.67± 15.76[b]
Brinjal	212.00±27.40[b]	241.33± 34.36[c]
Cabbage	45.00±12.76[a]	65.67± 10.41[a]
Bottle gourd	17.67±04.97[a]	31.00± 07.02[a]
Chilli	35.67±10.39[a]	18.33± 04.63[a]
F value	17.154	29.193
p value	00.000	00.000

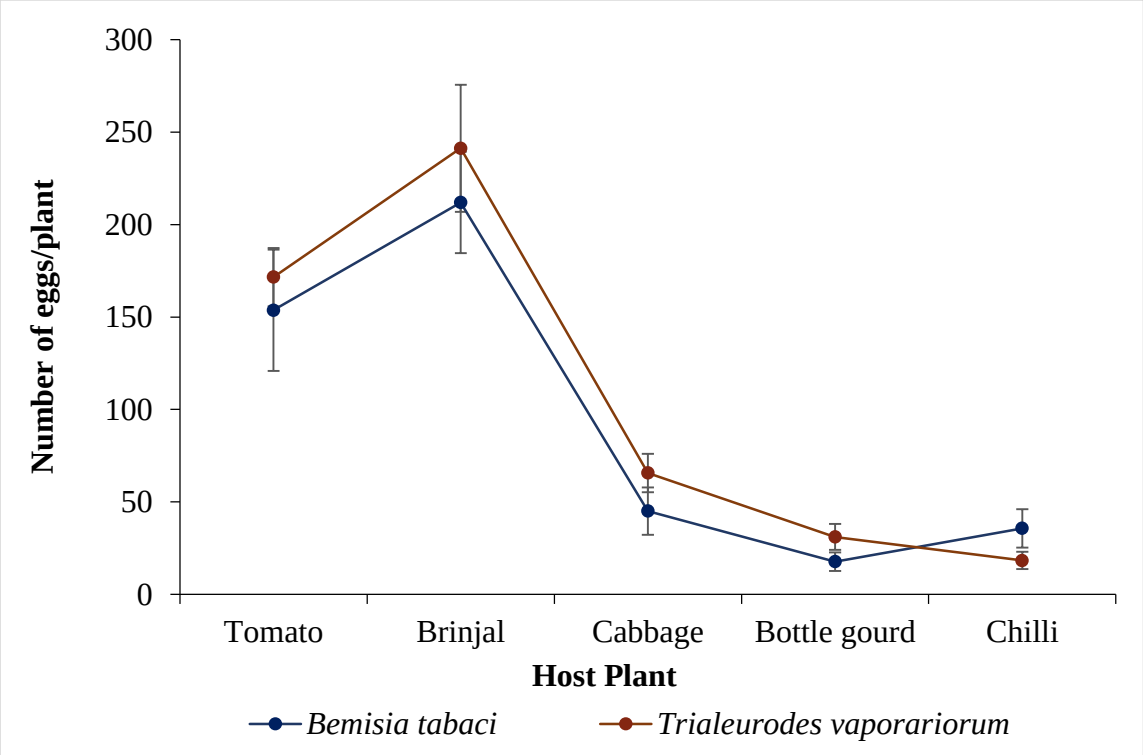
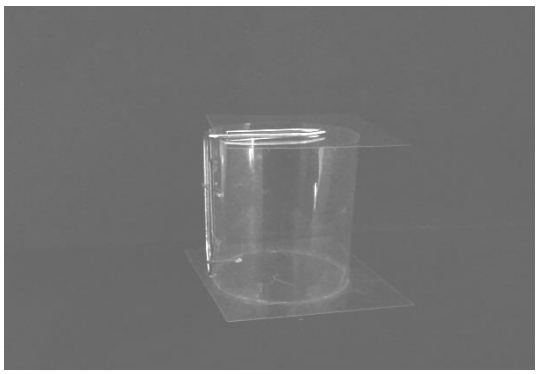


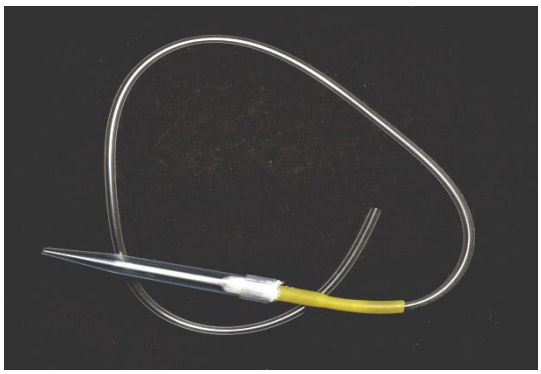
Fig. 4.13: Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the free-choice condition

1. Host preference experiment of whitefly by free choice method

2. Host preference experiment of whitefly by no choice method



3. Self-fabricated leaf cage



4. Aspirator

(A) **(B)**

5. Experiment of life table parameter on **(A)** Brinjal and **(B)** Tomato

Plate 5: Experiment of life table parameter, host feeding preference and ovipositional under controlled condition

having the highest number of deposited eggs *i.e.,* 241.33 *T. vaporariorum* followed by tomato, cabbage and bottle gourd having the number of laid eggs was 171.67, 65.67, and 31.00, respectively **(Fig. 4.13)**. However, contrary to *B. tabaci* least number of eggs laid on chilli plant. The overall eggs deposited spiraling whitefly was significantly higher than *B. tabaci.*

4.3.4 Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under the no-choice condition

Under no choice condition, the mean number of eggs laid by both genus is represented in **Table 4.14 and Fig. 4.14**. The observed readings of laid egg by *B. tabaci* and *T. vaporariorum* on different hosts were significantly different from each other noted as F= 05.523; p= 00.013 and F= 10.502; p= 00.001, respectively. Here, in the no-choice method, the mean egg deposited by *B. tabaci* was utmost in brinjal had 80.33 eggs laid on it followed by tomato (55.33), chilli (42.33), and cabbage (28.67). However, a dissimilar trend was recorded in the case of spiraling whitefly where the highest egg deposited on brinjal plant followed by tomato, cabbage, and bottle gourds having a mean number of deposited eggs were 95.00, 71.67, 45.33, and 29.33. The least number of eggs deposited by *B. tabaci* and *T. vaporariorum* were 20.33 and 11.33 on bottle gourd and chilli, respectively. The oviposition was found significantly higher in the case of *T. vaporariorum* on all hosts as compared to *B. tabaci.*

Table 4.14 Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under no-choice condition

Host plant	*Bemisia tabaci*	*Trialeurodes vaporariorum*
Tomato	55.33 ± 14.19^{ab}	71.67 ± 09.24^{bc}
Brinjal	80.33 ± 12.99^{b}	95.00 ± 16.19^{c}
Cabbage	28.67 ± 06.96^{a}	45.33 ± 10.74^{ab}
Bottle gourd	20.33 ± 06.74^{a}	29.33 ± 07.62^{a}
Chilli	42.33 ± 06.48^{ab}	11.33 ± 02.60^{a}
F value	05.523	10.502
p value	00.013	00.001

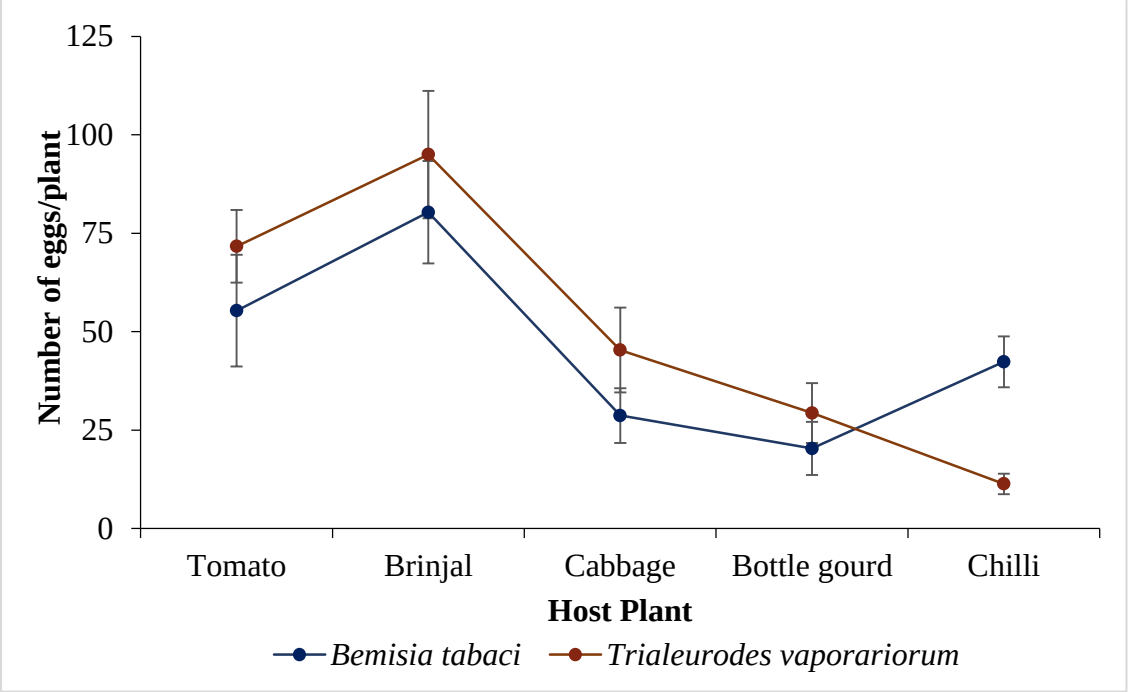
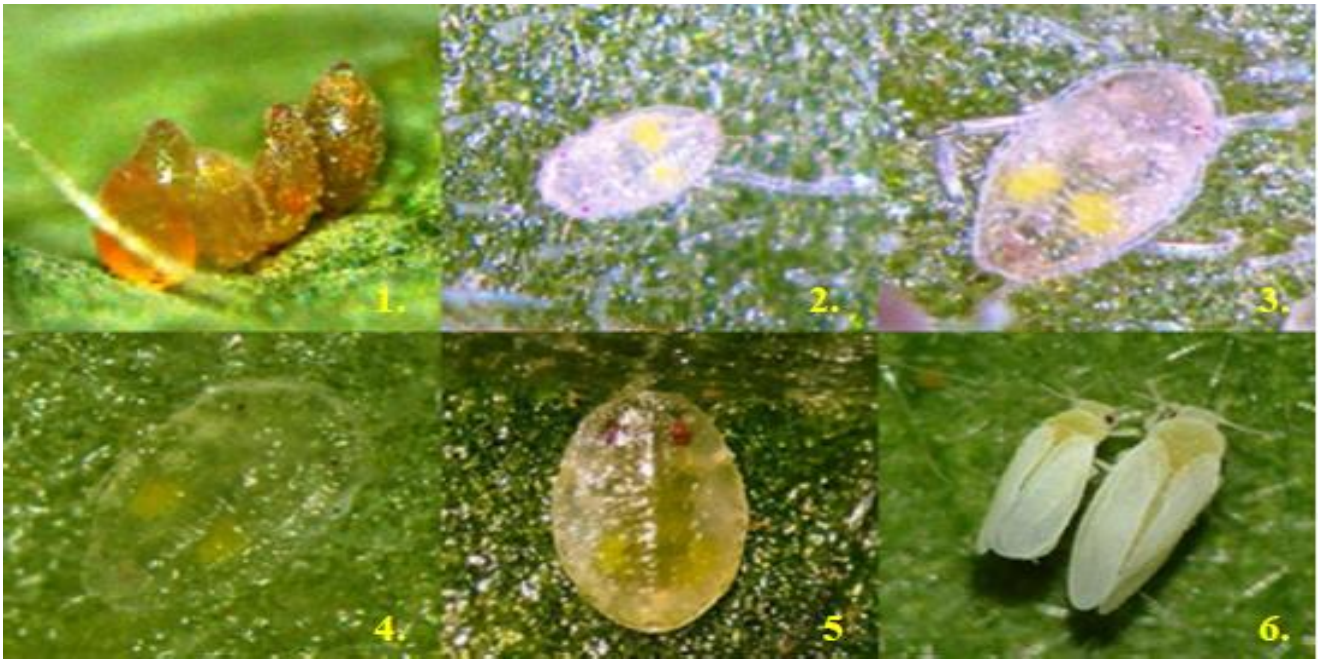


Fig. 4.14: Oviposition preferences of *B. tabaci* and *T. vaporariorum* on different host plants under no-choice condition

4.3.5 Duration of preimaginal development and survival rate of *B. tabaci* and *T. vaporariorum* on brinjal and tomato at 25 °C

The preimaginal developmental period of immature stages of *B. tabaci* and *T. vaporariorum* on tomato and brinjal were presented in **Table 4.15 and 4.16**. The overall development period (egg to adult) of both species was significantly influenced by host plants (F= 19.940; p= 0.000). *B. tabaci* and *T. vaporariorum* developed faster on brinjal (19.40 days and 21.57 days) than on tomato (22.40 days and 24.03 days). On brinjal crop *B. tabaci* showed a shorter development period than *T. vaporariorum*. No significant difference were found in the development time of second instar (F= 01.460; p= 0.296) of the both species while other preimaginal stage *viz*., egg (F= 17.685; p= 0.001), first instar (F= 23.025; p= 0.000), third instar (F= 21.201; p= 0.000) and fourth instar (F= 04.371; p= 0.042) showed a significant difference on tomato and brinjal for both species. The highest life span of egg stage was recorded on the tomato for *B. tabaci* (7.16±0.18 days) followed by *T. vaporariorum* (6.83±0.12 days) on brinjal and *T. vaporariorum* on tomato (6.66±0.08 days) and lowest developmental period on brinjal (5.73±0.17 days) for *B. tabaci* **(Table 4.15 and Fig. 4.15)**, whereas *T. vaporariorum* showed the highest survival rate on tomato (97.79 per cent), followed



1. Life stages of *Bemisia tabaci* (Gennadius). 1. Egg, 2. First instar, 3. Second instar, 4. Third instar, 5. Fourth instar, 6. Adults

2. Life stages of *Trialeurodes vaporariorum* (Westwood) 1. Egg, 2. First instar, 3. Second instar, 4. Third instar, 5. Fourth instar, 6. Adults

Plate 6: Different life stages of *B. tabaci* and *T. vaporariorum*

by brinjal (97.24 per cent) while, *B. tabaci* showed (95.72 per cent) survival rate on brinjal and (94.42 per cent) on tomato. Similarly, first instar of *T. vaporariorum* showed the highest development period on tomato (4.70±0.06 days) and lowest in brinjal (3.38±0.18 days) for *B. tabaci*. During the first instar *T. vaporariorum* showed the highest survival rate (94.14 per cent) on brinjal, whereas *B. tabaci* showed the lowest survival rate (80.10 per cent) on tomato **(Table 4.16 and Fig. 4.16)**. In second nymphal instar of *B. tabaci* and *T. vaporariorum* was at par and development period of *B. tabaci* was found less in tomato (3.16±0.18 days) as compared to brinjal (3.18±0.20 days) and survival rate of second nymphal instar was recorded maximum on tomato (94.50 per cent) over brinjal (93.76 per cent). Whereas, in the case of *T. vaporariorum* the maximum development duration was found on tomato *i.e.*, 3.53±0.18 days with a survival rate 95.55 per cent and the least duration were recorded in brinjal 3.10±0.06 days with a maximum survival rate 95.57 per cent. The third instar nymph of *B. tabaci* on brinjal took the lowest period (2.83±0.32 days) to complete their immature stage and the survival rate was 95.69 percent, at the same time *B. tabaci* took the highest development period 5.03±0.12 days on tomato plant with a survival rate 92.92 per cent. The developmental period of the final instar was comparatively longer to other nymphal instars in which *B. tabaci* showed a minimum developmental period of 3.40±0.15 days on tomato with the highest survival rate 83.14 per cent while on brinjal this duration was more (4.27±0.16 days) with the lowest survival rate 89.08 per cent. Among the host plants, brinjal was found the most suitable host for both species (*B. tabaci* and *T. vaporariorum*) based on development period and survival rate as compared to tomato.

Table 4.15 Duration of preimaginal development, in days (Mean±SE), of *B. tabaci* and *T. vaporariorum* on brinjal and tomato plants at 25 °C

Development stage	*Bemisia tabaci*		*Trialeurodes vaporariorum*		*F* value	*p* value
	Brinjal	Tomato	Brinjal	Tomato		
Egg	5.73±0.17^{a}	7.16±0.18^{b}	6.83±0.12^{b}	6.66±0.08^{b}	17.685	0.001
N1	3.38±0.18^{a}	3.63±0.12^{ab}	3.93±0.09^{b}	4.70±0.06^{c}	23.025	0.000
N2	3.18±0.20^{a}	3.16±.18^{a}	3.10±0.06^{a}	3.53±0.18^{a}	01.460	0.296
N3	2.83±0.32^{a}	5.03±0.12^{c}	3.67±0.09^{b}	4.77±0.26^{c}	21.202	0.000
N4	4.27±0.16^{b}	3.40±0.15^{a}	4.03±0.09^{ab}	4.36±0.34^{b}	04.371	0.042
Egg to Adult	19.40±0.72^{a}	22.40±0.06^{b}	21.57±0.18^{b}	24.03±0.44^{c}	19.940	0.000

Numbers followed by different letters within the same row are significantly different (p>0.001) N1, first nymph stage; N2, second nymph stage; N3, third nymph stage; N4, fourth nymph stage

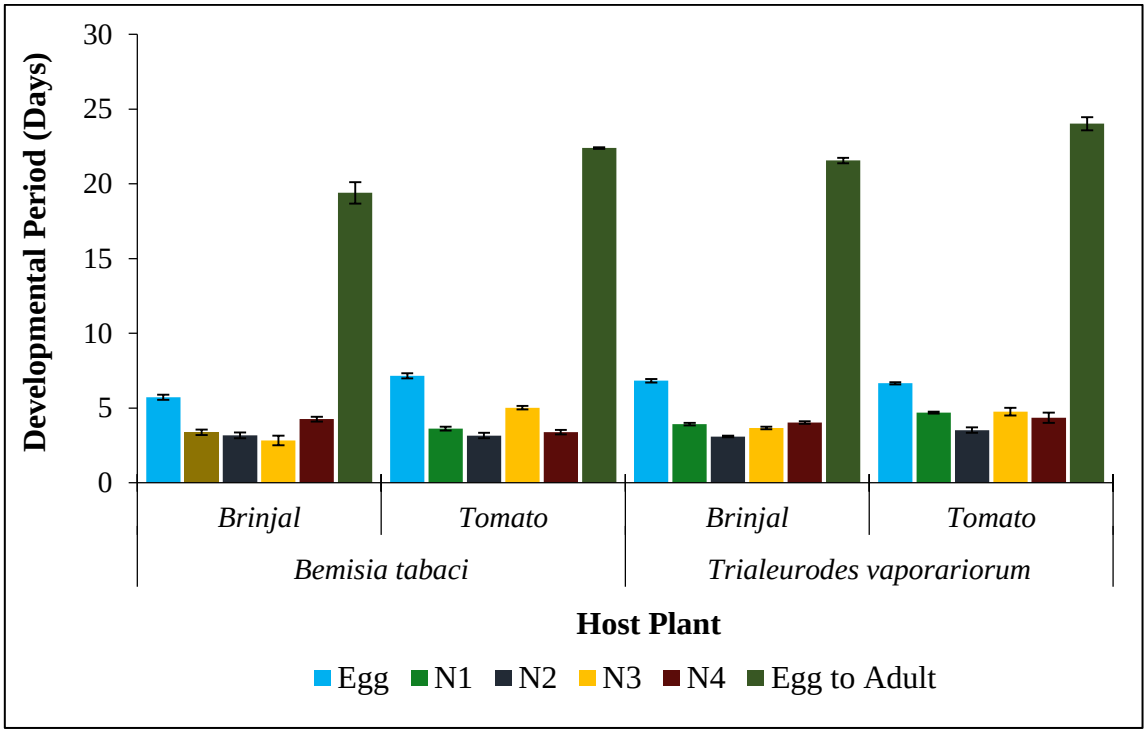


Fig. 4.15: Duration of preimaginal development of *B. tabaci* and *T. vaporariorum* on brinjal and tomato plants at 25 °C

Table 4.16 Survival rate for each one of the developmental stages of *B. tabaci* and *T. vaporariorum* on brinjal and tomato plants (shown as a percentage)

Development stage	*Bemisia tabaci*		*Trialeurodes vaporariorum*		*F* value	*p* value
	Brinjal	Tomato	Brinjal	Tomato		
Egg	95.72	94.42	97.24	97.79	-	-
N1	93.28	80.10	94.14	92.46	-	-
N2	93.76	94.50	95.57	95.55	-	-
N3	95.69	92.92	93.86	92.65	-	-
N4	89.08	83.14	90.28	89.99	-	-
Egg to Adult	84.09[a]	78.09[a]	85.62[a]	81.44[a]	00.639	00.601

Numbers followed by different letters within the same row are significantly different (p>0.001) N1, first nymph stage; N2, second nymph stage; N3, third nymph stage; N4, fourth nymph stage

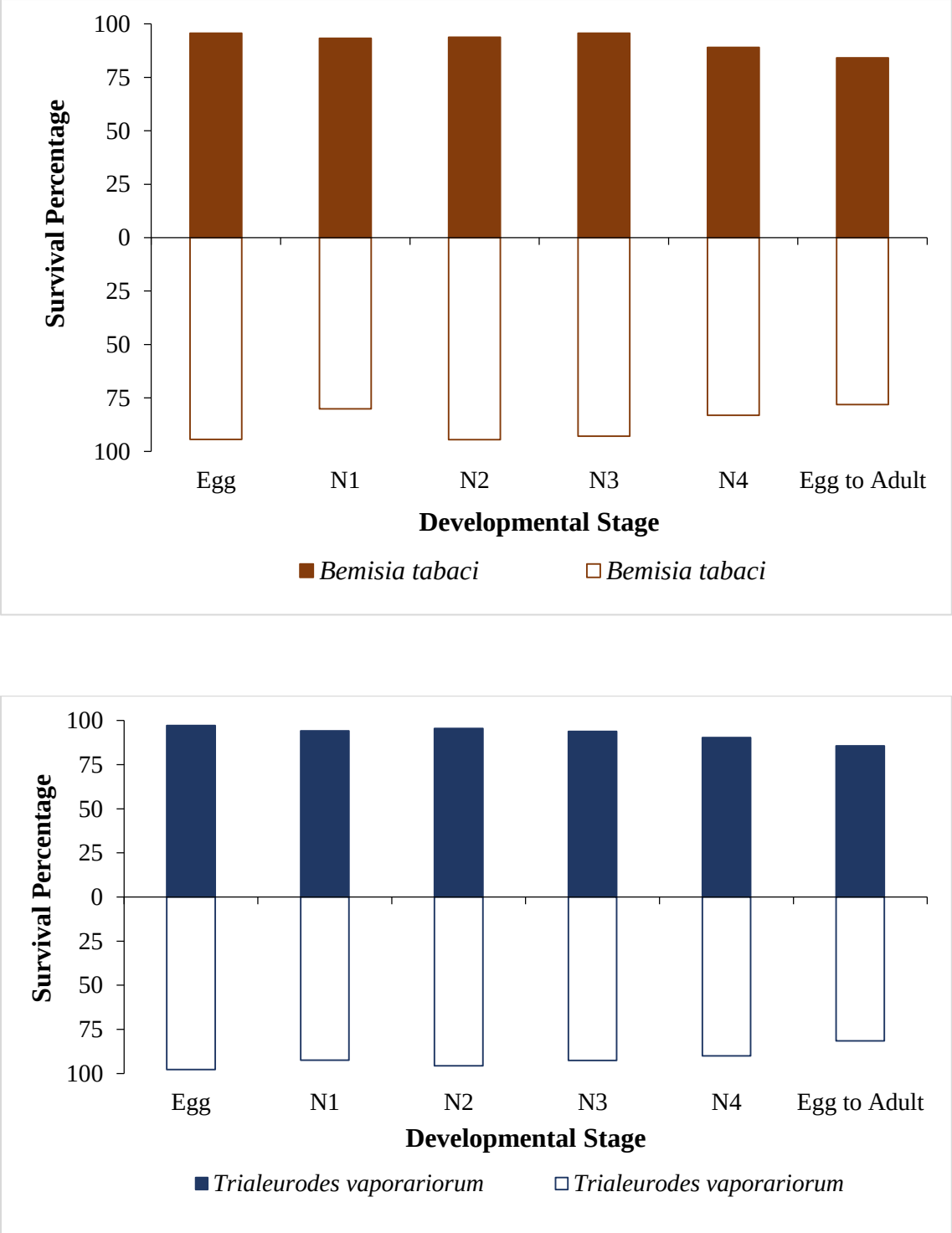


Fig. 4.16: Survival rate for each one of the developmental stages of *B. tabaci* and *T. vaporariorum* on brinjal and tomato plants

4.3.6 Total and daily fertility of each female and longevity of *B. tabaci* and *T. vaporariorum* in brinjal and tomato at 25 °C

Data presented in **Table 4.17** showed the fertility status of each male and female and the longevity of *B. tabaci* and *T. vaporariorum* was significantly difference on brinjal and tomato plant. On the brinjal plant the total mean eggs laid by female *B. tabaci* was 102.40±4.35 while on tomato plant number of eggs laid was 63.90±2.33. Whereas, an egg laid by per female of *T. vaporariorum* 149.30±4.17 on brinjal plant and 115.50±3.88 on tomato plant. The daily fertility of the *B. tabaci* on brinjal and tomato plant was found to be 3.90±0.70 and 3.10±0.52 eggs per female, respectively, while *T. vaporariorum* laid 5.50±0.87 and 4.90±0.72 eggs per female on brinjal and tomato plants, respectively. The mean longevity of male and female of *B. tabaci* on brinjal was 12.60±0.62 and 14.10±0.89 days, respectively, while in tomato longevity was found as 14.90±0.97 and 17.60±0.63 days, respectively. In the case of *T. vaporariorum* the average longevity of males and females on brinjal was 17.30±0.73 and 21.90±0.86 days, respectively and in tomato, the average longevity was 19.20±0.70 and 23.50±0.72, respectively **(Fig. 4.17)**.

Table 4.17 Total and daily fertility of each female (Mean±SE) and longevity of *B. tabaci* and *T. vaporariorum* in brinjal and tomato at 25 °C

	Bemisia tabaci		***Trialeurodes vaporariorum***		***F* value**	***p* value**
	Brinjal	**Tomato**	**Brinjal**	**Tomato**		
Fertility (eggs/female)	102.40±04.35^{b}	63.90±02.33^{a}	149.30±04.17^{d}	115.50±03.88^{c}	87.438	0.000
Daily fertility (eggs/female)	03.90±00.70^{a}	03.10±00.52^{a}	05.50±00.87^{a}	04.90±00.72^{a}	02.197	0.105
Longevity of male (days)	12.60±00.62^{a}	14.90±00.89^{b}	17.30±00.73^{c}	19.20±00.70^{c}	15.046	0.000
Longevity of female (days)	14.10±00.97^{a}	17.60±00.63^{b}	21.90±00.86^{c}	23.50±00.72^{c}	27.77	0.000

Numbers followed by different letters within the same row are significantly different (p>0.001)

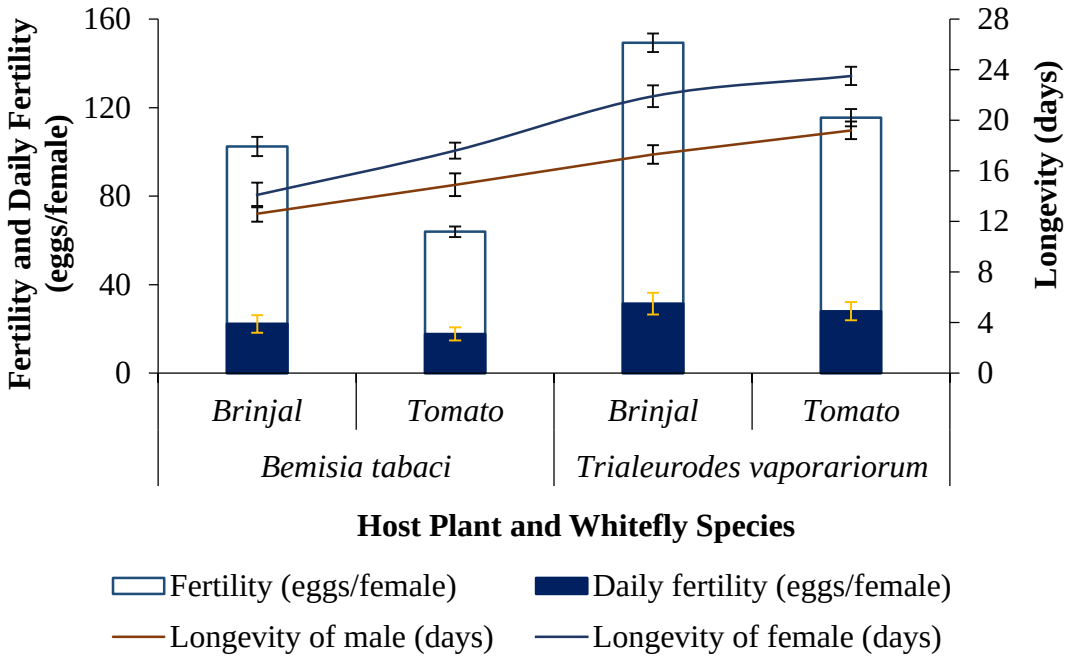


Fig. 4.17: Total and daily fertility of each female and longevity of *B. tabaci* and *T. vaporariorum* in brinjal and tomato at 25 °C

The results of host preference and oviposition suitability revealed that among the potential reproductive host plant brinjal and tomato were found to be most preferred host for feeding and oviposition of *B. tabaci* and *T. vaporariorum*. Similar results were observed by **Schuster (2003); Khan *et al*. (2011); Mansour *et al*. (2012) and Lorenzo *et al*. (2016).** The possible reasons of variability in host choice and oviposition is due to the morphological characteristics of these plants such as the glandular trichomes, hairiness, shape and color **(Berlinger, 1986; Oriani and Vendramim, 2010)**, chemical properties of host plant leaves **(Awmack and Leather, 2002)** and plant volatile compounds **(Bleeker *et al*., 2009)**. Whitefly biotypes and host plant variety often play important role in host preference and oviposition of whitefly **Omondi *et al*., 2005; Inbar and Gerlinger, 2008**. The results of present study showed that adults of whitefly preferred both brinjal and tomato plant as host plant and the population of adult whitefly remain constant on both plan till completion of experiment. The preference of brinjal and tomato plants as host for whitefly is due to the feeding and oviposition suitability on these plants (**Lei *et al*., 1999).** The low preference of bottle gourd and chilli by *B. tabaci* and *T. vaporariorum* can be attricuted to the antibiosis, but further research on this aspect is needed inorder to strengthen this claim. Antibiosis against

whitefly is mainly due to the presence of toxic secondary metabolites and anti-nutritional compounds **(Nombela *et al*., 2000 and Rodrıguez-Lopez *et al*., 2011)**.

The present study showed that the development period of *B. tabaci* and *T. vaporariorum* was lower on brinjal than tomato this result is supported by **Sharaf *et al*. (1985); Awmack and Leather (2002); Sood *et al*. (2006) and Hasan and Ansari (2011)**. The influence of different host plants on the development time of *B. tabaci* was also reported by **Coudriet *et al*. (1985); Muniz and Nombela (1997) and Nava-Camberos *et al*. (2001)**. Host plant significantly affect the developmental period of the egg stage of both whiteflies; this result is supported by **Iida *et al*. (2009)** who suggested that the host plant could influence the egg development duration because structure of the leaf tissue, influence the absorption rate of different solutes. But **Sanchez *et al*. (1997)** who suggested that the egg stage of whitefly do not feed or uptake solute form the host plant. The survival rate of nymphal stages of *B. tabaci* and *T. vaporariorum* was much similar to the results of **Wang and Tsai (1996)** and higher mortality was observed in the first and last instar of both the whitefly species. The early mortality at first instar stage could be attributed to the longer time required for crawlers to settle down on host plants **(Lin and Ren, 2005; Wang and Tsai, 1996)**. Later on, when the insect has attached itself, mortality risks are lower.

In the present investigation, adult longevity of whitefly differed significantly on brinjal and tomato and female longivity was found more than male in both the host plant which agreed with the finding of **Bonato *et al*. (2007)**.The male and female longevity of *B. tabaci* on both host plants was much similar to finding of **Ahmad and Rizvi (2014)** and **Hossain *et al*. (2018)**. Whereas in case of *T. vaporariorum* longevity of male and female was found maximum on tomato plants than on brinjal which agreed with the results of **Vande and Lenteren (1978)** and **Lorenzo *et al*. (2016)**.

The total fecundity of *B. tabaci* on tomato and brinjal was found similar with the results of **Kakimoto *et al*. (2007)** who observed 62.9 eggs/female and 109.50 eggs/female on tomato and brinjal respectively. Whitefly females reared on tomato showed a fecundity below the values as reported by **Yang and Chi (2006)** (114 eggs/female) and by **Bonato *et al*. (2007)** (105 eggs/female). Similarly in *T. vaporariorum* total fecundity on tomato and brinjal was found lower than fecundity

observed by **Rodrıguez-Lopez *et al*. (2011) and Lorenzo *et al*. (2016)**. The variation in fecundity rate of these insects may be due to difference in the external morphology of leaf (e.g; hairiness) and the biochemical properties of leaves (pH of leaf sap). Brinjal is a better nutritional host than tomato for the whitefly as it provide the best conditions for their feeding and/or offspring development **(Courtney and Kibota, 1990 and Khan *et al*., 2011)**, the hairiness of tomato leaves (glandular trichomes type IV) and the production of acylsucrose discourage the contact and settling of *B. tabaci* on tomato.

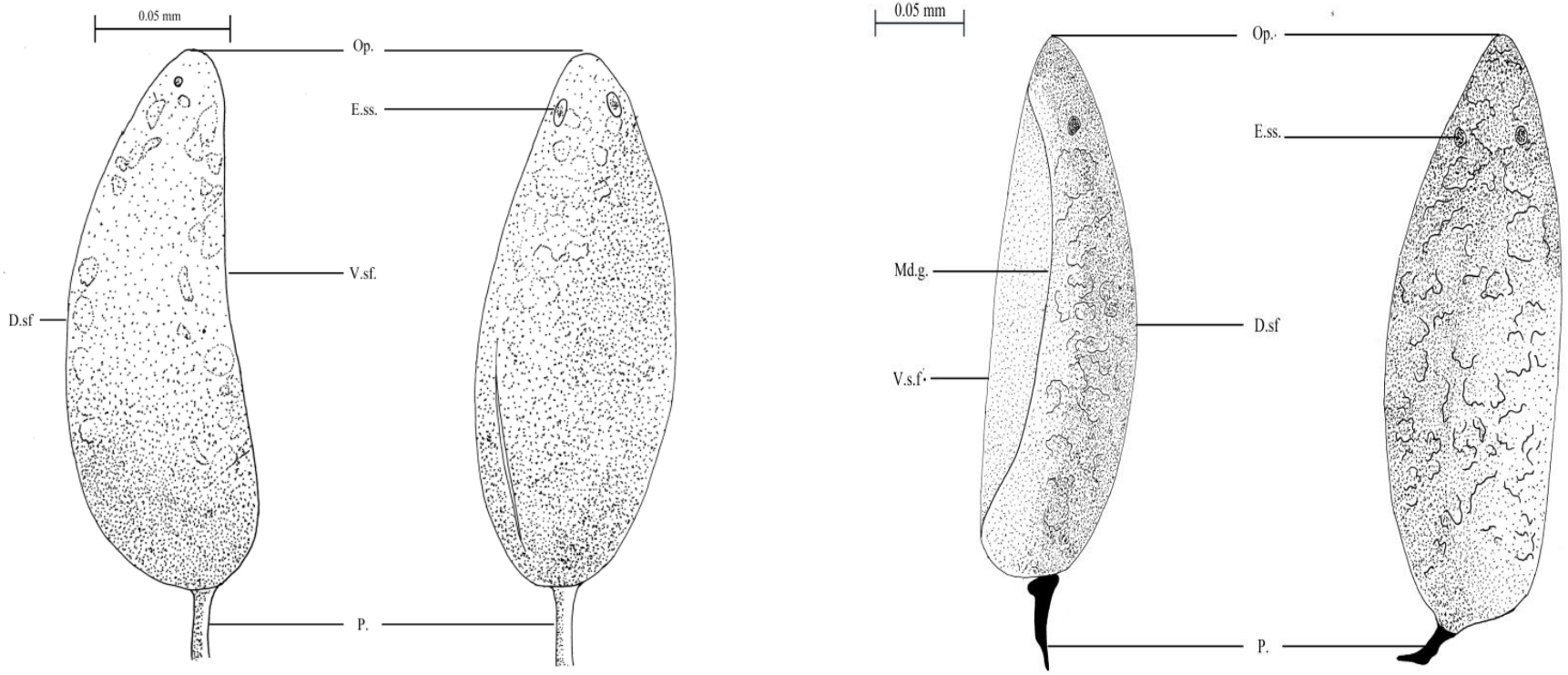
The whitefly, *B. tabaci* and *T. vaporariorum* showed higher survival rate, lower mortality rate, shorter development period and maximum potential fecundity on brinjal for both species as compared to tomato. Therefore it can be concluded from the above investigations and discussion that brinjal can serve as the most preferred host. Since Brinjal is a major vegetable crop in the country and it has been facing severe threat from whiteflies among all other vegetable crops, importance of developing specific and novel pest management strategies is a need of the hour. Moreover, Brinjal can also be used as trap crop against whiteflies in other vegetable ecosystem to reduce associated viral diseases. In order to reduce the pest load on brinjal which is carried season after season, avoidance of continuous cultivation of brinjal in extensive growing areas is suggested. Also, least preferred hosts such as chilly and bottle gourd can be alternated with Brinjal in sequential cropping system to reduce the population of whitefly.

4.4 Comparative morphological studies of life stages of two whitefly species, *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood)

Eggs: Comparative morphological study of *Bemisia tabaci* **(Fig. 4.18)** and *Trialeurodes vaporariorum* **(Fig. 4.18)** revealed that females of both species laid freshly yellow coloured eggs under the surface of leaves, which were covered with white waxy powder. The elliptical (apically pointed with a broadly rounded base) shape of the eggs was inserted upright into the leaf tissue by a short stalk (pedicel). The eggs could easily be differentiated based on their size, colour, arrangement patterns, and nature of the eggshell after hatching. *T. vaporariorum* laid yellow-coloured eggs (length= 0.22 mm; breadth= 0.09 mm) in neat circle or semicircle which turned dark brown or almost black before hatching while, in *B. tabaci* the eggs (length= 0.20 mm; breadth= 0.10 mm) was creamy yellow which changed into light golden brown and

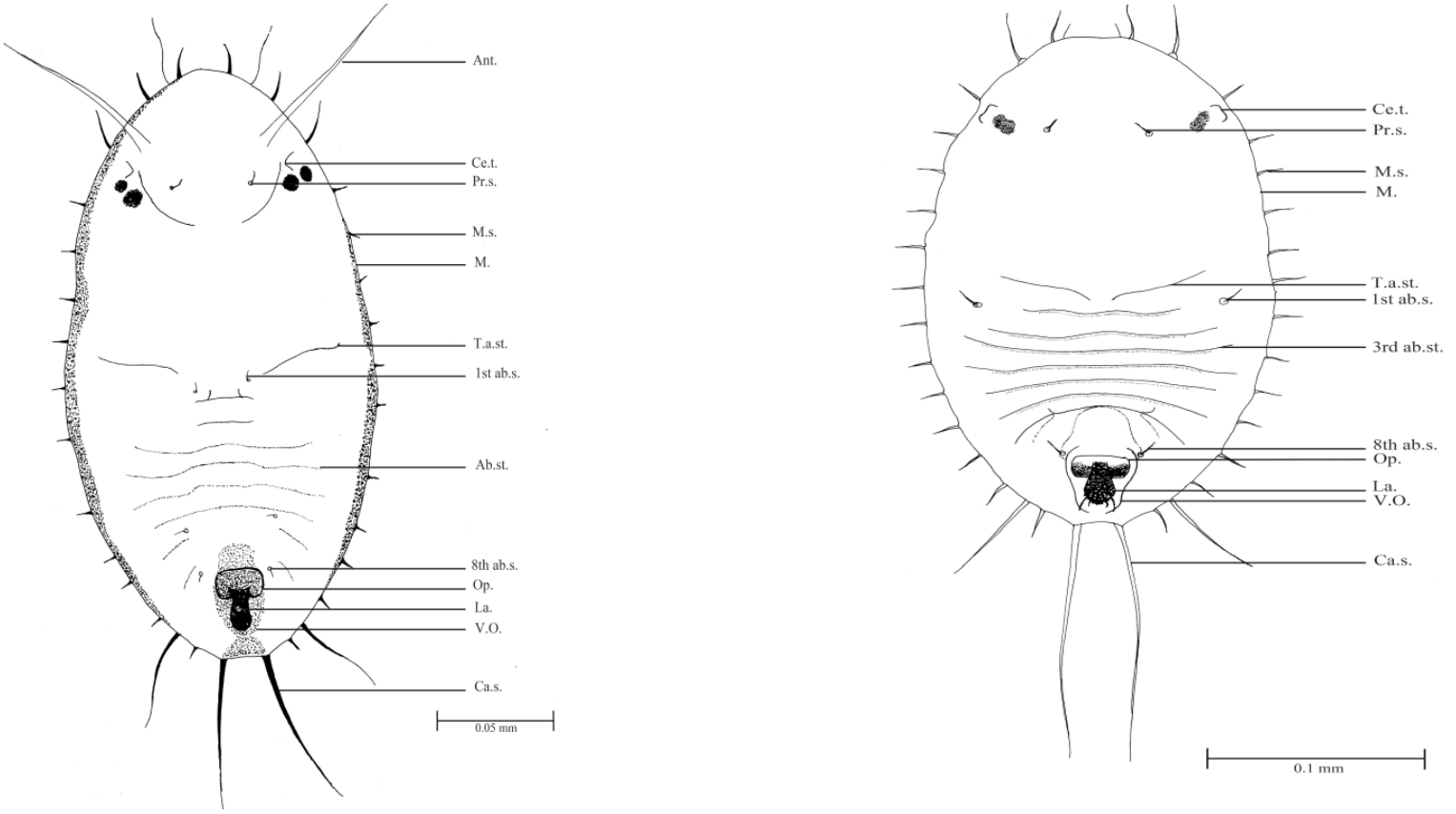
were laid singly in a scattered manner over the leaf surface. Right before hatching, the eggs of *T. vaporariorum* became kidney-shaped where the convex and concave side of the egg represented the dorsal and ventral surface of the emerging nymph, respectively. The eggshell became flattened laterally after the emergence of the nymph. In case of *B. tabaci,* two pairs of reddish eye spots were observed through the chorion before hatching and the eggshell retained its inflated shape after the nymphal emergence.

First nymphal instar: The first instar nymphs of both the species had functional legs and antennae, which crawled over the leaf surface until settled at one site for feeding and remain there during the subsequent moults. The young nymphs of both the species were elliptical (scale-like) and surrounded by a layer of white powdery wax along the margin, which was almost identical in both the species except slightly differed in the color (*T. vaporariorum*, pale yellow and *B. tabaci*, dark yellow). The first instar nymph had paired reddish eye-spots in the anterolateral region of the cephalothorax and two distinct yellow fat-bodies in the abdomen. The dorsal surface had a thin and membranous integument, covered with a layer of transparent wax. Slight differences were observed in the mounted specimens of the two species, where, *T. vaporariorum* had 17 pairs of well marginal setae while in *B. tabaci* there were 16 pairs. Similarly, cephalic tubercles were strongly developed and sub-rectangular shaped in *T. vaporariorum*; while they were weakly developed and sub-elliptical shaped, along with a pair of cephalic setae in *B. tabaci*. A total of eight sutures (including thoracoabdominal suture) were present in the abdominal area of both the species along with two abdominal setae. The vasiform orifice of *T. vaporariorum* was broadly subcordate in shape and opened posteriorly, while in *B. tabaci* it was almost quadrate in shape and closed posteriorly. The lingula was half-covered by the operculum in both species, however, in *T. vaporariorum* the distal end of the lingula was armed with spines. The size of the nymph varied slightly in the two species with *T. vaporariorum* **(Fig. 4.19)** measuring 0.27 mm in length and 0.16 mm in breadth, and *B. tabaci* **(Fig. 4.19)** nymph measuring 0.25 mm in length and 0.15 mm in breadth.



(a) (b)

Fig. 4.18: Morphology of egg (lateral and dorsal view) a- *Bemisia tabaci*, b-*Trialeurodes vaporariorum*. Op.- apex; E.ss.– Eyes spots; V.sf.- Ventral surface; D.sf.- Dorsal surface; Md. g– Median groove; P.- Peduncle.



(a) (b)

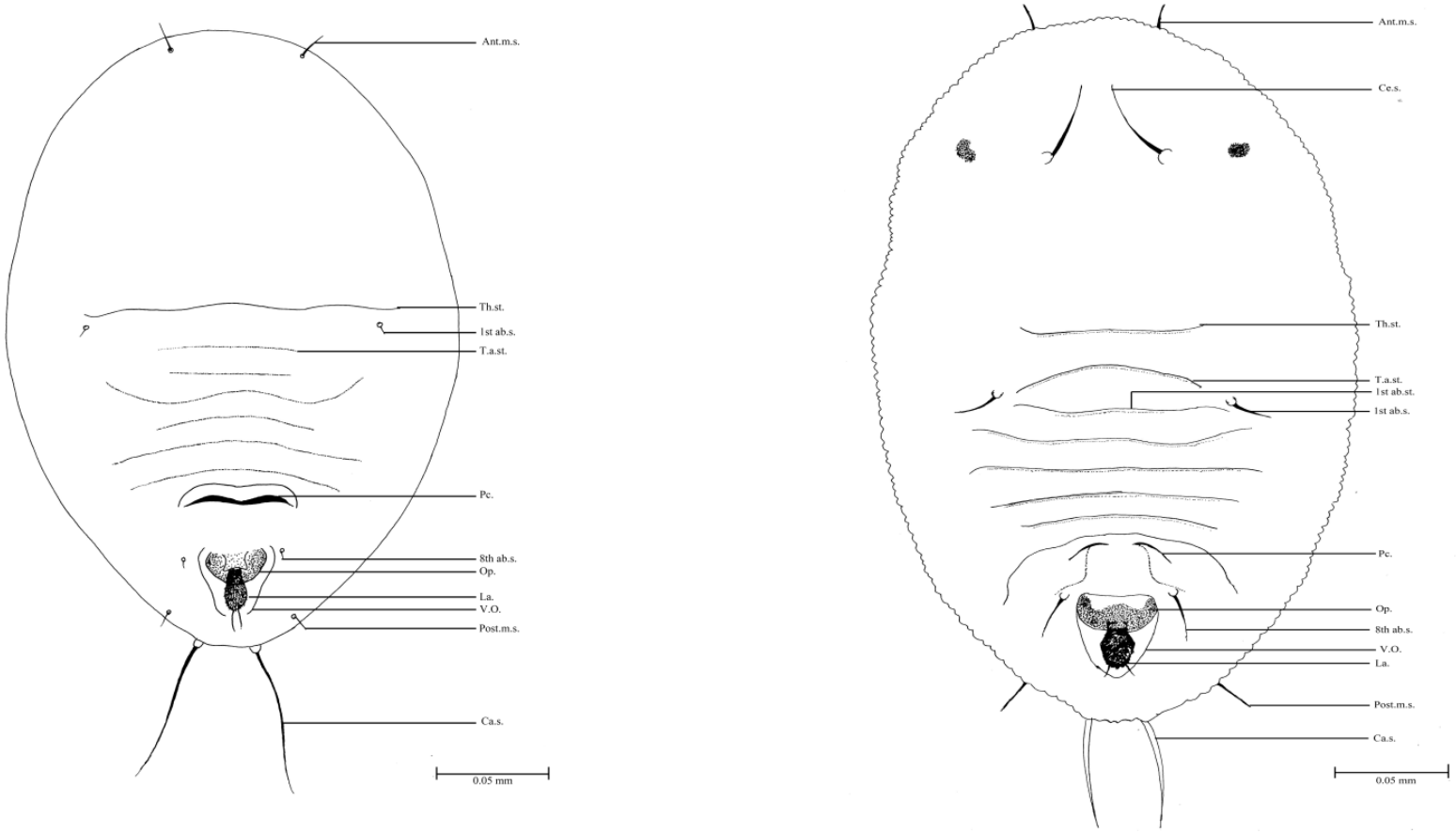
Fig. 4.19: First instar nymphs of a- *Bemisia tabaci*, b- *Trialeurodes vaporariorum*. Ant.- Antenna; Ce.t.- Cephalic tubercles; Pr.s.- Prothoracic setae; M.s.- Marginal setae; M-Margin; T.a.st.- Thoraco-abdominal suture; 1st ab. s.- First abdominal segment; Ab.st.- abdominal suture; 8th ab.s.- Abdominal setae on 8th segment; Op.-Operculum; La.-Lingula; V.O.- Vasiform orifice; Ca.s.- Caudal setae. 3rd ab. st.- Third abdominal suture.

Second nymphal instar: The functional legs, antennae and marginal setae degenerated in second nymphal instar which was differentiated from the first instar based on size, transparency, shape and position of the vasiform orifice. The second instar nymphs of *T. vaporariorum* were oval with a distinctly crenulated margin, while in *B. tabaci*, the crenulated margin was not distinct. In both the species, anterior and posterior marginal setae were small and less noticeable but the caudal setae were well developed and prominent. In case of *T. vaporariorum*, two pairs of the dorsal setae were prominently present on the 8th abdominal segment and cephalic segment, while in *B. tabaci*, 8th abdominal setae were minute and cephalic setae was completely absent. The vasiform orifice was subcordate with notched posterior end and the size of lingula was the same as that of the orifice, with a pair of lateral lobes in *T. vaporariorum*, while in *B. tabaci*, orifice was a triangular shape with posteriorly open and lingula was swollen distally and pointed. Both species had distinct sutures on the eighth abdominal segments along with two sutures observed on the cephalothorax that confine the meso and metathorax. The living nymphs were distinguished only by their size *i.e*., *B. tabaci* nymphs **(Fig. 4.20)** (length= 0.35 mm; breadth= 0.22 mm) were slightly smaller than those of *T. vaporariorum* **(Fig. 4.20)** (length= 0.38 mm; breadth= 0.25mm).

Third nymphal instar: Third instar of both species was considerably flattened, larger and more transparent than the second instar and it was not distinguishable in vivo. In the case of *T. vaporariorum*, characters like distinct marginal crenulations and marginal, caudal, dorsal and subdorsal setae were similar to the second instar. However, they can easily be distinguished from the second instar based on their larger size, rearward bend in the antennae, the vasiform orifice and its associated structures, which resemble with the pupal instar (vasiform orifice is located farther away from the caudal margin, lingual with two pairs of lateral lobes and faintly indicated caudal furrow are present in the third instar). In case of *B. tabaci*, third instar showed more similarity with the pupal stage instead of second nymphal instar, mainly in presence of three pairs of dorsal setae, vasiform orifice and a faintly visible caudal furrow and can be distinguished from the pupal instar based on antennae which is similar to the second instar. The third instar of the two species showed resemblance in the presence and position of the dorsal setae, while, differs in various aspects including non-uniformly crenulated margins, triangular

shape of vasiform orifice and swollen lingula without lobes in *B. tabaci.* Also, the average measurements of mounted specimens of the third instar in *T. vaporariorum* **(Fig. 4.21)** were 0.62 mm in length and 0.38 mm in breadth, while in *B. tabaci,* **(Fig.4.21)** was 0.50 mm in length and 0.34 mm in breadth.

Fourth nymphal instar (pupal stage): The pupal instar was identified most easily out of all the immature stages as it was dissimilar from the previous instars. Pupae of both the species were distinguished in vivo. In *T. vaporariorum,* the living pupa was pale, opaque and yellowish-white in appearance, raised from the surface of the leaf and surrounded by a thin palisade of transparent-whitish wax, and the dorsal surface bears glassy wax rods, while in case of *B. tabaci*, the pupa was distinctly yellow, and the palisade of wax and dorsal glassy wax rods were absent. However, tufts of white wax were frequently present in thoracic tracheal pores. Average measurements of microscopic mounts differed in both the species with *T. vaporariorum* **(Fig. 4.22)** measuring 0.71 mm in length, 0.43 mm in breadth; and in *B. tabaci,* **(Fig. 4.22)** 0.69 mm in length; and 0.50 mm in breadth. In mounted specimens, *T. vaporariorum* pupa was oval-shaped, posteriorly rounded with a uniformly crenulated margin, distinct crenulations on the margin of thoracic and caudal pores. While *B. tabaci* pupa was oval or elliptical shaped, posteriorly pointed with irregular crenulation and indistinct tracheal pores on the margin. In *T. vaporariorum,* about 64 well-developed papillae were present in a single row on the sub margin, among them 4-5 were relatively larger. Four pairs of large well-developed papillae were also present on the sub dorsum. However, in *B. tabaci,* submarginal papillae were completely absent and indicated as small inconspicuous "micro-setae". The paired dorsal setae of *T. vaporariorum* were found in the 1st and 8th abdominal, while in B. tabaci one to seven pairs of well-developed dorsal setae were present. In *T. vaporariorum,* the pupal instar was differentiated from previous instars by the presence of moulting sutures, larger size, elongate vasiform orifice, presence of caudal furrow and three pairs of lateral lobes in the lingula. While in *B. tabaci,* vasiform orifice was triangular and the lingula was pointed as in the preceding instar. Also, a well-developed caudal furrow was present.



(a) (b)

Fig. 4.20: Second instart nymph of (a) *Bemisia tabaci* and (b) *Trialeurodes vaporariorum*. Ant.m.s.- Anterior marginal seta; Th.st.-Thoracic suture; 1st abs.s.- seta on first abdominal segment; T.a.st.- Thoraco-abdominal suture (transverse moulting suture); Pc.- Pockets; 8th ab.s.- Seta on eighth abdominal segment; Op.- Operculum; La.- Lingula; V.O.- Vasiform Orifice; Post.m.s.- Posterior marginal seta; Ca.s.- Caudal seta. Ce.s.- Cephalis seta; 1st abs.st. – first abdominal suture.

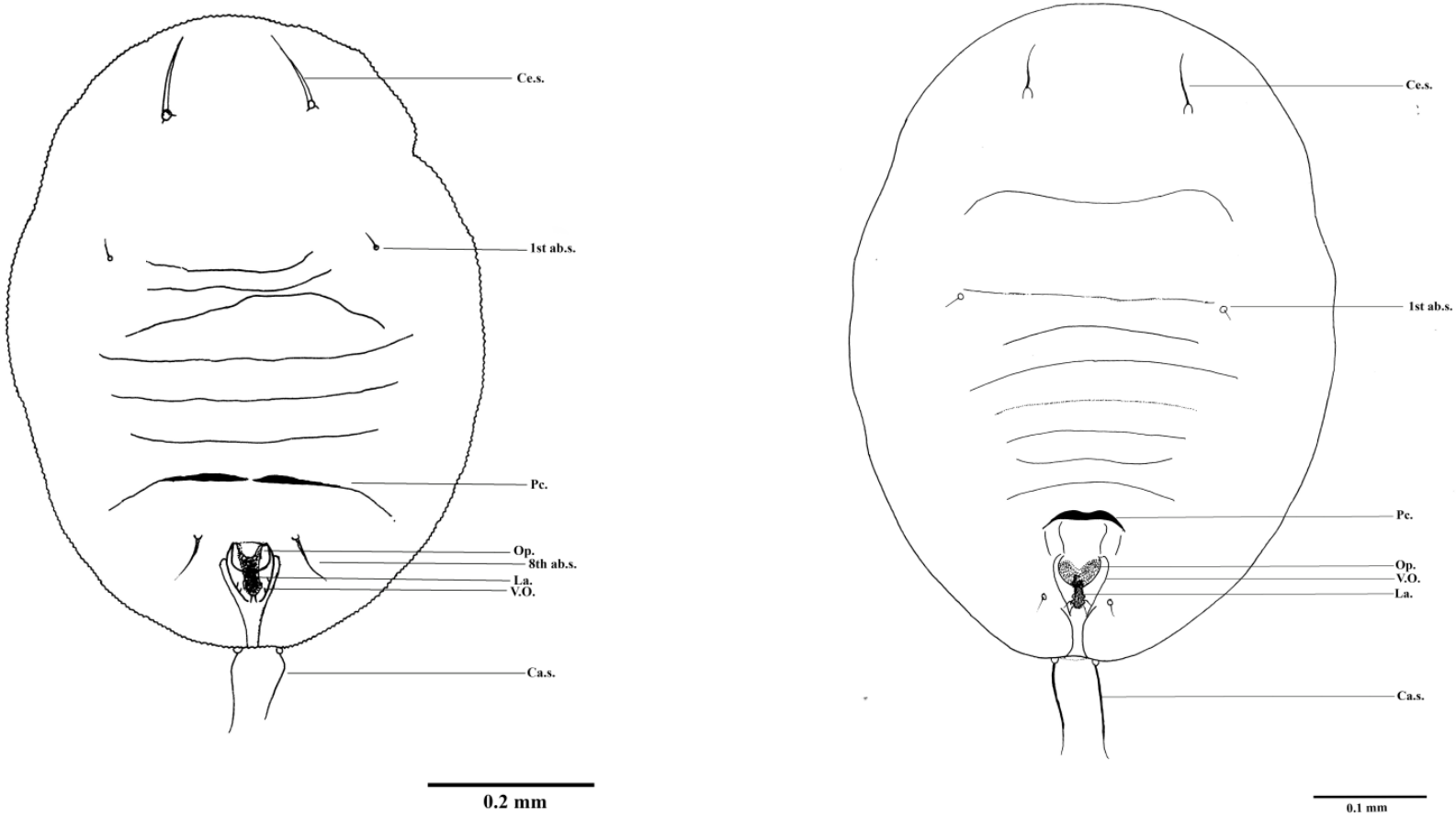


Fig. 4.21: Third instar nymphs of (a) *Bemisia tabaci* and (b) *Trialeurodes vaporariorum*. Ce.s.- Cephalic setae; 1st ab.s.- Seta on first abdominal segment; Pc.- Pocket; Op.- Operculum; 8th ab.s.- Seta on eighth abdominal segment; La.-Lingula; V.O.- Vasiform orifice; Ca.s.- Caudal setae.

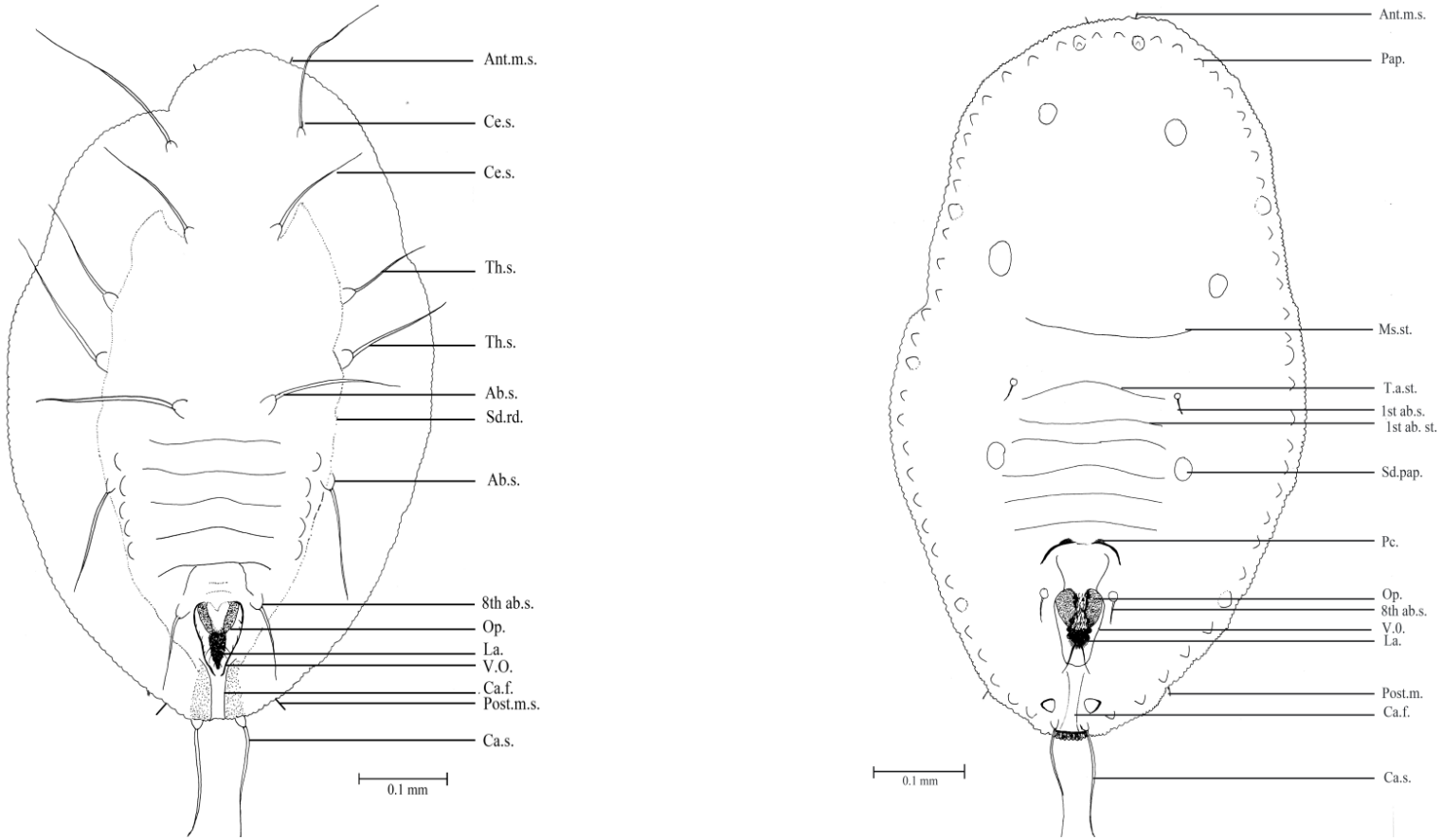
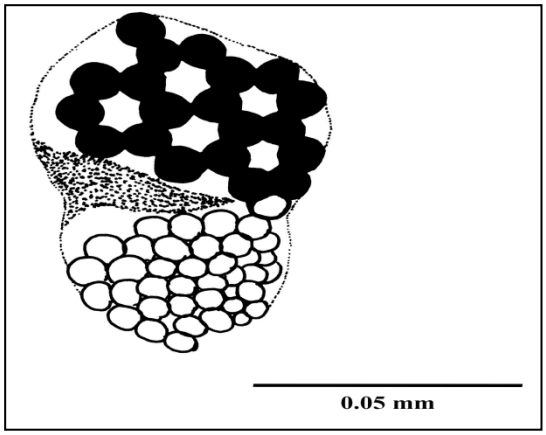


Fig. 4.22: Fourth instar nymphs of (a) *Bemisia tabaci* and (b) *Trialeurodes vaporariorum*. Ant.m.s.- Anterior marginal setae; Ce.s.- Cephalic setae; Th.s.- Thoracic setae; Ab.s.- Abdominal setae; Sd.rd.- Subdorsal ridge; Ab.s.- Abdominal seta; 8^{th} ab.s.- Seta on eighth abdominal segment; Op.- Operculum; La.- Lingula; V.O.- Vasiform orifice; Ca.f.- Caudal furrow; Post.m.s.- Posterior marginal setae; Ca.s.- Caudal setae. Ms.st. - Mesothoracic setae.

Adult stage: The adults of both the species were similar in appearance with a pale yellow colour and presence of two pairs of white immaculate wings, which were thinly dusted with a white waxy powder. In the case of *B. tabaci*, adults were somewhat smaller than *T. vaporariorum* with a darker yellow colour. In mounted specimens of *B. tabaci* adults, the compound eyes were divided and each eye had two groups of lenses with a single lens forming a "bridge" between the two groups, while in *T. vaporariorum* adults, the eyes were divided but there was no lens forming a bridge between the two groups of facets (fig. 4.4.6a1 and 4.4.6b1). The antennae in *B. tabaci* comprised of seven segments with pit sensoria on 3rd, 5th, 6th and 7th segment and stout sensory setae on the 3rd and 7th segment. The antennae in *T. vaporariorum* were similar to those of *B. tabaci*, but without pit sensorium on 6th segment and stout sensory setae on the 3rd segment **(Fig. 4.23)**.

The tibiae of the mesothoracic legs in *B. tabaci* were surrounded with randomly arranged stout spines, while in *T. vaporariorum*, the stout spines were typically arranged in two lateral "tufts" **(Fig. 4.23)**. The ventral surface of abdomen in both the species had two pairs of wax plates on 3rd and 4th segment in females and four pairs of wax plate (from 3rd to 6th segment) in males **(Fig. 4.24)**. The surface of these wax plates was distinctly reticulate in case of *B. tabaci*, while in *T. vaporariorum*, the structures were striated. The supragenital plate in *B. tabaci* was weakly developed in the female but modified into a tube-like collar in males which projects from the tip of the abdomen along with the male genitalia distally. While in *T. vaporariorum*, the supra-genital plate was well developed and clearly defined in the female and modified into a tube-like collar in males which was strongly sclerotized and darkly pigmented. The abdomen in case of *T. vaporariorum* males also differed in presence of several rows of distinct pores on the dorsal surface. The shape and size of vasiform orifice (located on the supra-genital plate) were similar in both the species, while it differed from the immature stages in terms of its sub-circular shape and elongated narrow lingula.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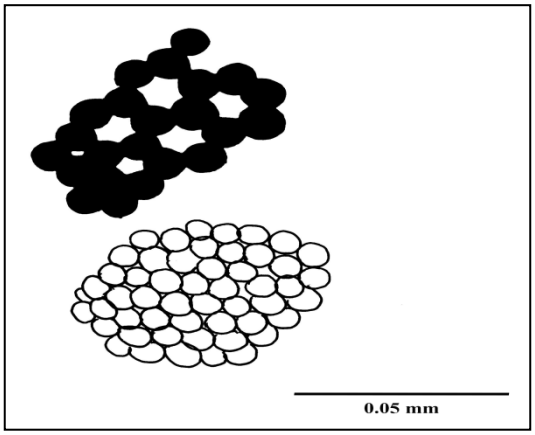
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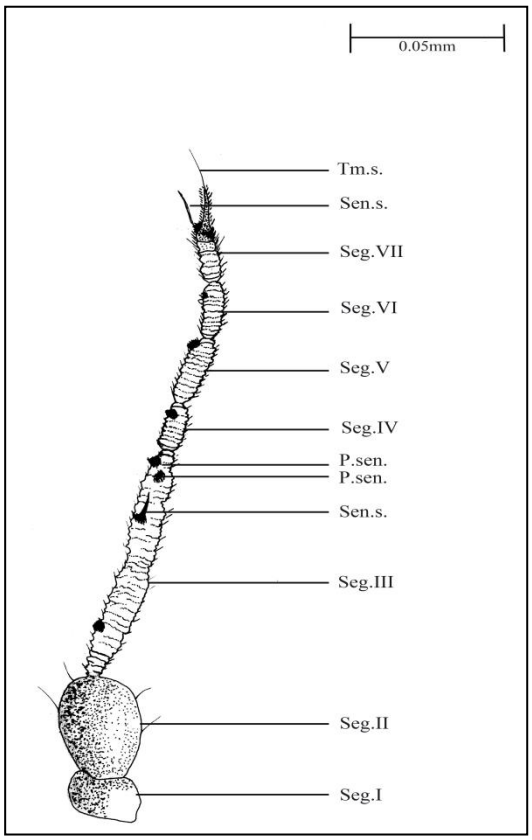
1b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Seg.V
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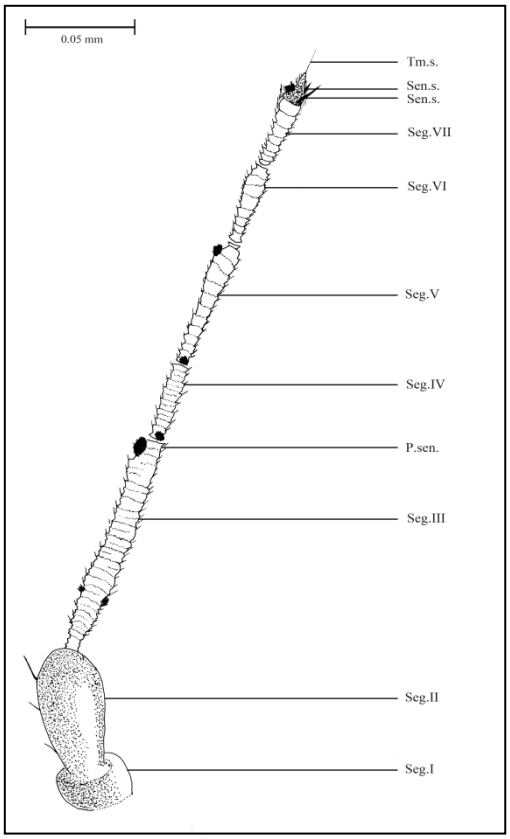
P.sen.
P.sen.
Sen.s.
Seg.III
Seg.II
Seg.I

2a


0.05 mm
Tm.s.
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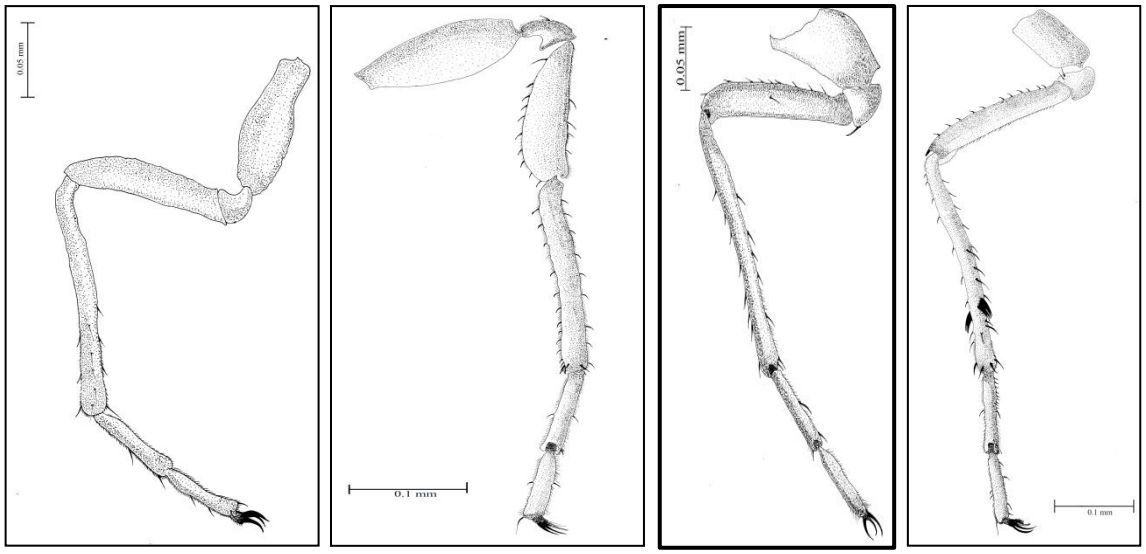
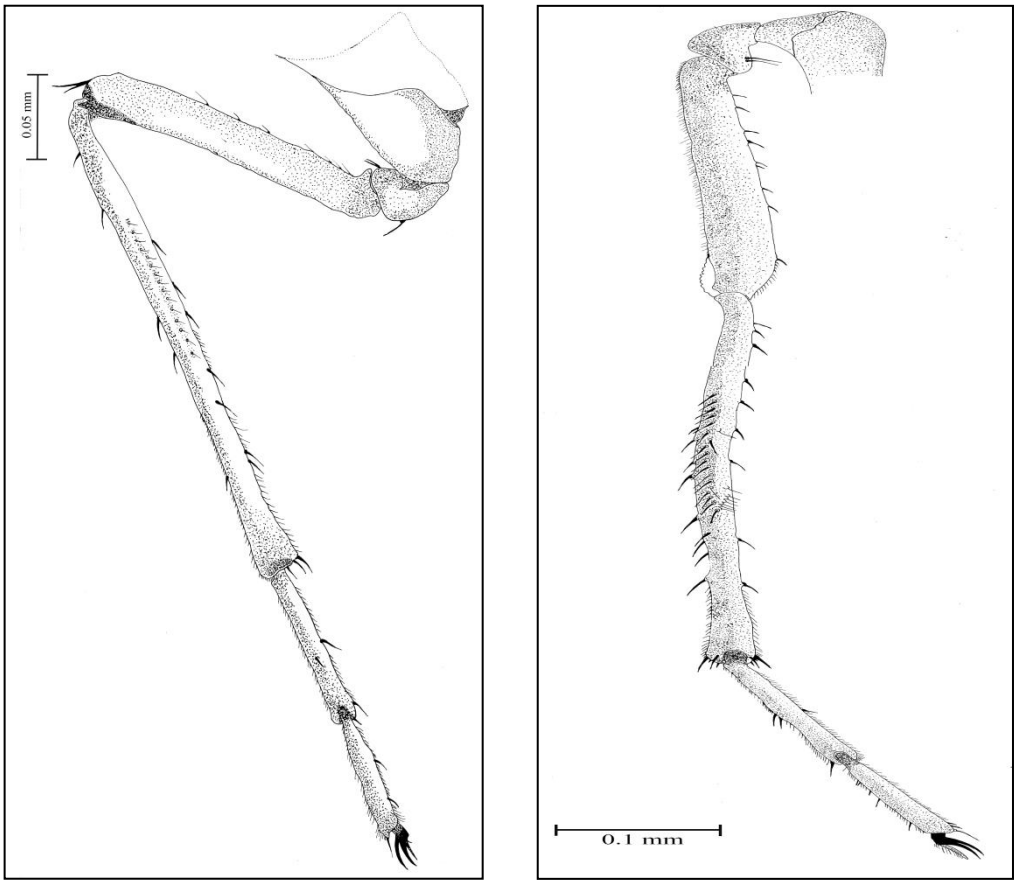
2b



3a **3b** **4a** **4b**



5a **5b**

Fig. 4.23: **a**- *Bemisia tabaci* **b**- *Trialeurodes vaporariorum.* 1- Eye; 2- Antenna; 3- Foreleg; 4- Midleg; 5- Hindleg; Tm.s.- Terminal seta; Sen.s.- Sensory seta; Seg.- Segment; P.sen.- Pit sensorium; Sen.s.- Sensory seta

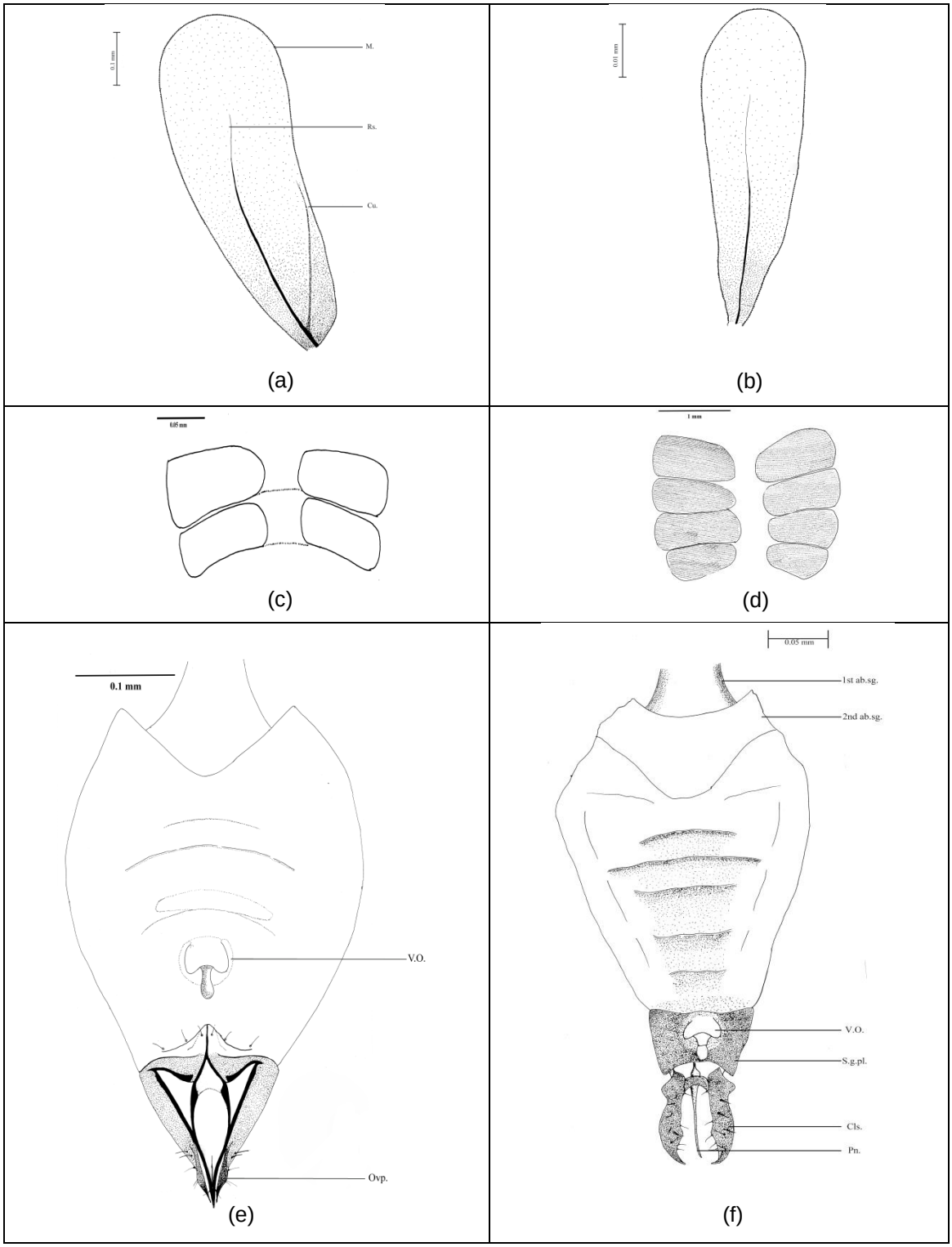


Fig. 4.24: *Bemisia tabaci*. a- forewing; b- hindwing; c- waxplate (female); d- waxplate (male); e- abdomen (male); f- abdomen (female). M.- Margin; Rs.- Radius; Cu.- Cubitus; ab. Sg.- First abdominal segment; V.O.- Vasiform Orifice; s.g.pl.- Supra genital plate; Cls.- Claspers; Pn.- Penis; Ovp.- Ovipositor

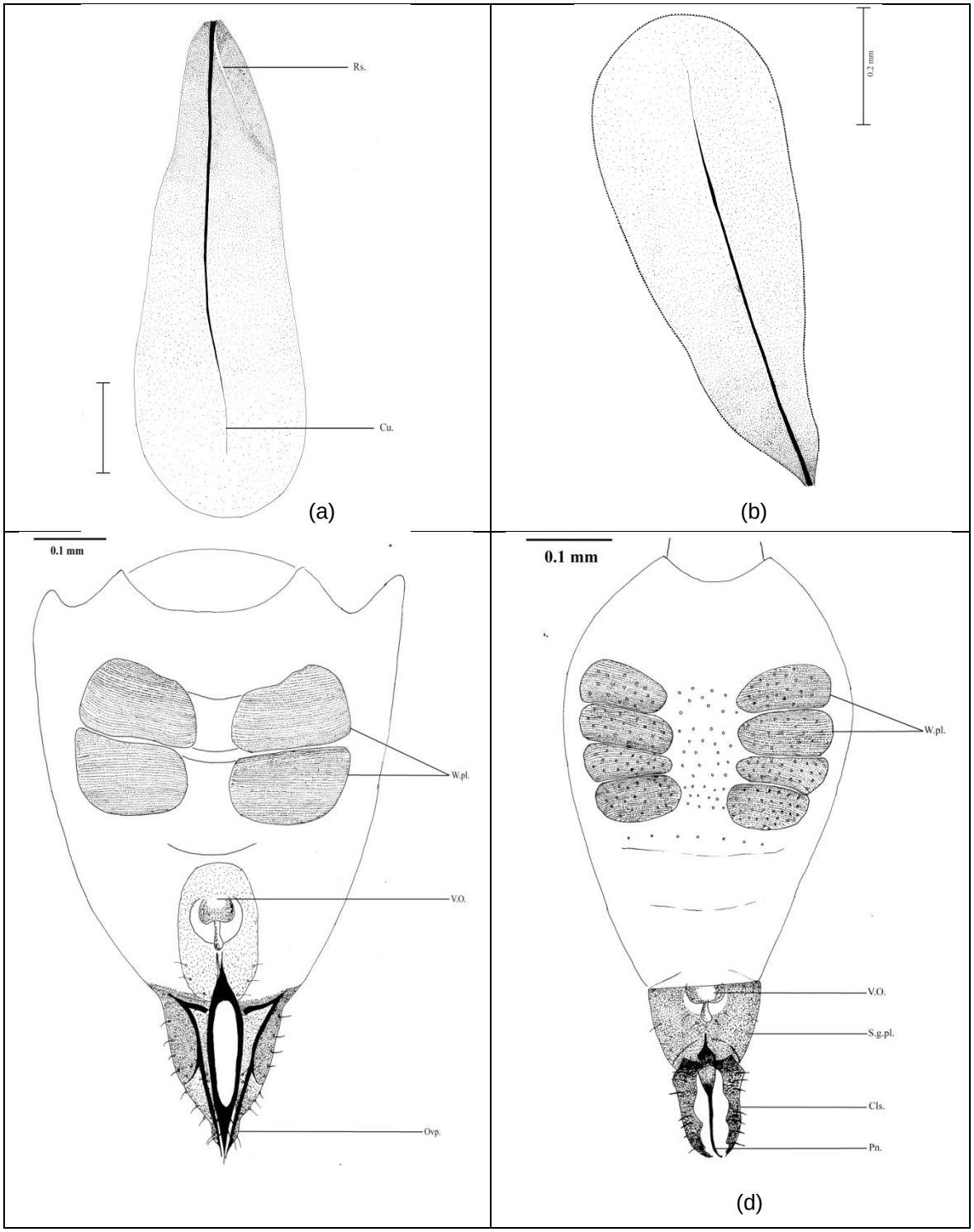


Fig. 4.24: *Trialeurodes vaporariorum*. a- forewing; b- hindwing; c- abdomen (male); d- abdomen (female) M.- Margin; Rs.- Radius; Cu.- Cubitus; V.O(e)Vasiform Orifice; s.g.pl.- Supra genital plate; Cls.- Claspers; Pn.- Penis; Ovp.- Ovipositor; W.pl.- Wax plate.

Whiteflies along with other homopterans are the most important and prominent among the Invasive Alien Species (IAS) which enters into a country and cause extensive damage. Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus* Martin) is a recent example. IAS are introduced as any developmental stage through imported agricultural produces, through airports and seaports. Having known the identification of whitefly species at any developmental stage forms the first line of defence at quarantine centres, where the invasive species can be identified and excluded well before entering into the country even if they are mixed with a population of other species. Identification of whiteflies until recently has largely relied on the puparium. In recent days, molecular tools have been developed for identification of whitefly species. While correct identification of the pest species is as equally important as the method of pest management utilized, resources for identification of all the life stages are still lacking. In this study, the morphological difference was observed in all the stages among the species and within the species. Size, structure of vasiform orifice, arrangement of setae was some of the sound characters for differentiating the species at any stage of development. Morphology of both the species described in the study was confirmed with the description given by **Mound (1963) and Martin and Mound (2007)**. Although there were some differences in setal arrangements in comparison with the previous studies, those differences may have occurred due to the development in different host leaf surface **(Chaubey *et al.*, 2010).** Similarly, the study of comparative biology of *B. tabaci* and *T. vaporariorum* revealed no significant difference in total developmental duration on tomato. Our results were in coincidence with **(Ahn *et al.*, 2001 and Lorenzo *et al.*, 2016)**, working on the same plant and under similar environmental conditions. Developmental stages of insect are affected by the plant morphological characters such as plant surface, hairiness, glandular trichomes, shape and colour of the leaves **(Berlinger, 1986 and Oriani and Vendramim, 2010).** Duration of development was found to be sub equivalent in both the species when they were reared on tomato. The difference in duration of development was not recorded as the plant characters which affects the biology were the same. The adult longevity and fecundity of *B. tabaci* and *T. vaporariorum* on tomato plants were found to be different from those reported by **Ahn *et al.* (2001); Lorenzo *et al.*, (2016) and Coudriet *et al.* (1985).** Fecundity and longevity of both the species (*B. tabaci* and *T. vaporariorum*) under study are usually inconstant and it is altered by factors such as age, temperature

(Enkegaard, 1993), nutritional availability and also the host plant **(Liu and Oetting, 1994).** Understanding the biology of a pest is crucial in finding out the correct life stage at which the pest management intervention would give maximum output. The present study provides a comprehensive understanding of the biology of two whitefly species which are notorious as they damage the crops directly by feeding and indirectly by transmitting devastating plant viruses. Further, this study gains its importance as it gives a comprehensive knowledge of biology and morphology of two whitefly species and fills the knowledge gap that existed for decades. Future studies are much needed on taking this preliminary information further to nullify the effect caused by the whiteflies on agriculture.

4.5 Distribution and phylogenetic analysis of whitefly species from North-western Himalayan region

DNA markers represent a very effective tool for analyzing the genetic diversity of any insect. The known frequencies of each allele in the population efficient characterization of whitefly could be achieved through molecular markers. Total 32 samples of whitefly were collected from different hosts growing in open environments areas from 45 different locations of the North-Western Himalayan region (Table). Out of these 32 samples, 20 samples were of *B. tabaci* and 12 samples of *T. vaporariorum*. These two species were distinguished by using morphological features **(Table 4.18).** The collected samples of whitefly were preserved in -20 ^{o}C for later use. From all the samples, single whitefly was taken and used for DNA extraction. The DNA of individual whitefly was extracted by using DNA extraction kit developed by Genetix Biotech Asia Pvt. Ltd. and the chemicals used for running PCR reaction were obtained from Bangalore, Genei (India). For *B. tabaci* two primer pairs *i.e.*, C1-J-2195-F and TL2-N-3014-R; LCO-1490-F and HCO-2198-R were used while for *T. vaporariorum* Tvap-F and Wf-R were used. In case of *B. tabaci* 18 samples got amplification **(Table 4.18)** and produce bands at 880 bp by using the primer pair C1-J-2195-F and TL2-N-3014-R while rest of the two samples did not show any amplification with this primer pair. These remaining two samples showed amplification with the primer pair LCO-1490-F and HCO-2198-R at 700 bp. The 12 samples of *T. vaporariorum* showed amplification with the primer Tvap-F and Wf-R at 756 bp. These results indicated that the used primers are effective in showing amplification in the collected whitefly samples but these primers are

Plate 7: Collection of whitefly samples from different location for molecular identification

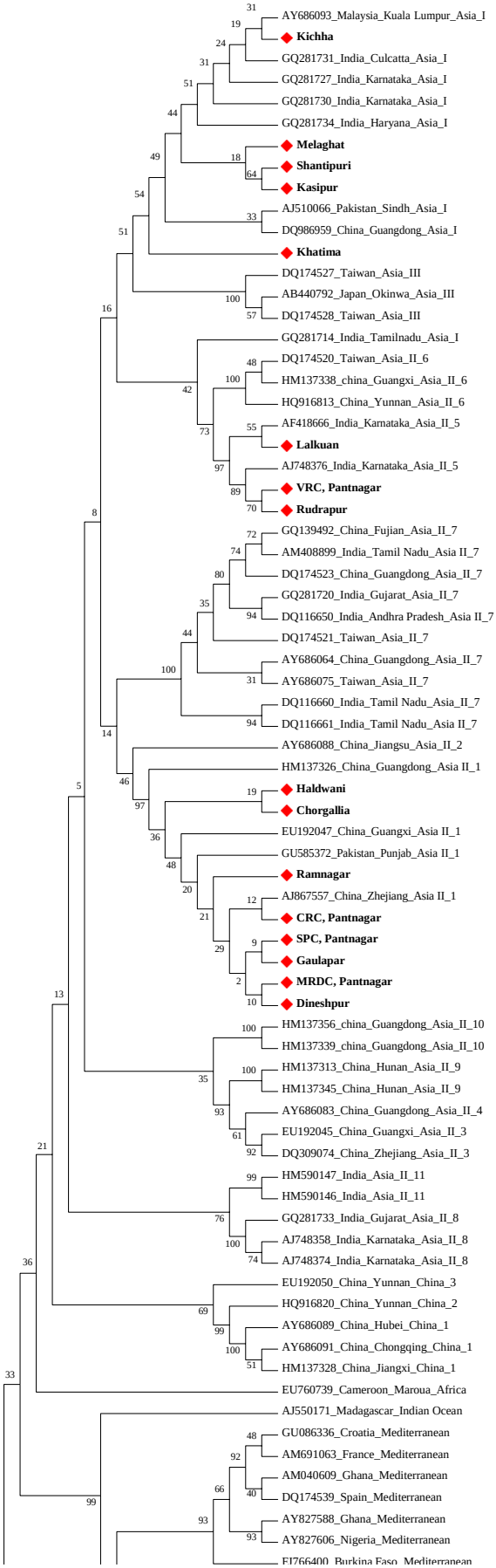
monomorphic in terms of band position and hence cannot be used to differentiate the species on basis of band size and hence the sequencing techniques were employed in the present study.

Table 4.18 Distribution of *T. vaporariorum* and *B. tabaci* genetic groups across Uttarakhand

Sample No.	Collection site	Host plant	Geographical location	Identified Cryptic species
1.	VRC, Pantnagar	Brinjal	29°01′53″N79°22′27″E	Asia II-5
2.	CRC, Pantnagar	Brinjal	29°01′10″N 79°28′57″E	Asia II-1
3.	SPC, Pantnagar	Cowpea	29°01′42″N79°27′58″E	Asia II-1
4.	MRDC, Pantnagar	Tulsi	29°01′58″N79°27′01″E	Asia II-1
5.	Shantipuri	Brinjal	28°58′13″N79°32′41″E	Asia I
6.	Kichha	Brinjal	28°54′41″N79°30′51″E	Asia I
7.	Rudrapur	Bitter gourd	28°98′75″N 79°41′41″E	Asia II-5
8.	Haldwani	Okra	29°13′21″ N79°31′42″E	Asia II-1
9.	Kashipur	Brinjal	29°12′37″N78°57′42″E	Asia I
10.	Dineshpur	Brinjal	29°02′46″N79°19′17″E	Asia II-1
11.	Ramnagar	Brinjal	29°23′39″N79°07′35″E	Asia II-1
12.	Kotabagh	Brinjal	29°23′56″N79°18′00″E	MEAM 1
13.	Chorgallia	Tomato	29°07′21″N79°42′05″E	Asia II-1
14.	Gaulapar	Soybean	29°10′35″N79°35′25″E	Asia II-1
15.	Melaghat	Brinjal	28°51′07″N80°03′16″E	Asia I
16.	Khatima	Potato	28°92′09″N79°96′96″E	Asia I
17.	Haridwar	Potato	29°57′00″N78°09′49″E	MEAM 1
18.	CRC, Pantnagar (Pigeonpea)	Pigeonpea	29°01′10″N 79°28′57″E	MEAM 1
19.	Lalkuan	Brinjal	29°06′76″N79°51′82″E	Asia II-5
20.	College of Agriculture, Pantnagar	Soybean	29°02′36″N79°48′45″E	Uganda
21.	Dhari	Cucurbit	29°21′03″N79°49′40″E	*Trialeurodes vaporariorum*
22.	Dharimkhol	Common Bean	29°41′53″N79°37′48″E	*Trialeurodes vaporariorum*
23.	Mukteshwar	Common Bean	29°35′21″N79°38′38″E	*Trialeurodes vaporariorum*
24.	Bhimtal	Cucurbit	29°20′41″N79°33′06″E	*Trialeurodes vaporariorum*
25.	Bhowali	Tomato	29°22′55″N79°31′10″E	*Trialeurodes vaporariorum*
26.	Pithoragarh	Soybean	29°34′56″N80°12′59″E	*Trialeurodes vaporariorum*
27.	Jgeshwar Dham	Cabbage	29°63′84″N79°85′28″E	*Trialeurodes vaporariorum*
28.	Almora	Tomato	29°35′21″N79°39′05″E	*Trialeurodes vaporariorum*
29.	Pokrad	Potato	29°40′52″N79°64′74″E	*Trialeurodes vaporariorum*
30.	Lohaghat	Cauliflower	29°24′15″N80°05′05″E	*Trialeurodes vaporariorum*
31.	Chaffi	Potato	29°22′06″N79°34′53″E	*Trialeurodes vaporariorum*
32.	Padampuri	Tomato	29°38′04″N79°61′94″E	*Trialeurodes vaporariorum*

The PCR product obtained from all 32 samples was used for sequencing. The Homology search was carried out using NCBI Blast and the difference in COI sequences of *B. tabaci* was determined using the sequence alignment editor Bio Edit version (10.7) and compared against the consensus sequences of **Dinsdale *et al*. (2010)**. The alignment was further analyzed using the MEGA 6.0 program, using the Neighbor-joining method with a "bootstrap" value of 1000. In case of *B. tabaci* a phylogenetic tree **(Fig. 4.25)** was obtained which depicted that 8 specimens matched to the mt COI of cryptic species Asia II-1 and 5 specimens matched to the mt COI of cryptic species Asia I. The analysis of these specimen depicted that *B.tabaci* Asia II-1 is distributed in CRC, SPC, MRDC, Haldwani, Dineshpur, Ramnagar, Gaulapar, and Chorgallia, while Asia I is distributed in Shantipuri, Kichha, Kasipur, Melaghat, and Khatima. Three samples matched with Asia II-5 (VRC, Rudrapur, and Lalkuan) and MEAM 1 (Haridwar, Kotabagh, and CRC-Pigeonpea) while one sample (College of Agriculture, Pantnagar) matched with Uganda. In case of *T. vaporariorum* the obtained phylogenetic tree **(Fig. 4.26)** revealed that there was no variation in the collected 12 samples of *T. vaporariorum* from Dhari, Dharimkhol, Mukteshwar, Bhimtal, Bhowali, Pithoragarh, Jageshwar Dham, Pokrad, Almora, Chaffi, Lohaghat, Padampuri, and samples obtained from NCBI blast.

The survey and analyses performed here provided a detailed picture of species composition and diversity within the whitefly complex in the North-Western Himalayan region. This is also the first detailed report of whitefly phylogeny in this region. The results of the study revealed the presence of four genetic groups namely Asia II-5, Asia II-1, Asia I, and MEAM I. Asia II-1 (45%) was found as the most prominent group followed by Asia I (25 %), Asia II-5 and MEAM 1 (15%) each, and Uganda (5%) **(Fig. 4.27)**. Similar kind of reports on the distribution of the genetic group of whitefly in India indicated the presence of five species namely Asia I, Asia II-1, Asia II-3, Asia II-7, Asia II-8, and MEAM I **(Rekha *et al*., 2005 and Reddy *et al*., 2012)**. The dominance of Asia II-1 and Asia I was also reported earlier by **Ellango *et al*. (2015)** in India. The presence of these genetic groups in adjoining areas like Delhi, Ludhiana, and Muzaffarpur was also reported by **Ellango *et al*. (2015)**. However, among the seventeen genetic groups, the cryptic species Asia 1 has the largest distribution across the Asia reported by **Hu *et al*. (2014)**. Our extensive survey followed by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Kichha
GQ281731_India_Culcatta_Asia_I
GQ281727_India_Karnataka_Asia_I
GQ281730_India_Karnataka_Asia_I
GQ281734_India_Haryana_Asia_I
Melaghat
Shantipuri
Kasipur
AJ510066_Pakistan_Sindh_Asia_I
DQ986959_China_Guangdong_Asia_I
Khatima
DQ174527_Taiwan_Asia_III
AB440792_Japan_Okinwa_Asia_III
DQ174528_Taiwan_Asia_III
GQ281714_India_Tamilnadu_Asia_I
DQ174520_Taiwan_Asia_II_6
HM137338_china_Guangxi_Asia_II_6
HQ916813_China_Yunnan_Asia_II_6
AF418666_India_Karnataka_Asia_II_5
Lalkuan
AJ748376_India_Karnataka_Asia_II_5
VRC, Pantnagar
Rudrapur
GQ139492_China_Fujian_Asia_II_7
AM408899_India_Tamil Nadu_Asia II_7
DQ174523_China_Guangdong_Asia_II_7
GQ281720_India_Gujarat_Asia_II_7
DQ116650_India_Andhra Pradesh_Asia II_7
DQ174521_Taiwan_Asia_II_7
AY686064_China_Guangdong_Asia_II_7
AY686075_Taiwan_Asia_II_7
DQ116660_India_Tamil Nadu_Asia_II_7
DQ116661_India_Tamil Nadu_Asia II_7
AY686088_China_Jiangsu_Asia_II_2
HM137326_China_Guangdong_Asia II_1
Haldwani
Chorgallia
EU192047_China_Guangxi_Asia II_1
GU585372_Pakistan_Punjab_Asia II_1
Ramnagar
AJ867557_China_Zhejiang_Asia II_1
CRC, Pantnagar
SPC, Pantnagar
Gaulapar
MRDC, Pantnagar
Dineshpur
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HM137339_china_Guangdong_Asia_II_10
HM137313_China_Hunan_Asia_II_9
HM137345_China_Hunan_Asia_II_9
AY686083_China_Guangdong_Asia_II_4
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AY686091_China_Chongqing_China_1
HM137328_China_Jiangxi_China_1
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AJ550171_Madagascar_Indian Ocean
GU086336_Croatia_Mediterranean
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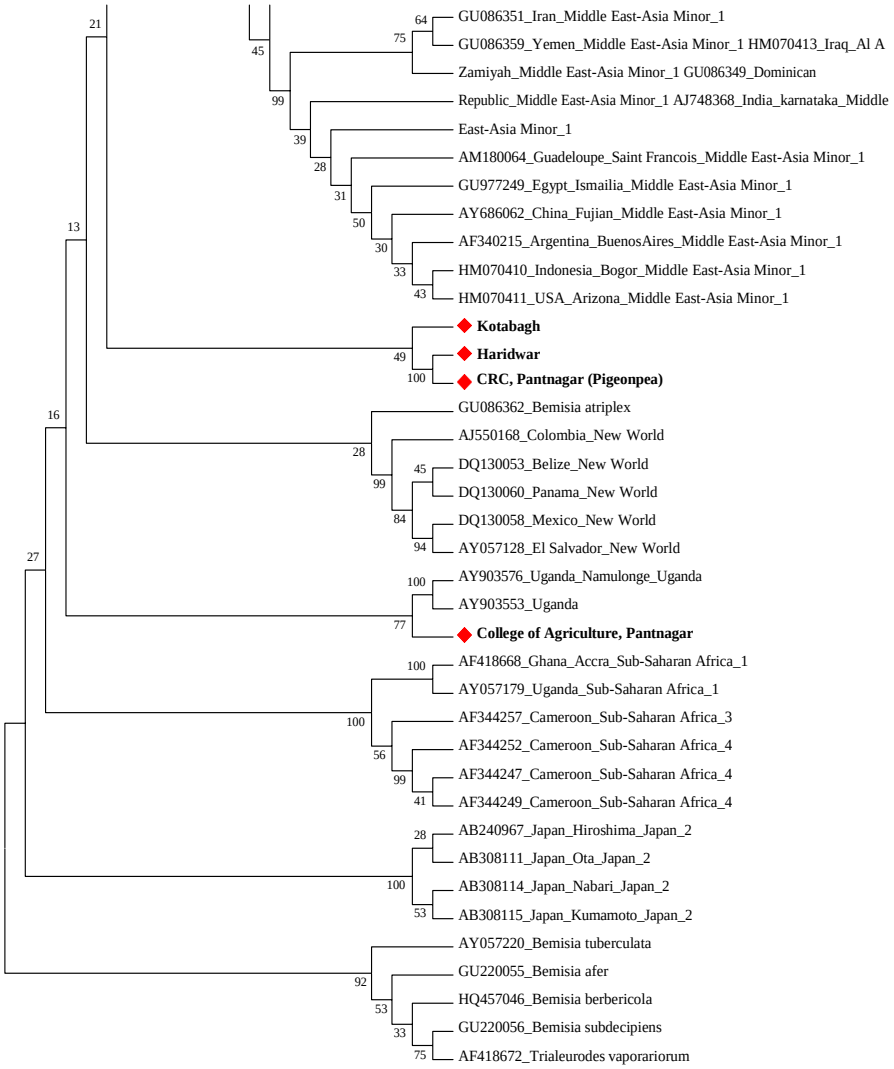
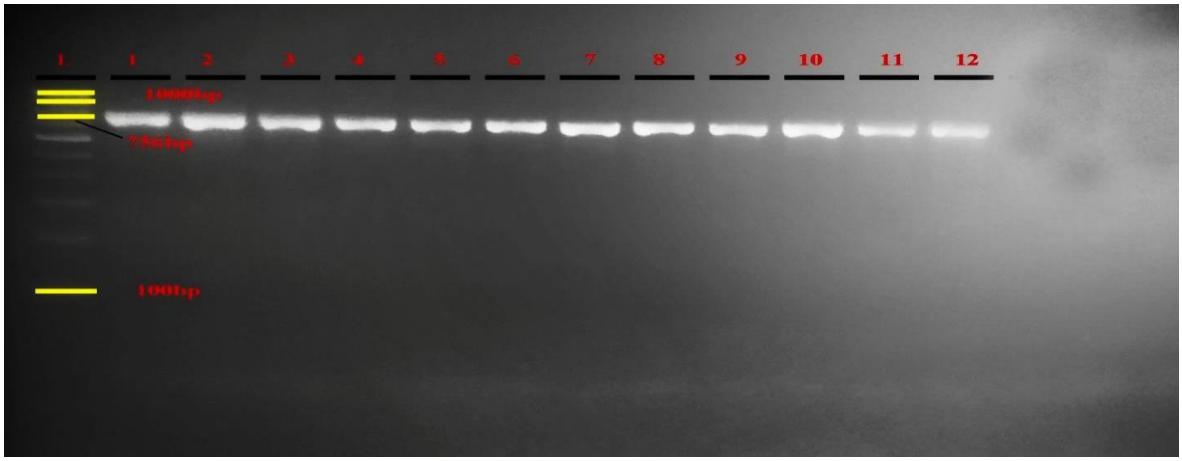
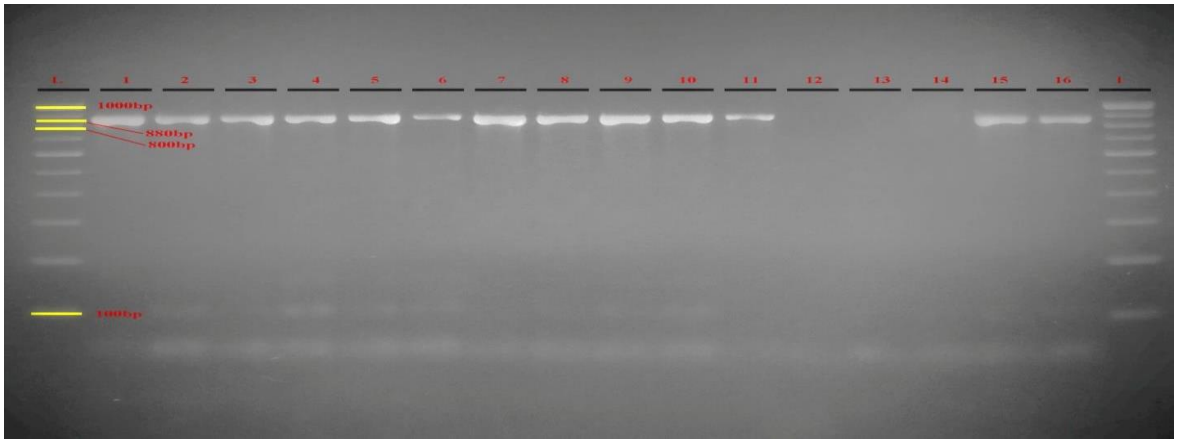


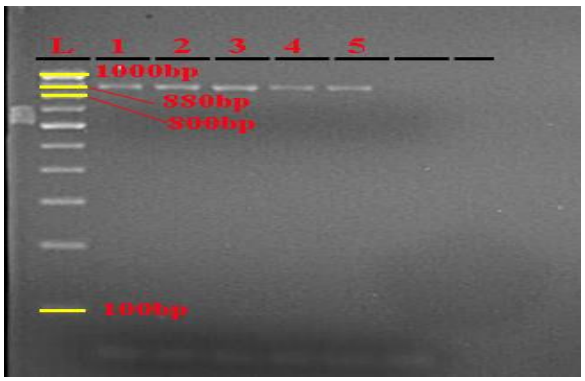
Fig. 4.25: Phylogentic tree of *Bemisia tabaci*



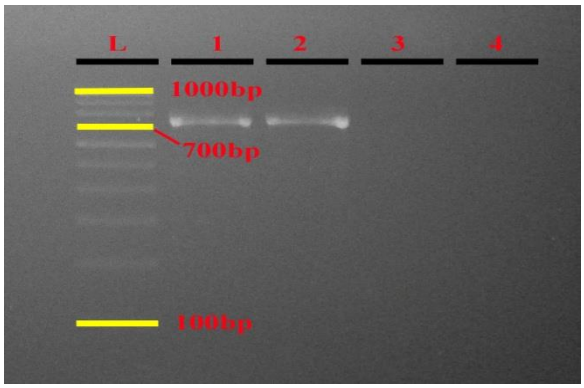
1. Gell pictures showing amplification profile of marker Tvapf and Wfr, here 1-12 represents samples collected from Dhari, Dharimkhol, Muktehwar, Bhimtal, Bhowali, Pithoragarh, Jageshwar, Almora Pokhraj, Lohaghat, Chaddhafarm and Padampuri respectively.



2. Gell pictures showing amplification profile of marker C1-J-2195F and TL2-N-3014R, here 1-11 represents samples collected from VRC, Pantnagar, CRC, Pantnagar, SPC, Pantnagar, MRDC, Pantnagar, Shantipuri, Kichha, Rudrapur, Haldwani, Kashipur, Dineshpur, Ramnagar and 15-16 represents samples collected from Kotabagh, Chorgallia respectively.



3. Gell pictures showing amplification profile of marker C1-J-2195F and TL2-N-3014R, here 1-5 represents samples collected from Gaulapar, Melaghat, Khatima, Haridwar, CRC, Pantnagar (Pigeonpea) respectively.



4. Gell pictures showing amplification profile of LCO-1490-F and HCO-2198-R, here 1-2 represents samples collected from Lalkuan and College of Agriculture Pantnagar respectively.

Plate 8: Gel picture showing amplification of different primer

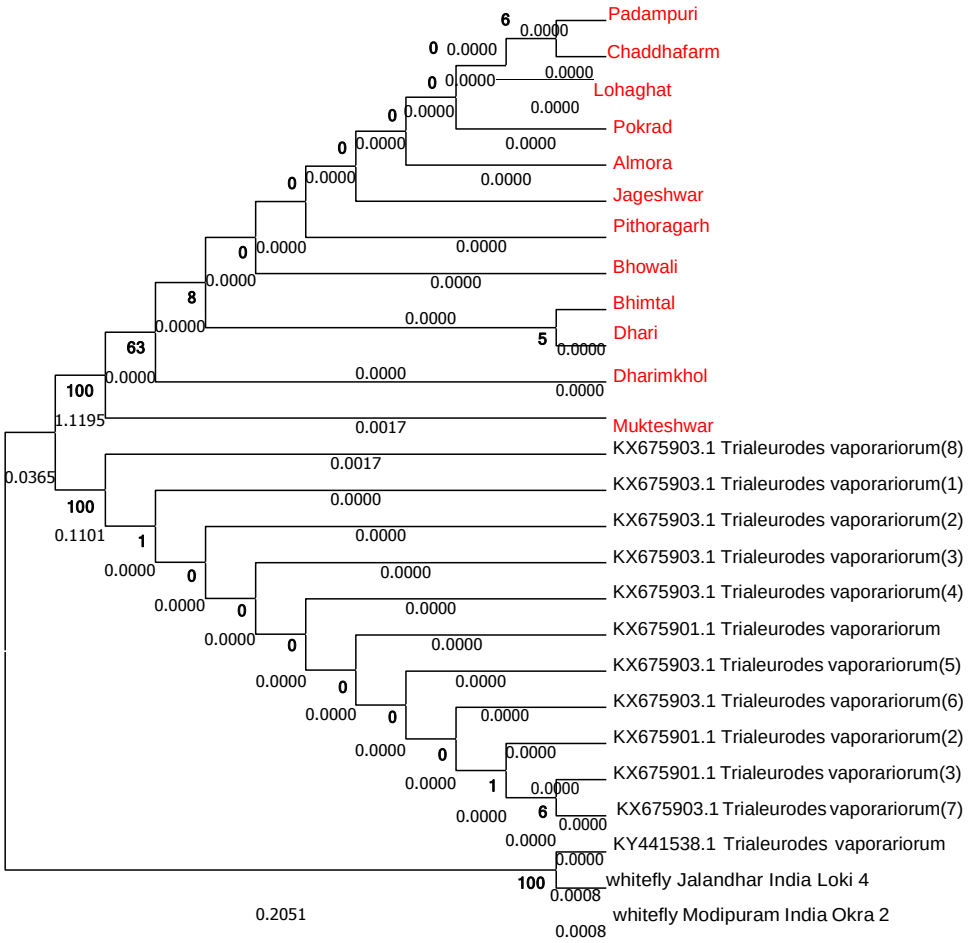


Fig. 4.26: Phylogenetic tree of *Trialeurodes vaporariorum*

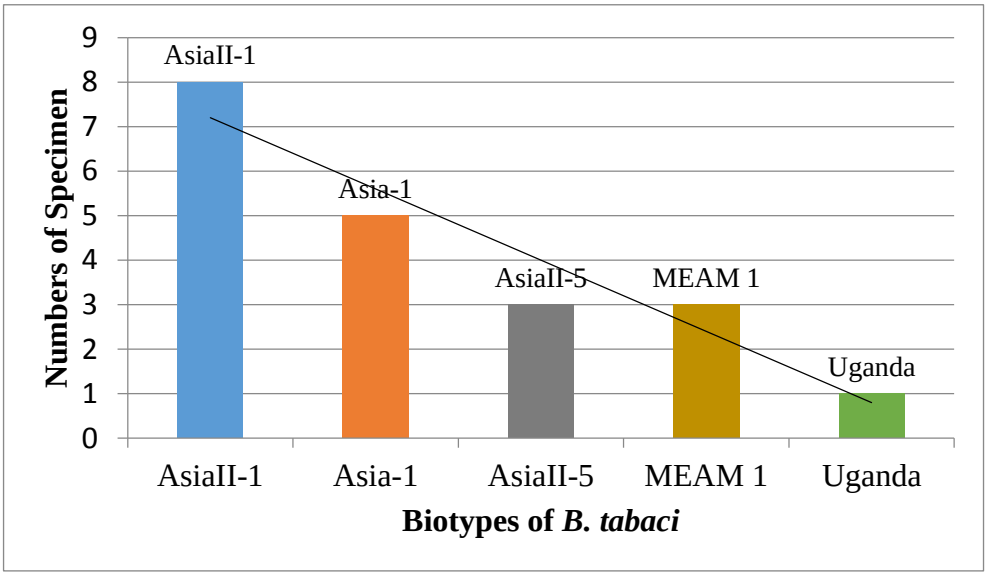


Fig. 4.27: Distribution of Biotype of *B. tabaci*

sequencing showed that the invasive MEAM1 genetic group was distributed in Haridwar, Kotabagh, and CRC-Pigeonpea locations. The results of our study proved that the genetic group MEAM1 possesses high fecundity but it is restricted to some specific locations. These results for the MEAM1 genetic group were also reported earlier by **Rekha *et al*. (2005).** In case of *T. vaporariorum* the phylogenetic tree suggested that *T. vaporariorum* is a single species and these result were in contrast with the results obtained for *B. tabaci* **(Boykin *et al*., 2007)**. These results indicated that biotype, as well as host-associated genetic differences, were not found in *T. vaporariorum*. The phylogenetic analysis of *Trialeurodes vaporariorum* was carried out by using the mt CO1 gene obtained from NCBI- GenBank. Several factors including the fecundity, survival rate, and insecticide resistance were responsible for the buildup of the genetic group in *B. tabaci* population **(Boykin *et al*., 2007 and Ahmed *et al*., 2011)**. The obtained information is highly useful for monitoring future patterns of abundance, displacement, diversity, and species composition of whitefly. This would help in developing management strategies for effective control of whitefly species. This finding of a new genetic group of whitefly in the present study provides solid evidence about the complexity of this species complex. It is possible that some more newly developed whitefly genetic groups are also present and their revelation will require a more intensive sampling regimen. The results of the present study not only reveal new genetic groups of whitefly but also depicted the possibility of finding a newly developed group if further research are conducted.

4.6 Repellent and oviposition deterrent effects of selected plant essential oil against *Bemisia tabaci* (Gennadius)

4.6.1 Repellency effect of the essential oils against *B. tabaci* in free choice method

The study of ANOVA showed significant differences among the treatments of essential oil application at 3h (F= 12.22; df= 3; p= 0.000), 6h (F= 7.879; df = 3; p= 0.002), 12h (F= 4.317; df= 3; p= 0.021) and 24 h (F= 15.569; df= 5; p= 0.000) **(Table 4.19)**. The repellency was found to be in a range of 9.34% (citronella oil) to 71.68% (mint oil) **(Fig. 4.28)**. These results revealed that mint has most repellent effect as compared to other treatments as well as control. The repellency index ranges from 0.64 (mint oil) to 0.76 (lemongrass oil). The present investigation revealed that, after 3HAT

Table 4.19 Per cent repellency (Mean ± SE)[a] of adult *B. tabaci* and repellent class of Citronella, mint lemongrass and tulsi oil to varying exposure time in a dual choice bioassay

Treatment	Per cent repellency at different time intervals				Mean repellency	Repellency class	Repellency index	Classification
	3hrs.	6hrs.	12hrs.	24hrs.				
Citronella	09.34±2.56[a]	19.12±3.79[a]	49.40±3.21[b]	52.98±3.80[bc]	32.71±10.87	II	0.66±0.11	Repellent
Mint	24.04±4.37[bc]	28.90±5.13[bc]	33.90±3.85[ab]	71.68±7.12[c]	39.63±10.87	II	0.64±0.11	Repellent
Tulsi	38.30±1.57[c]	44.42±5.12[c]	32.62±5.91[ab]	28.90±2.26[a]	36.06±03.39	II	0.65±0.02	Repellent
Lemongrass	11.70±2.42[ab]	20.32±1.83[a]	26.78±4.59[a]	33.22±3.97[ab]	23.00±04.59	II	0.76±0.04	Repellent
F	12.225	7.879	4.317	15.569	-	-	-	-
P value	0.000	0.002	0.021	0.000				

[a]Original data; mean followed by the same letter in the column do not differ by Tukey test (P ≤ 0.05). For ANOVA, data were arcsine transformed.

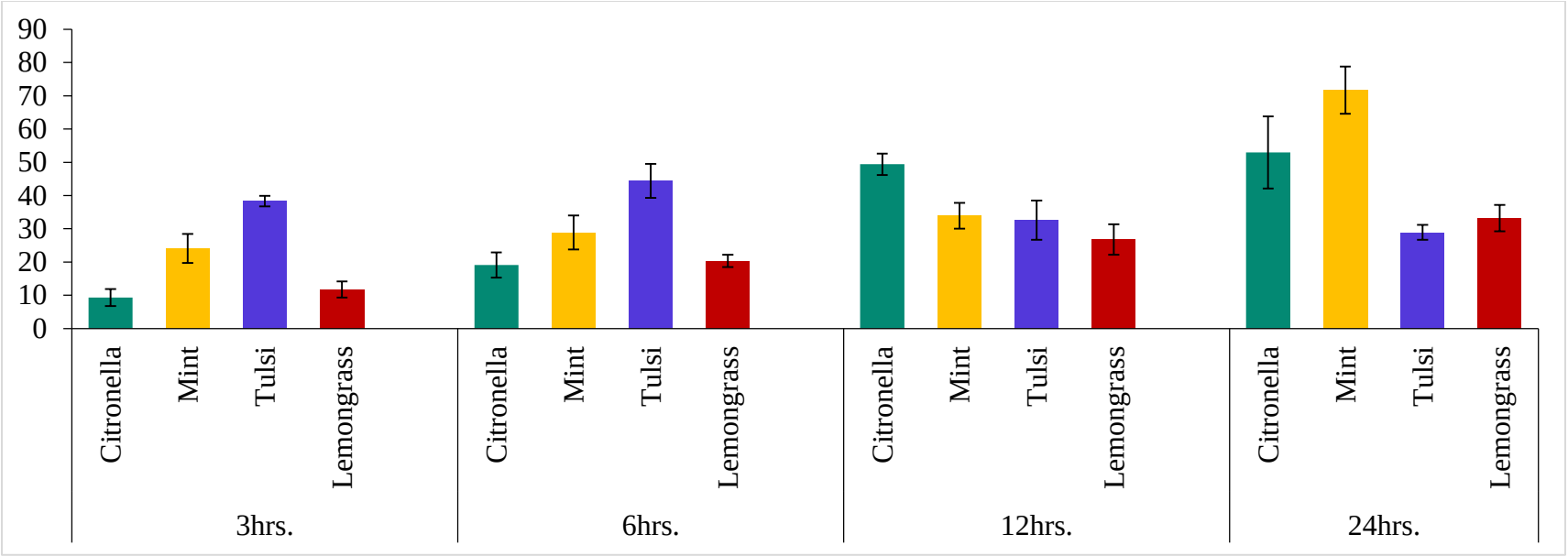


Fig. 4.28: Per cent repellency of different oils at different time intervals against *B. tabaci*

and 6HAT, tulsi oil indicated the maximum repellency (38.30 and 44.42%) followed by mint oil (24.04 and 28.90) and lemongrass (11.70 and 20.32%), while essential oil of citronella had the significantly low repellency (09.34 and 19.12%). Post hoc contrasts between time points indicated that whitefly repellency was significantly among the tested oils. The repellency per cent caused by all essential oils after 12 HAT, ranged from 49.40% to 26.78%. Among the essential oils, lemongrass was found to be least repellent with a value of 26.78%, followed by, tulsi oil (32.62), mint oil (33.90), and citronella oil (49.40%). Similarly, at 24 HAT, mint oil showed the highest repellency of 71.68%, followed by citronella oil (52.98) and lemongrass oil (33.22), whereas significantly low repellency was observed in tulsi oils (28.90%).The highest overall mean repellency (39.63%) was recorded in mint oil with a repellency index of 0.64, followed by tulsi and citronella oil with a repellency of 32.71 and 36.06%; and RI of 0.65 and 0.66, respectively. Significantly low repellency was recorded in lemongrass oil (23.00%; RI= 0.76). Based on the mean repellency rate, all four essential oils showed repellency of class II.

4.6.2 Oviposition deterrence of whiteflies in dual choice method

The *t*-test results of the dual choice experiment showed that all four essential oils (citronella, mint, tulsi and lemongrass) have strong oviposition deterrence effects on whitefly adults. There were significant differences between the controls and citronella essential oil (t= 3.194; *df*= 3; *p*= 0.033), mint oil (t= 3.864; *df*= 4; *p*= 0.018), tulsi oil (t= 2.913; *df*= 4; *p*= 0.044) and lemongrass oil (t= 3.068; *df*= 4; *p*= 0.037) after 24HAT in the bioassay, respectively **(Table 4.20 and Fig. 4.29)**.

The results of the ANOVA revealed significant differences among the treatments, (*F*= 5.000; *df*= 3; *p*= 0.012). The greatest oviposition activity index of -0.65 was observed for mint essential oil, with per cent effective repellency of 78.68% at 24 h in the bioassay, followed by tulsi and citronella essential oil with a per cent oviposition activity of -0.43 and -0.39; and ER% of 59.80 and 56.35%, respectively. Significantly low oviposition activity index was recorded in lemongrass oil (-0.19; ER%= 32.25) **(Fig. 4.29)**. Based on the per cent effective repellency mint, tulsi and citronella essential oils worked as moderately deterrent (MD) and lemongrass essential oil had no deterrent effect (N).

Table 4.20 The oviposition deterrent activities of citronella, mint, tulsi and lemongrass essential oils against *B tabaci* in a dual choice bioassay

Treatment	Number of eggs (Mean±SE)		t-value	*df*	*p*-value	OAI	ER (%)	Suscepti-bility
	Treated	Control						
Citronella	07.00±02.32	16.04±03.84	3.194*	4	0.033	-0.39[ab]	56.35	MD
Mint	07.80±02.35	36.60±09.02	3.864*	4	0.018	-0.65[a]	78.68	MD
Tulsi	08.20±01.82	20.40±05.74	2.913*	4	0.044	-0.43[a]	59.80	MD
Lemongrass	08.40±01.50	12.40±01.20	3.068*	4	0.037	-0.19[c]	32.25	N
F *P*	-	-	-	-	-	5.000 0.012	-	-

Original data; mean followed by the same letter in the column do not differ by Tukey test ($P \leq 0.05$). OAI=oviposition activity index; ER% =per cent effective repellency. ER=98%-100%, strongly deterrent (SD); ER=80%-97% were indicated as fairly deterrent (FD); ER=50%-80% were indicated as moderately deterrent (MD); ER <50% were indicated as no-effect (N).

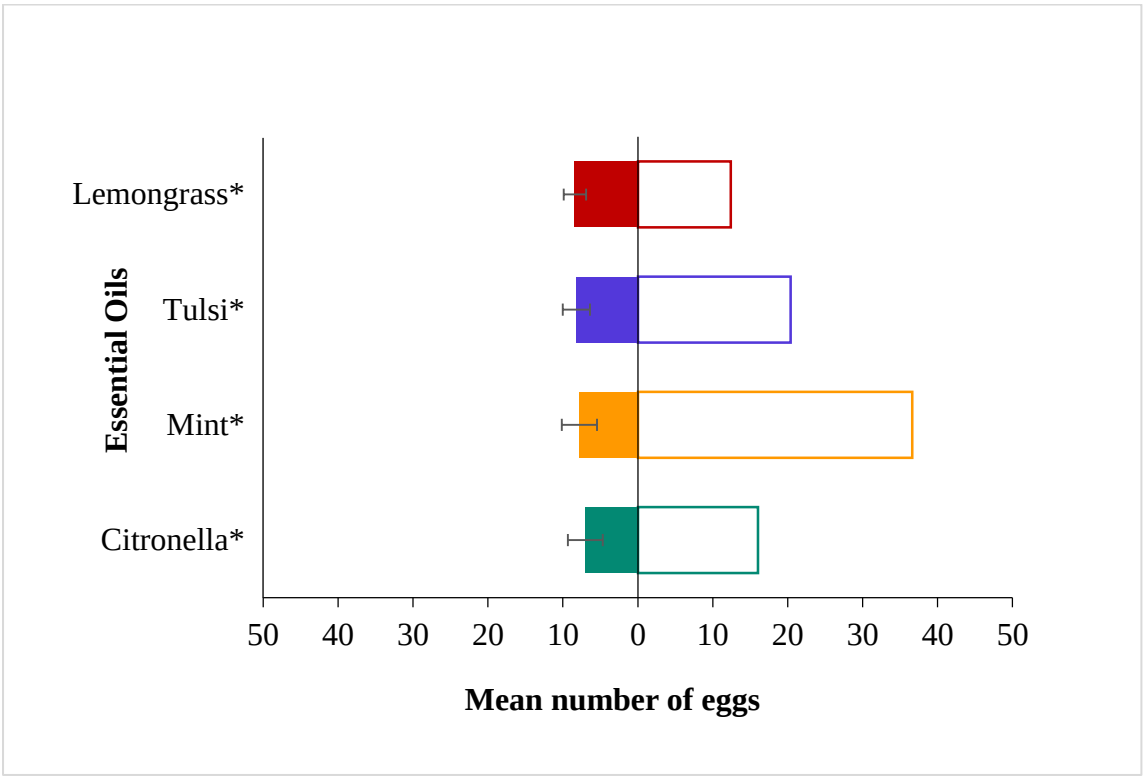


Fig. 4.29: Oviposition deterrence of different essential oils in dual choice bioassay

4.6.3 Oviposition deterrence of whiteflies in no-choice method

The oviposition deterrence effects of the four essential oils (citronella, mint, tulsi and lemongrass) were tested against *B. tabaci* adults in the no-choice bioassay. The *t*-test results of the no-choice bioassay showed that all four essential oils (citronella, mint, tulsi, and lemongrass) have strong oviposition deterrence effects on *B. tabaci* adults. There were significant differences between the controls and citronella essential oil (t= 5.091; *df*= 3; *p*= 0.007), mint oil (t= 4.415; *df*= 4; *p*= 0.01), tulsi oil (t= 4.310; *df*= 4; *p*= 0.013) and lemongrass oil (t= 4.781; *df*= 4; *p*= 0.009) after 48HAT in the no-choice bioassay, respectively **(Table 4.21 and Fig. 4.30)**. The oviposition activity index was found to be in a range of -0.17 (lemongrass) to -0.54 (mint oil) with per cent effective repellency 28.98% to 70.24%. The highest oviposition activity index of -0.54 was observed for mint essential oil with per cent effective repellency 70.24 % after 48h in the bioassay, followed by tulsi and citronella essential oil with a per cent oviposition activity of 0.41 and -0.36; and ER% of 58.01 and 52.83%, respectively. Significantly low oviposition activity index was recorded in lemongrass oil (-0.17; ER%= 28.98). Based on the suitability citronella, mint, and tulsi oil belonged to moderately deterrent (MD) while lemongrass oil recorded as no deterrent effect (N).

Table 4.21 The oviposition deterrent activities of citronella, mint, tulsi and lemongrass essential oils against *B tabaci* in a no choice bioassay

Treatment	Number of eggs (Mean±SE)		OAI	ER (%)	Suscepti-bility	t-value	*df*	*p*-value
	Treated	Control						
Citronella	10.00±03.35	21.20±04.40	-0.36	52.83	MD	5.091	4	0.007
Mint	14.40±03.19	48.40±09.52	-0.54	70.24	MD	4.415	4	0.012
Tulsi	11.00±02.55	26.20±05.91	-0.41	58.01	MD	4.310	4	0.013
Lemongrass	09.80±00.73	13.80±01.36	-0.17	28.98	N	4.781	4	0.009

Original data; mean followed by the same letter in the column do not differ by Tukey test ($P \leq 0.05$). OAI=oviposition activity index; ER% =per cent effective repellency. ER=98%-100%, strongly deterrent (SD); ER=80%-97% were indicated as fairly deterrent (FD); ER=50%-80% were indicated as moderately deterrent (MD); ER <50% were indicated as no-effect (N).

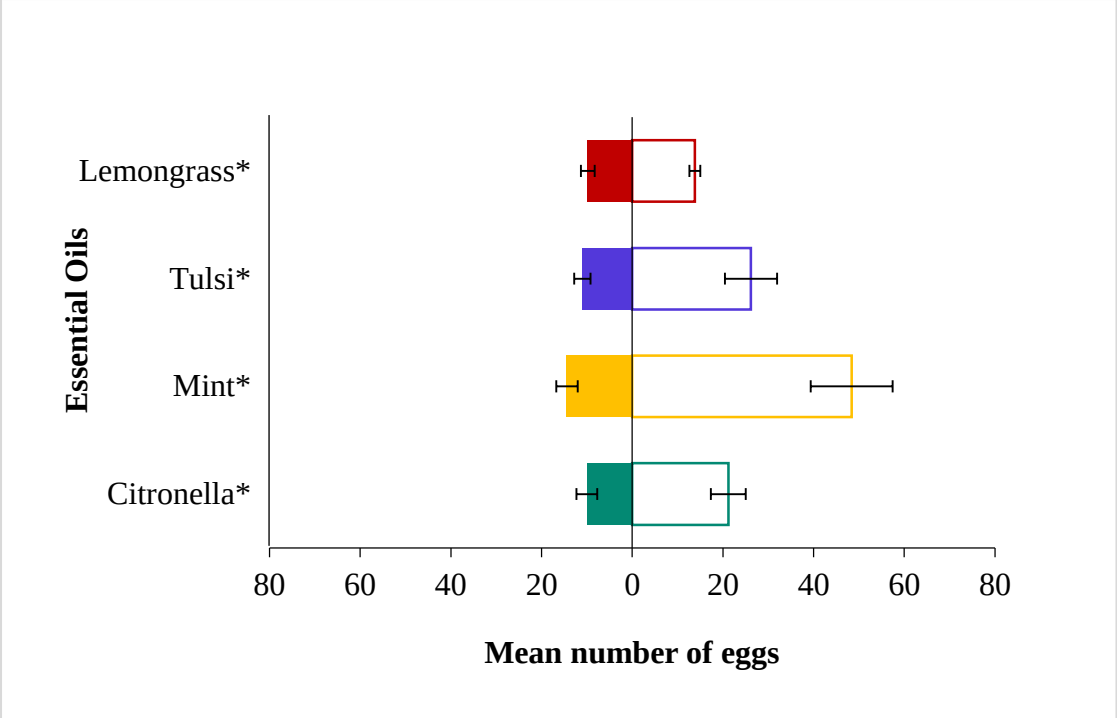


Fig. 4.30: Oviposition deterrence of different essential oils in no choice bioassay

4.6.4 Trapping of *B. tabaci* on oil treated and untreated yellow sticky traps

The trapping of *B. tabaci* on yellow sticky trap treated with essential plant oils and untreated (control) were evaluated in greenhouse after 24 h. Although all treated yellow sticky traps had fewer whiteflies compared to the untreated (control) traps, the results revealed that none of the oil significantly reduced adult trapping on yellow sticky traps **(Table 4.22 and Fig. 4.31)**. The mean adult whiteflies trapped in the control yellow sticky trap (212.60±29.87) was higher than the citronella treated yellow sticky trap (147.80±30.41), with a significant difference of (t= 6.228, *df*= 4, *p*= 0.003) between treatment and control. Similarly, in the case of mint oil, fewer whiteflies were trapped in mint oil-treated YST (112.40±24.09) as compared to control YST (186.00±39.35) and showed significant difference (t= 3.705, *df*= 4, *p*= 0.021).Tulsi oil was statistically significant as compared to the control (t= 5.884, *df*= 4, *p*= 0.004) as the mean population of *B. tabaci* trapped on tulsi oil-treated YST (148.00±12.81) was lower than control YST (202.80±09.19). In comparison to lemongrass oil treated YST (107.20±10.63), adult whiteflies were more attracted towards the control YST (155.60±10.77) and had significant difference (t= 3.417, *df*= 4, *p*= 0.027).

Table 4.22 Trapping of *B. tabaci* on oil treated and untreated yellow sticky traps

YST Treatment	Replicates	Two choice	Total trapped adult whiteflies (Mean±SE)	t-value	*p*-value
Citronella	10	Treated	147.80±30.41*	6.228	0.003
		Control	212.60±29.87		
Mint	10	Treated	112.40±24.09*	3.705	0.021
		Control	186.00±39.35		
Tulsi	10	Treated	148.00±12.81*	5.884	0.004
		Control	202.80±09.19		
Lemongrass	10	Treated	107.20±10.63*	3.417	0.027
		Control	155.60±10.77		

*The significant differences between the treatment and non-treatment group were determined by paired t test (P<0.05).

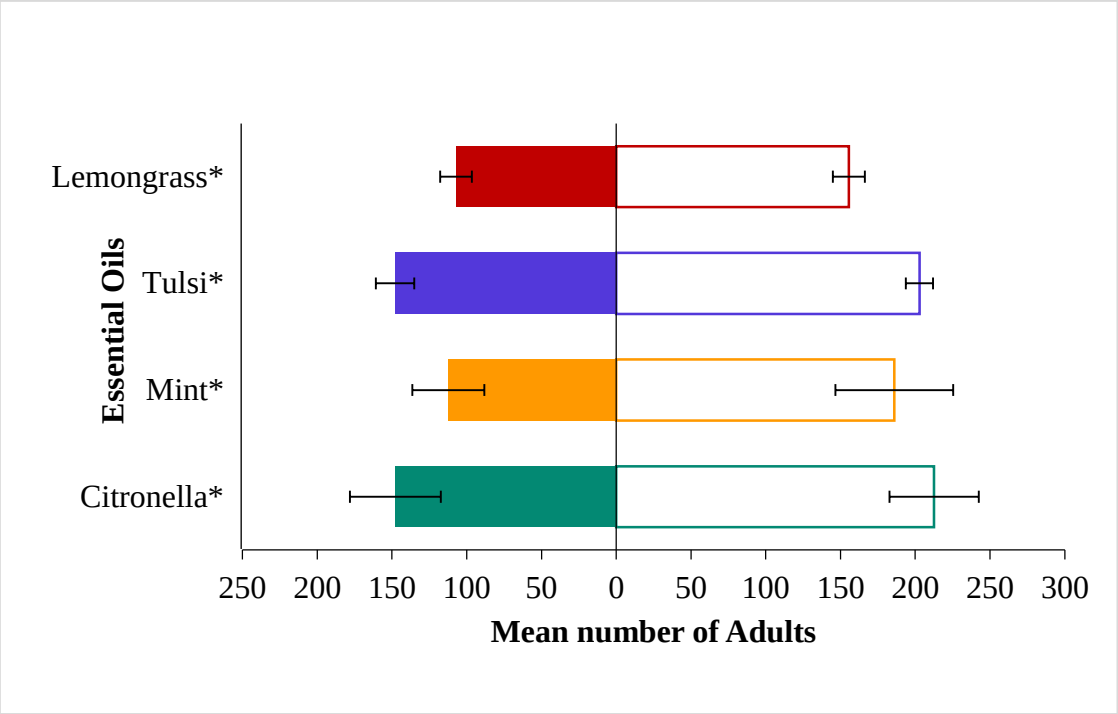


Fig. 4.31: Trapping of *B. tabaci* on oil treated and untreated yellow sticky traps

The present study revealed that tested essential oils had strong effects on *B. tabaci* landing as well as oviposition. In dual choice and no-choice bioassay fewer *B. tabaci* adults were aligning on the oil treated chilli leaves as compared with control; however, they were observed as repellents and ovipositional deterrent. The results of present study were much similar to earlier report of **Butler and Henneberry (1990) and Butler and Henneberry (1991)**. Among the four tested oil mint had the highest repellency effect on *B. tabaci*. Previous research showed that the essential oil of mint has potent repellency against some insect species for example thrips, aphid and whitefly **(Koschier *et al.*, 2002)**. Similarly, tulsi and citronella oils also showed significant repellent action which maintained class II of repellency classification. These results were also supported by finding of **Chittihunsa and Samngamnim (1999); Keita *et al.* (2001) and Saad *et al.* (2017)** who observed the repellent action of *O. basillicum* against *N. virescens*, *H. armigera*, and *C. maculatus* respectively. Lemon grass oil showed the lowest repellent action and similar results were obtained by **Adhikari *et al.* (2002) and Sharaby and Mona (2014)**. In generally, volatile compounds released by plants may help phytophagous arthropods to find a suitable host plant **(Bleeker *et al.*, 2011 and Jiao *et al.*, 2012)**. In this way, the application of an essential oils (non- host odor) decrease the alignment of insect pest on host plant by masking the odour of the host plant. Application of essential oils *viz*., citronella, mint and tulsi showed moderate ovipositional deterrent effect while, lemongrass oil had no deterrent effect in both dual choice and no choice bioassay. Similar results were observed by **Ngoh *et al.* (1998); Koschier and Sedy (2003); Koschier *et al.* (2002) and Pascual-Villalobos and Ballesta-Acosta (2003)**. Reduction of oviposition might be a consequence when adult insects avoid settling on a host plant **(Panda and Khush, 1995)**.

The finding of present study on repellency and ovipositional deterrent effect of essential oils (citronella, mint, tulsi and lemon grass) against *B. tabaci* provide an informative data for the development of new management strategies against pest *B. tabaci*. Hence, the oils can be used as bio-insecticides for the control of whitefly in polyhouse as well as field. However, further studies are required to understand the biological activity of the major compounds extracted from citronella essential oil. Their impact on non-target species including predators, parasitoids, and pollinators cannot be ignored and should be evaluated.

Summary and Conclusions

Chapter 5 SUMMARY AND CONCLUSION

The present study entitled "**Biological and Phylogenetical Studies of Whiteflies from North-Western Himalayan region**" was undertaken during the year 2017-2020, the laboratory experiment were conducted in insect molecular and taxonomy laboratory of department of entomology and field trials were conducted at experimental area of Vegetable Research Center (VRC) at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar (Uttarakhand).

Extensive surveys were conducted in 45 locations of 4 district of Uttarakhand from 2017 to 2019 to record the potential reproductive host associated with *B. tabaci* and *T. vaporariorum*. For *B. tabaci*, 70 host plant species belonging to 30 different plant families were recorded. The family Asteraceae and Fabaceae showed highest number of host plant species (10) followed by Solanaceae (7), Cucurbitaceae (6) and Malvaceae (4). out of these 73 species, 27species (37%) were weeds, 16 species (22%) were economic crops, 15 species (21%) were vegetables, 12 species (16%) were ornamental and flowers and 2 species (4%) were fruit crop. Similarly, for *T. vaporariorum*, 47 host plant species belonging to 19 families were screened. The highest number of host plants species were recorded from Asteraceae (10) followed by Solanaceae (6) and Fabaceae (6) and least host plants were found in Brassicaceae (3). The 21 species (45%) were found to be weeds while 2 species (4%) were fruit crops. The results of the survey revealed that a wide range of reproductive host plant species of *B. tabaci* and *T. vaporariorum* was present in the Uttarakhand. Thus the result revealed that host plants belonging to family Asteraceae, Fabaceae, Solanaceae, Cucurbitaceae, were found as most preferred host plant by both *B. tabaci* and *T. vaporariorum*.

The seasonal incidence of whitefly (*B. tabaci*) on tomato and brinjal crops was studied during the year 2017-18 & 2018-19 at VRC, Pantnagar. Initially whitefly population was observed on tomato and brinjal crop after 30 days of transplanting. During 2017-18, the population reached at peak on the 48th SW on tomato (5.40 adults/three leaves) and 51th SW on brinjal crop (7.79 adults/three leaves) and attained its peak during 2018-19 on tomato and brinjal at 49th SW (6.20 adults per three leaves) and 50th SW (8 adults per three leaves).

The correlation coefficient studies for the year 2017-18 and 2018-19 indicated that whitefly population had significantly negative correlation with max. temperature ($r= -0.50^{**}$ and $r= -0.53^{**}$), min. temperature ($r= -0.61^{**}$ and $r= -0.57^{**}$) and evaporation ($r= -0.64^{**}$ and $r= -0.66^{**}$) on both tomato and brinjal plant while non-significant correlation was observed with sunshine hour in both the studied years on both tomato and brinjal plant. The regression analysis of both the year (2017-18 and 2018-19) indicated that various weather factors *viz*., temperature (max. and min.), relative humidity (morning and evening), rainfall, wind velocity, sun shine hours and evaporation had influencing effect on population of *B. tabaci* on brinjal and tomato with reasonable accuracy ($R^2= 0.66$ and $R^2= 0.75$ in 2017-18) ($R^2= 0.82$ and $R^2= 0.70$ in 2018-19).

The feeding preference of *B. tabaci* and *T. vaporariorum* on different host plants were recorded under free-choice and no choice condition during the year 2018-19 at IPM Laboratory Department of Entomology. The results revealed that brinjal was the most preferred host for both whitefly species under both the methods while the least preferred host was found to bottle gourd and chilli for *B. tabaci* and *T. vaporariorum* respectively, in both the methods. Similar trend was also observed for the oviposition preference test in free choice and no choice condition. Oviposition significantly higher in the case of *T. vaporariorum* on all hosts as compared to *B. tabaci.*

The study of biotic potential (developmental time, survival rates, longevity and fecundity) of two whitefly species reared on brinjal and tomato host plants were characterized during the year 2018-19 at IPM Laboratory Department of Entomology. The preimaginal developmental period of immature stages of *B. tabaci* and *T. vaporariorum* was faster on brinjal (19.40 days and 21.57 days) than on tomato (22.40 days and 24.03 days). The survival rate was also maximum in brinjal host crop for both the species as compared to tomato plant. Overall the brinjal was found the most suitable host for both species (*B. tabaci* and *T. vaporariorum*) based on development period and survival rate as compared to tomato. On the brinjal plant the total mean eggs laid by *B. tabaci* was 102.40 and on tomato plant number of eggs laid was 63.90, while an egg laid by per female of *T. vaporariorum* was 149.30 on brinjal plant and 115.50 on tomato plant. The mean longevity of male and female of *B. tabaci*

on brinjal was 12.60 and 14.10 days, respectively, while in tomato longevity was found to be 14.90 and 17.60 days, respectively. In the case of *T. vaporariorum* the average longevity of males and females on brinjal was 19.20 and 21.90 days, respectively and in tomato, the average longevity was 17.30 and 23.50, respectively.

The comparative morphological studies of life stages of two whitefly species, *B. tabaci* and *T.vaporariorum* was conducted during 2018-19 at Insect Taxonomy Laboratory of Department of Entomology. The results revealed that eggs could easily be differentiated based on their size, colour and arrangement patterns. After hatching *T. vaporariorum* laid yellow-coloured eggs (length= 0.22 mm; breadth= 0.09 mm) in neat circle or semicircle which turned dark brown or almost black before hatching while, in *B. tabaci* the eggs (length= 0.20 mm; breadth= 0.10 mm) was creamy yellow which changed into light golden brown and were laid singly in a scattered manner. In case of first instar slight differences were observed in the mounted specimens of the two species, *T. vaporariorum* had 17 pairs of well marginal setae while in *B. tabaci* 16 pairs of marginal setae were found. Similarly, cephalic tubercles were strongly developed and had sub-rectangular shape in *T. vaporariorum*; while they were weakly developed and had sub-elliptical shape in *B. tabaci*. The size of the nymph varied slightly in the two species with *T. vaporariorum* measuring 0.27 mm in length and 0.16 mm in breadth, and *B. tabaci* nymph measuring 0.25 mm in length and 0.15 mm in breadth. In case of second instar of *T. vaporariorum*, two pairs of the dorsal setae were prominently present on the 8^{th} abdominal segment and cephalic segment, while in *B. tabaci*, 8^{th} abdominal setae were minute and cephalic setae was completely absent. The vasiform orifice was subcordate with notched posterior end and the size of lingula was the same as that of the orifice, with a pair of lateral lobes in *T. vaporariorum*, while in *B. tabaci*, orifice was a triangular shape with posteriorly open and lingula was swollen distally and pointed. The living nymphs were distinguished only by their size *i.e*., *B. tabaci* nymphs (length= 0.35 mm; breadth= 0.22 mm) were slightly smaller than those of *T. vaporariorum* (length= 0.38 mm; breadth= 0.25mm) nymph. The third instar of the two species showed resemblance in the presence and position of the dorsal setae, while, differs in various aspects including non-uniformly crenulated margins, triangular shape of vasiform orifice and swollen lingula without lobes in *B. tabaci*. Also, the average measurements of mounted specimens of the third instar in

T. vaporariorum were 0.62 mm in length and 0.38 mm in breadth, while in *B. tabaci*, was 0.50 mm in length and 0.34 mm in breadth. In case of pupae or fourth instar both the species were easily distinguishable. In *T. vaporariorum*, the living pupa was pale, opaque and yellowish-white in appearance, raised from the surface of the leaf and surrounded by a thin palisade of transparent-whitish wax, and the dorsal surface bears glassy wax rods, while in case of *B. tabaci*, the pupa was distinctly yellow, and the palisade of wax and dorsal glassy wax rods were absent. The pupae of *T. vaporariorum* measured 0.71 mm in length and 0.43 mm in breadth while in *B. tabaci* it measures, 0.69 mm in length; and 0.50 mm in breadth. In *T. vaporariorum*, about 64 well-developed papillae were present in a single row on the sub margin, among them 4-5 were relatively larger. Four pairs of large well-developed papillae were also present on the sub dorsum. However, in *B. tabaci*, submarginal papillae were completely absent and indicated as small inconspicuous "micro-setae". The paired dorsal setae of *T. vaporariorum* were found in the 1st and 8th abdominal, while in *B. tabaci* one to seven pairs of well-developed dorsal setae were present. In mounted specimens of *B. tabaci* adults, the compound eyes were divided and each eye had two groups of lenses with a single lens forming a "bridge" between the two groups, while in *T. vaporariorum* adults, the eyes were divided but there was no lens forming a bridge between the two groups of facets. The antennae in *B. tabaci* comprised of seven segments with pit sensoria on 3rd, 5th, 6th and 7th segment and stout sensory setae on the 3rd and 7th segment. The antennae in *T. vaporariorum* were similar to those of *B. tabaci*, but without pit sensorium on 6th segment and stout sensory setae on the 3rd segment. The tibiae of the mesothoracic legs in *B. tabaci* were surrounded with randomly arranged stout spines, while in *T. vaporariorum*, the stout spines were typically arranged in two lateral "tufts".

The molecular diversity of whitefly species were analyzed by using mt COI markers in the Insect Molecular Laboratory of Department of Entomology during the year 2018-19. In case of *B. tabaci* a phylogenetic tree was obtained which depicted that 8 specimens matched to the mt COI of cryptic species Asia II-1 and 5 specimens matched to the mt COI of cryptic species Asia I. The analysis of these specimen depicted that *B.tabaci* Asia II-1 is distributed in CRC, SPC, MRDC, Haldwani, Dineshpur, Ramnagar, Gaulapar, and Chorgallia, while Asia I is distributed in

Shantipuri, Kichha, Kasipur, Melaghat, and Khatima. Three samples matched with Asia II-5 (VRC, Rudrapur, and Lalkuan) and MEAM 1 (Haridwar, Kotabagh, and CRC-Pigeonpea) while one sample (College of Agriculture, Pantnagar) matched with Uganda. In case of *T. vaporariorum* the obtained phylogenetic tree revealed that there was no variation in the collected 12 samples of *T. vaporariorum* from Dhari, Dharimkhol, Mukteshwar, Bhimtal, Bhowali, Pithoragarh, Jageshwar Dham, Pokrad, Almora, Chaffi, Lohaghat, Padampuri, and samples obtained from NCBI blast.

The repellency and oviposition deterrent effects of selected plant essential oil against *Bemisia tabaci* was conducted at IPM laboratory of Department of Entomology during 2018-19. The repellency effect of the essential oils against *B. tabaci* in free choice method revealed that the highest overall mean repellency (39.63%) was recorded in mint oil with a repellency index of 0.64, followed by tulsi and citronella oil with a repellency of 32.71 and 36.06%; and RI of 0.65 and 0.66, respectively. Significantly low repellency was recorded in lemongrass oil (23.00%; RI= 0.76). Based on the mean repellency rate, all four essential oils showed repellency of class II. Similarly, oviposition deterrence of whiteflies in dual choice method revealed that the greatest oviposition activity index of -0.65 was observed for mint essential oil, with per cent effective repellency of 78.68% at 24 h in the bioassay, followed by tulsi and citronella essential oil with a per cent oviposition activity of -0.43 and -0.39; and ER% of 59.80 and 56.35%, respectively. Significantly low oviposition activity index was recorded in lemongrass oil (-0.19; ER%= 32.25). Based on the per cent effective repellency mint, tulsi and citronella essential oils worked as moderately deterrent (MD) and lemongrass essential oil had no deterrent effect (N). The Oviposition deterrence of whiteflies in no-choice method indicated that the oviposition activity index was found to be in a range of -0.17 (lemongrass) to -0.54 (mint oil) with per cent effective repellency 28.98% to 70.24%. The highest oviposition activity index of -0.54 was observed for mint essential oil with per cent effective repellency 70.24 % after 48h in the bioassay, followed by tulsi and citronella essential oil with a per cent oviposition activity of 0.41 and -0.36; and ER% of 58.01 and 52.83%, respectively. Significantly low oviposition activity index was recorded in lemongrass oil (-0.17; ER%= 28.98). Based on the suitability citronella, mint, and tulsi oil belonged to moderately deterrent (MD) while lemongrass oil recorded as no deterrent effect (N).

The trapping of *B. tabaci* on yellow sticky trap treated with essential plant oils and untreated (control) were evaluated in greenhouse after 24 h. Although all treated yellow sticky traps had fewer whiteflies compared to the untreated (control) traps, the results revealed that none of the oil significantly reduced adult trapping on yellow sticky traps.

From the present study it can be concluded that *B. tabaci* mostly preferred host plants from Asteraceae and Fabaceae family while *T. vaporariorum* preferred host plants from Asteraceae and Solanaceae family. These host plants include crops, weeds, fruits and ornamental plants, widely distributed over vast geographical area of north western Himalayan region and hence whitefly is a serious threat of this region. The seasonal incidence of both whitefly species reached at peak between 48^{th} and 49^{th} SW on brinjal plant and tomato plant indicated the inverse relation of temperature and whitefly population. The study of different weather parameters effect on whitefly population enables to find the appropriate time to manage their population. As brinjal plant was found to be most susceptible host plant for whitefly due to its survival rate, fecundity and longevity so such crops not recommended growing under the recorded climatic conditions. The morphological studies and life cycle of pest enables easy identification of certain genus of whitefly to make suitable crop protection strategy. As different biotype of the pest has a specific management strategy so, study of molecular diversity of the available whitefly species will help researcher to develop specific modules against certain biotypes. Apart from present study many plants have certain active ingredients need to be explored which have repellent and oviposition deterrent properties. This pest has potential to easily adapt for new host and can also increase its incidence area, therefore more study is required to find new biotype and host of these whiteflies. The current study helps farmer to remove the alternative hosts in areas near tomato and brinjal production fields and thus consequently prevent the establishment and spread of whitefly. There is future opportunity to study host preference studies on different cultivars in the area of HPR that will be helpful in identification of resistant and tolerant lines. Also, there is a need to study morphometrical and biological variations in whitefly in different region of Uttarakhand.

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Appendices

APPENDIX

Weekly weather data 2017

STATION NAME : PANTNAGAR **LONGITUDE : 79 deg. 30' E**
LATITUDE : 29 deg. N **ALTITUDE : 243.84 m. AMSL**

Month	Date	Metro Week No.	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
			Max.	Min.	0712 am	1412 pm					
Jan	01-07	1	22.6	9.3	92	59	000.0	0	06.3	3.6	1.8
Jan	08-14	2	18.2	4.3	93	52	013.0	1	06.2	4.3	1.4
Jan	15-21	3	19.2	7.0	95	59	000.0	0	04.5	4.9	1.3
Jan	22-28	4	22.6	8.5	92	55	047.4	2	05.3	4.7	1.8
Jan-Feb	29-04	5	21.2	9.4	93	60	000.0	0	05.3	3.3	1.6
Feb	05-11	6	23.2	8.5	92	47	000.0	0	05.9	5.3	1.9
Feb	12-18	7	25.2	9.3	91	49	000.0	0	07.1	2.8	1.6
Feb	19-25	8	26.9	10.4	92	45	000.0	0	07.2	5.3	2.8
Feb-Mar	26-04	9	27.4	9.5	87	39	000.8	1	08.0	4.4	2.9
Mar	05-11	10	25.9	10.0	86	50	002.8	1	07.8	5.0	3.3
Mar	12-18	11	25.6	7.9	88	36	000.0	0	08.4	6.3	3.6
Mar	19-25	12	30.5	13.9	82	38	000.0	0	08.3	5.0	3.6
Mar-Apr	26-01	13	34.6	16.9	82	34	000.0	0	09.1	6.0	4.8
Apr	02-08	14	35.5	17.6	72	28	001.0	1	07.3	7.5	6.8
Apr	09-15	15	35.3	15.1	66	21	000.0	0	09.5	7.1	7.0
Apr	16-22	16	36.7	24.5	57	40	000.0	0	07.9	8.0	7.9
Apr	23-29	17	37.4	20.5	61	23	003.0	1	09.0	8.2	9.0
Apr-May	30-06	18	37.4	19.7	55	21	000.0	0	09.5	6.6	7.7
May	07-13	19	37.3	23.7	62	40	006.0	1	10.1	8.1	8.1
May	14-20	20	38.3	22.8	69	36	029.0	1	09.1	7.2	8.9
May	21-27	21	38.6	23.8	65	35	003.6	2	09.4	6.9	8.9
May-Jun	28-03	22	36.0	23.5	66	39	000.4	1	08.0	8.4	8.5
Jun	04-10	23	37.4	25.4	66	50	007.0	1	05.9	8.5	7.8
Jun	11-17	24	38.2	24.7	66	44	010.2	1	09.6	7.3	8.6
Jun	18-24	25	35.9	25.6	76	54	001.0	1	06.8	5.8	6.3
Jun-Jul	25-01	26	35.8	26.4	82	63	054.8	3	06.4	7.9	7.7
Jul	02-08	27	31.0	25.4	94	83	207.2	7	02.1	5.6	4.8
Jul	09-15	28	31.7	25.9	90	83	072.0	5	04.5	6.1	4.1
Jul	16-22	29	33.9	26.2	87	75	080.4	5	06.6	5.2	4.7
Jul	23-29	30	32.3	25.2	88	70	042.8	4	05.0	8.3	4.3
Jul-Aug	30-05	31	31.2	25.7	91	82	203.8	6	02.6	6.5	3.7
Aug	06-12	32	31.8	26.0	91	77	147.8	6	02.8	5.5	4.7
Aug	13-19	33	32.7	25.6	92	71	118.8	5	03.4	6.5	4.2
Aug	20-26	34	31.8	25.6	88	77	057.6	3	05.4	4.9	3.7
Aug-Sep	27-02	35	31.8	25.0	89	76	120.8	4	04.8	5.0	3.9
Sep	03-09	36	32.0	24.0	90	66	056.0	2	07.3	3.4	4.0
Sep	10-16	37	34.0	25.2	86	64	000.0	0	08.5	3.0	4.2
Sep	17-23	38	32.6	24.6	92	74	168.0	3	05.9	4.0	3.2
Sep	24-30	39	32.3	23.4	88	65	007.2	1	05.4	3.5	3.2
Oct	01-07	40	33.1	23.8	88	61	000.0	0	05.2	2.5	2.6
Oct	08-14	41	33.6	20.3	78	48	000.0	0	08.3	2.4	3.2
Oct	15-21	42	33.5	18.0	86	50	000.0	0	09.0	2.1	3.1
Oct	22-28	43	30.8	14.5	87	46	000.0	0	07.9	2.5	2.7
Oct-Nov	29-04	44	28.4	14.7	90	53	000.0	0	04.4	1.9	2.3
Nov	05-11	45	28.7	12.8	94	52	000.0	0	04.8	1.3	2.0
Nov	12-18	46	27.9	11.3	86	40	000.0	0	06.9	2.5	2.0
Nov	19-25	47	26.1	8.6	93	43	000.0	0	07.3	4.2	2.5
Nov-Dec	26-02	48	24.7	7.8	92	48	000.0	0	07.1	1.8	1.9
Dec	03-09	49	23.3	10.9	93	60	000.0	0	03.7	2.5	1.6
Dec	10-16	50	23.1	11.4	94	66	002.8	1	05.0	5.5	1.6
Dec	17-23	51	21.3	8.3	95	64	000.0	0	05.6	3.0	1.4
Dec	24-31	52	22.5	7.2	96	66	000.0	0	06.2	1.8	1.0

Weekly weather data 2018

STATION NAME : PANTNAGAR **LONGITUDE : 79 deg. 30' E**
LATITUDE : 29 deg. N **ALTITUDE : 243.84 m. AMSL**

Month	Date	Metro Week No.	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
			Max.	Min.	0712 am	1412 pm					
Jan	01-07	1	15.2	6.0	95	81	000.0	0	02.5	3.0	0.8
Jan	08-14	2	12.9	5.3	95	79	000.0	0	01.2	2.6	0.8
Jan	15-21	3	20.2	4.2	93	65	000.0	0	05.5	2.7	1.2
Jan	22-28	4	18.6	6.4	94	70	006.8	1	03.6	4.2	1.1
Jan-Feb	29-04	5	20.6	6.9	94	60	000.0	0	05.8	3.9	1.2
Feb	05-11	6	23.2	5.6	95	50	000.0	0	06.4	5.4	1.8
Feb	12-18	7	23.0	9.2	93	61	004.0	2	06.1	5.3	1.9
Feb	19-25	8	26.9	11.5	89	51	000.0	0	07.7	3.0	2.3
Feb-Mar	26-04	9	28.7	11.5	91	44	000.0	0	07.5	5.6	3.1
Mar	05-11	10	29.5	10.7	92	39	000.0	0	08.8	5.5	4.0
Mar	12-18	11	31.1	11.8	81	44	000.0	0	08.5	4.9	4.3
Mar	19-25	12	31.9	12.7	83	40	000.0	0	09.0	4.6	4.3
Mar-Apr	26-01	13	33.6	14.5	78	47	000.0	0	08.2	5.3	5.8
Apr	02-08	14	33.4	18.7	78	52	029.2	1	08.0	5.2	6.0
Apr	09-15	15	31.3	16.2	81	49	013.0	2	06.4	4.6	4.8
Apr	16-22	16	37.2	17.2	73	19	000.0	0	09.4	6.1	7.4
Apr	23-29	17	36.2	19.5	65	36	000.0	0	09.2	7.1	7.7
Apr-May	30-06	18	35.1	22.0	70	41	002.8	1	09.2	9.6	7.2
May	07-13	19	37.0	21.1	67	32	000.0	0	08.4	7.5	8.3
May	14-20	20	35.6	23.1	76	52	005.8	1	08.4	7.6	7.9
May	21-27	21	39.7	22.5	65	34	000.0	0	09.3	7.8	9.4
May-Jun	28-03	22	35.5	23.0	70	55	038.4	4	07.1	9.6	8.3
Jun	04-10	23	35.1	26.0	82	64	087.6	2	07.7	7.5	8.0
Jun	11-17	24	34.6	26.2	85	63	042.8	2	05.2	5.0	5.7
Jun	18-24	25	37.2	26.1	76	45	000.0	0	07.9	6.0	6.8
Jun-Jul	25-01	26	35.9	26.6	81	68	018.2	1	06.4	7.5	7.3
Jul	02-08	27	32.6	25.4	90	70	180.8	3	06.0	3.5	5.6
Jul	09-15	28	32.5	26.0	88	78	173.2	3	03.1	6.1	4.2
Jul	16-22	29	33.3	26.9	82	73	079.6	2	06.7	3.7	6.6
Jul	23-29	30	31.2	25.7	91	80	169.0	5	02.2	5.6	4.6
Jul-Aug	30-05	31	29.7	24.1	94	84	218.1	7	01.0	2.2	3.5
Aug	06-12	32	30.9	24.9	90	80	126.4	3	03.6	2.6	4.3
Aug	13-19	33	31.9	26.1	89	72	073.4	3	04.0	1.5	3.3
Aug	20-26	34	30.9	25.5	95	83	160.8	5	03.2	1.1	4.4
Aug-Sep	27-02	35	30.7	25.5	92	81	086.8	5	02.0	3.3	2.7
Sep	03-09	36	32.3	25.3	90	76	076.6	3	06.0	4.9	4.1
Sep	10-16	37	31.9	24.3	93	78	015.6	2	05.6	6.0	3.9
Sep	17-23	38	32.1	22.6	90	73	049.2	3	06.8	6.6	4.0
Sep	24-30	39	30.4	22.0	91	70	080.6	2	04.6	5.4	3.1
Oct	01-07	40	32.3	18.5	84	60	000.0	0	09.1	4.6	4.0
Oct	08-14	41	30.9	17.1	83	61	002.6	1	07.3	4.7	3.5
Oct	15-21	42	30.7	14.3	87	59	000.0	0	07.8	3.5	3.3
Oct	22-28	43	29.6	12.0	90	51	000.0	0	08.3	3.4	3.1
Oct-Nov	29-04	44	29.9	13.7	87	54	004.2	1	07.1	3.2	2.7
Nov	05-11	45	27.5	11.7	94	54	000.0	0	07.7	2.8	2.4
Nov	12-18	46	26.5	11.8	92	63	000.0	0	06.5	2.1	2.2
Nov	19-25	47	26.3	10.5	93	53	000.0	0	07.7	1.8	2.6
Nov-Dec	26-02	48	25.8	10.7	95	61	000.0	0	06.4	1.9	2.3
Dec	03-09	49	23.9	7.8	93	61	000.0	0	06.2	1.8	1.9
Dec	10-16	50	22.6	6.6	95	60	000.8	0	06.3	1.9	2.0
Dec	17-23	51	22.5	5.0	97	51	000.0	0	06.8	2.0	1.9
Dec	24-31	52	20.3	3.9	97	52	000.0	0	06.7	2.0	1.5

Weekly weather data 2019

STATION NAME : PANTNAGAR **LONGITUDE : 79 deg. 30' E**
LATITUDE : 29 deg. N **ALTITUDE : 243.84 m. AMSL**

Month	Date	Metro Week No.	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
			Max.	Min.	0712 am	1412 pm					
Jan	01-07	1	21.3	6.0	91	60	000.0	0	06.0	####	1.6
Jan	08-14	2	21.7	5.7	94	57	000.0	0	05.8	####	1.7
Jan	15-21	3	21.7	5.7	93	53	000.0	0	06.1	2.1	1.8
Jan	22-28	4	20.5	8.6	88	57	014.2	2	03.8	3.8	2.1
Jan-Feb	29-04	5	20.9	7.0	93	63	000.0	0	06.1	1.6	1.8
Feb	05-11	6	21.3	9.1	95	66	015.0	2	04.7	3.4	2.0
Feb	12-18	7	22.7	10.8	94	64	012.0	2	04.8	2.8	1.9
Feb	19-25	8	24.3	11.4	92	64	003.2	1	04.6	2.8	2.4
Feb-Mar	26-04	9	21.5	9.0	92	69	006.8	3	05.7	2.2	2.6
Mar	05-11	10	26.0	8.9	85	50	000.0	0	09.4	2.2	3.6
Mar	12-18	11	27.8	11.9	90	47	002.6	1	06.4	1.8	3.2
Mar	19-25	12	30.7	11.7	85	41	000.0	0	09.1	1.2	4.8
Mar-Apr	26-01	13	32.3	15.5	85	50	000.0	0	07.7	1.6	4.5
Apr	02-08	14	33.3	18.0	70	43	000.0	0	08.4	4.4	5.9
Apr	09-15	15	35.7	17.3	74	32	003.2	1	09.2	4.9	7.1
Apr	16-22	16	33.2	17.8	72	37	011.2	2	07.7	4.5	6.0
Apr	23-29	17	38.3	20.0	63	25	000.0	0	10.1	5.6	9.0
Apr-May	30-06	18	39.1	21.1	60	18	000.0	0	09.9	7.1	10.1
May	07-13	19	40.7	19.6	51	16	000.0	0	10.2	8.1	10.5
May	14-20	20	37.2	20.9	65	29	000.0	0	07.1	7.1	9.3
May	21-27	21	30.6	21.5	57	17	000.0	0	09.9	6.6	10.1
May-Jun	28-03	22	34.9	23.0	50	28	000.0	0	09.8	8.7	11.1
Jun	04-10	23	38.9	26.0	63	37	023.4	1	10.0	6.9	10.1
Jun	11-17	24	39.0	25.1	69	36	018.4	1	09.4	8.6	10.9
Jun	18-24	25	35.9	24.2	77	52	062.2	3	08.2	7.0	7.2
Jun-Jul	25-01	26	35.3	25.7	74	51	153.0	1	08.8	5.5	8.0
Jul	02-08	27	38.2	25.7	62	39	023.4	1	08.8	7.9	10.0
Jul	09-15	28	39.7	25.2	69	35	018.4	1	10.6	7.7	10.4
Jul	16-22	29	36.8	24.5	70	43	002.0	1	08.0	7.7	8.4
Jul	23-29	30	34.9	25.5	81	58	213.2	3	08.2	5.3	7.2
Jul-Aug	30-05	31	33.3	26.0	88	67	108.2	4	04.8	5.0	4.9
Aug	06-12	32	32.7	25.8	88	70	116.5	4	05.1	3.8	4.7
Aug	13-19	33	32.0	25.4	89	74	051.2	5	05.2	5.8	4.8
Aug	20-26	34	32.3	24.7	90	66	037.8	2	05.3	2.4	4.1
Aug-Sep	27-02	35	33.8	25.7	86	66	174.6	2	06.1	1.9	4.5
Sep	03-09	36	33.1	25.3	90	72	112.2	2	05.8	2.6	4.0
Sep	10-16	37	33.1	25.7	89	70	007.8	2	05.5	3.5	4.3
Sep	17-23	38	32.1	22.4	88	62	014.2	2	07.0	4.5	3.6
Sep	24-30	39	30.9	23.0	88	65	006.2	1	06.1	1.8	3.6
Oct	01-07	40	30.9	21.3	92	57	000.0	0	07.6	1.9	2.9
Oct	08-14	41	31.9	18.8	88	47	000.0	0	08.6	2.4	3.2
Oct	15-21	42	31.0	18.0	86	50	000.0	0	06.0	1.2	2.7
Oct	22-28	43	29.6	16.2	92	47	000.0	0	06.5	2.2	2.8
Oct-Nov	29-04	44	29.2	17.1	89	57	000.0	0	01.2	2.4	2.0
Nov	05-11	45	29.2	14.0	85	44	000.0	0	06.0	2.7	2.4
Nov	12-18	46	29.0	13.3	91	44	000.0	0	06.6	3.2	2.2
Nov	19-25	47	25.8	11.5	94	47	000.0	0	04.7	1.8	2.1
Nov-Dec	26-02	48	25.6	11.5	92	54	029.2	1	06.3	3.5	2.6
Dec	03-09	49	23.8	8.3	95	47	000.0	0	07.2	1.4	1.9
Dec	10-16	50	27.5	13.1	91	49	029.2	2	05.5	2.4	2.3
Dec	17-23	51	15.4	9.3	95	78	000.0	0	02.1	5.6	1.3
Dec	24-31	52	12.5	5.9	96	75	000.0	0	01.6	3.4	1.1

Weekly weather data 2020

STATION NAME : PANTNAGAR **LONGITUDE : 79 deg. 30' E**
LATITUDE : 29 deg. N **ALTITUDE : 243.84 m. AMSL**

Month	Date	Metro Week No.	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
			Max.	Min.	0712 am	1412 pm					
Jan	01-07	1	20.1	7.5	92	55	008.0	2	05.0	2.1	2.0
Jan	08-14	2	14.5	8.3	95	83	028.2	2	01.2	2.2	1.4
Jan	15-21	3	18.1	9.9	94	76	048.1	2	03.3	1.2	1.6
Jan	22-28	4	17.8	6.8	93	73	000.7	1	04.2	1.8	1.7
Jan-Feb	29-04	5	18.0	6.0	95	64	029.8	2	05.3	2.8	2.7
Feb	05-11	6	20.9	4.0	97	45	000.0	0	08.6	1.7	2.4
Feb	12-18	7	22.9	8.4	94	62	000.0	0	06.9	1.8	2.9
Feb	19-25	8	24.2	11.9	93	57	023.2	2	06.0	3.1	3.0
Feb-Mar	26-04	9	24.6	11.6	92	61	000.0	0	06.1	1.1	2.6
Mar	05-11	10	24.2	11.3	91	58	029.5	3	06.7	3.8	3.7
Mar	12-18	11	25.7	13.7	84	49	015.6	3	07.7	3.5	3.4
Mar	19-25	12	28.5	12.6	86	44	000.0	0	09.8	1.4	3.9
Mar-Apr	26-01	13	29.3	15.1	88	38	001.0	1	08.0	4.8	4.7
Apr	02-08	14	32.4	13.1	80	26	000.0	0	10.2	2.5	6.2
Apr	09-15	15	34.9	15.9	71	25	000.0	0	09.7	2.3	6.6
Apr	16-22	16	35.4	20.1	58	30	000.0	0	06.0	2.6	6.8
Apr	23-29	17	32.0	18.3	64	44	070.8	1	07.2	3.9	5.5
Apr-May	30-06	18	31.6	20.9	73	48	004.5	2	08.5	3.5	5.6
May	07-13	19	32.3	19.5	69	47	053.8	3	09.6	3.4	6.2

CURRICULUM VITAE

Name	**:**	Chenesh Patel	**Phone Number**	**:**	7017514161
Mailing Address	**:**	D-199 Yadunandan Nagar Tifra Bilaspur Chhattisgarh 495223	**Permanent Address**	**:**	Same as mailing address
E-mail	**:**	cheneshpatel28@gmail.com			
Career objectives	**:**	To keep working in research field and make useful contributions towards the society.			

Educational Qualification

Sr. No.	Examination Passed	Institution	Year	Percentage/ CGPA
1.	M.Sc. (Entomology)	GBPUA&T, Pantnagar	2016	8.51
2.	B.Sc. (Ag.)	IGKVV, Raipur	2014	7.83
3.	Intermediate	Bharat Mata Higher Secondary School, Bilaspur	2007	80.20%
4.	High School	Bharat Mata Higher Secondary School, Bilaspur	2005	76.50%

Specialization: **Major:** Entomology **Minor:** Plant Pathology

Thesis Title: "Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region"

Publication: 04

Conference/Seminars/Workshops/Training Attended: Online Workshop on Data analysis and Statistical Computing through SPSS and R software.

List of papers presented in conference/seminar during degree programme: 02

Software Skills: SPSS, R Software.

Professional Skills: MS Excel, MS Office, BioEdit, Clustal W and MEGA 7.

Professional Affiliations (Membership, etc.,): Life Time Membership of Society for Plant Biochemistry and Biotechnology

Awards/Honours/Achievements: DST Inspire

Place: Pantnagar
Date: March, 2021

Patel.
(Chenesh Patel)
Author

Name	:	Chenesh Patel	**I.D. No.**	:	48090
Sem.& year	:	1st semester, 2016-17	**Degree**	:	Ph.D.
Major	:	Entomology	**Deptt.**	:	Entomology
Minor	:	Plant Pathology			
Thesis Title	:	**Biological and Phylogenetical studies of Whiteflies from North-Western Himalayan Region**			
No. of pages	:	127	**Advisor**	:	Dr. R. M. Srivastava

ABSTRACT

An integrated approach was carried out to explore the diversity of reproductive host plant, along with the seasonal incidence, host preference and biotic potential, taxonomic identification using molecular and morphological tools and use of essential oils for the management of whiteflies in Uttarakhand Himalayan region. Extensive surveys were conducted in 45 locations of 4 district of Uttarakhand during 2017-2019 to record the potential reproductive host associated with *Bemisia tabaci* and *Trialeurodes vaporariorum* and total 118 host plant species belonging to 49 families were documented. Host plants belonging to family Asteraceae, Fabaceae, Solanaceae, Cucurbitaceae, were found as most preferred host plant by both *B. tabaci* and *T. vaporariorum*. Whitefly (*B. tabaci*) was present on brinjal and tomato throughout the cropping season at Vegetable Research Centre, Pantnagar during 2017-2019 and its peak activity was observed on last week of December in both the crops. Whitefly population had significantly negative correlation with maximum temperature ($r= -0.50^{**}$ and $r= -0.53^{**}$), minimum temperature ($r= -0.61^{**}$ and $r= -0.57^{**}$) and evaporation ($r= -0.64^{**}$ and $r= -0.66^{**}$) while non significant correlation was observed with sunshine hours in both the years on tomato and brinjal plants. The feeding and oviposition preference and biotic potential studies proved that among all brinjal was the most preferred host for feeding and oviposition followed by tomato and cabbage for *B. tabaci* and *T. vaporariorum* while the least preferred host recorded was bottle gourd and chilli for *B. tabaci* and *T. vaporariorum* respectively. Similarly, the preimaginal developmental period of immature stages of *B. tabaci* and *T. vaporariorum* was faster on brinjal (19.40 days and 21.57 days) than on tomato (22.40 days and 24.03 days). The survival rate was also maximum in brinjal plants for both the species as compared to tomato. The comparative morphological studies of life stages of *B. tabaci* and *T. vaporariorum* showed distinct differences in morphological features such as the no. of marginal setae, vasiform orifice, ligula, antennae and eyes. Morphological and morphometric features of both whitefly species were imaged and illustrated in detail for correct field level identification. The molecular diversity of *B. tabaci* and *T. vaporariorum* using mt COI markers followed by sequencing revealed the preponderance of genetic diversity in whitefly species. In case of *B. tabaci*, five different types of biotypes were found *i.e*., Asia II-1, Asia I, Asia II-5, MEAM 1 and Uganda. In case of *T. vaporariorum* the obtained phylogenetic tree revealed that there was no variation in the collected samples. Various plant essential oils were tested for repellency and ovipositional deterrent effect against *B. tabaci*. Among all the essential oils, mint oil showed maximum repellency and ovipositional deterrence, followed by tulsi and citronella oil while, significantly low repellency and ovipositional deterrent effect was recorded in lemongrass oil.

(R. M. Srivastava)
Advisor

(Chenesh Patel)
Author

नाम	:	चैनेश पटेल	परिचायक सं0	:	48090
सत्र एवं प्रवेश का वर्ष	:	प्रथम, 2016–17	उपाधि	:	परास्नातकोत्तर (कृषि)
मुख्य	:	कीट विज्ञान	विभाग	:	कीट विज्ञान
शोधग्रन्थ	:	''उत्तर पश्चिमी हिमालय क्षेत्र से सफेद मक्खी का जैविक एवं वंशावलिक अध्ययन''			
पृष्ठ संख्या	:	127	सलाहकार	:	डा0 आर0 एम0 श्रीवास्तव

सारांश

इस शोध में सफेद मक्खी के प्रबन्धन के लिए एकीकृत कीट प्रबन्धन प्रणाली अपनायी गई जिसके अन्तर्गत मेजबान पादप की पहचान और उसकी विविधता, मौसमीय हमले की घटनायें, मेजबान वरीयता, आण्विक एंव रूपात्मक विशेषताओं से जैविक क्षमता की पहचान एंव पादप जनित आवश्यक तेलों का प्रयोग किया गया। वर्ष 2017 से 2019 तक बेमीसिया तबाकी एंव ट्राईएलुरोड्स वेपोरेरियम से जुड़े संभावित प्रजनन मेजबानो पादपों की पहचान के लिए उत्तराखण्ड के विभिन्न जिलों में 45 स्थानों पर व्यापक सर्वेक्षण किया गया जिसके फलस्वरूप 49 पादप कुलों से सम्बन्धित 118 पादप प्रजातियों को दर्ज किया गया। इन सर्वेक्षणों में पाया गया कि बेमीसिया तबाकी एंव ट्राइएलुरोड्स ने मेजबान कुलो में ऐस्टेसी, फैबेसी, सोलेनेसी एंव कुकुरबिटेसी को महत्व दिया। वर्ष 2017 से 2019 तक सब्जी अनुसंधान केन्द्र पन्तनगर मे बैंगन एंव टमाटर के सम्पूर्ण फसल जीवन चक्र के दौरान बेमीसिया तबाकी की उपस्थिति दर्ज की गई और दिसम्बर के आखिरी सप्ताह में इनकी गतिविधि चरम पर दर्ज की गई। दोनों वर्षों में टमाटर एंव बैगन के पौधों पर, सफेद मक्खी की जनसंख्या पर अधिकतम तापमान ($r = -0.50$ और $r = -0.53$) न्यूनतम तापमान ($r = -0.61$ और $r = -0.57$) व वाष्पीकरण का नकारात्मक सहसम्बन्ध तथा सूर्यप्रकाश का महत्वहीन सम्बन्ध देखा गया। भक्षण व अण्डवहन वरीयता और जैविक क्षमताओं के अध्ययनों से साबित किया कि अन्य मेजबानों की तुलना में व्हाइट फ्लाई ने क्रमशः बैगन, टमाटर और गोभी को सर्वाधिक तथा मिर्च एंव लौकी को कम महत्व दिया। इसी प्रकार से सफेद मक्खी की प्रारम्भिक परिपक्वता बैगन में (19.40 दिन और 21.57 दिन) अधिक थी। सफेद मक्खी की दो प्रजातियों बेमीसिया तबाकी एवं ट्राईएलुरोड्स वेपोरेरियम के विभिन्न जीवन चरणों का तुलनात्मक अध्ययन किया गया। प्रजातियों की तुलनात्मक विशेषताओं जैसे परिधीय सीटी, वैसीफार्म छिद्र, लिगुला, ऐन्टीना और आँखों का वृहत अध्ययन किया गया। दोनों प्रजातियों के आकारकीय मापन द्वारा क्षेत्र स्तर पर सही पहचान के लिये इन्हे विस्तरित रूप से चित्रित किया गया।

बेमीसिया तबाकी एंव ट्राइएलुरोड्स में COI मार्कर और अनुक्रमण से देखा गया कि आण्विक विविधता, आनुवंशिक विविधता से प्रधान हैं । बेमीसिया तबाकी में पॉच प्रकार के बायोटाइप एशिया II-1, एशिया I, एशिया II-5, मियाम 1 और युगान्डा देखे गए और ट्राइएलुरोड्स में कोई विभिन्नता नही देखी गई। विभिन्न पादप जनित तेलों से प्रतिकर्षण एंव अण्डा निवारक परीक्षण किया गया। विभिन्न पादप जनित तेल जैसे सिट्रोनेला, तुलसी व पुदीना तेल से बेमीसिया तबाकी में प्रतिकर्षण तथा अण्डे देने में कमी दर्ज की गई।

(आर0 एम0 श्रीवास्तव)
सलाहकार

(चैनेश पटेल)
शोधकर्ता