STUDIES ON BIOECOLOGY OF HADDA BEETLE, *HENOSEPILACHNA VIGINTIOCTOPUNCTATA* F. AND NON-CHEMICAL MEANS OF ITS MANAGEMENT IN BRINJAL

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By

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Dedicated
To my Sister
(Late) Nahid Qamar

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Certificate

This is to certify that the work embodied in this dissertation entitled ***"Studies on bioecology of hadda beetle, Henosepilachna vigintioctopunctata F. and non-chemical means of its management in brinjal"*** *submitted in partial fulfillment of the requirement for the degree of Master of Philosophy (Ag.) Plant Protection (Entomology) carried out by* ***Ms. Muntaha Qamar*** *under my supervision is the original work. This work has not been submitted either partially or fully to this or other University/Institute for the award of any other degree/diploma. The candidate has fulfilled the prescribed conditions given in the ordinance and regulations of Aligarh Muslim University, Aligarh, (U.P.) India.*

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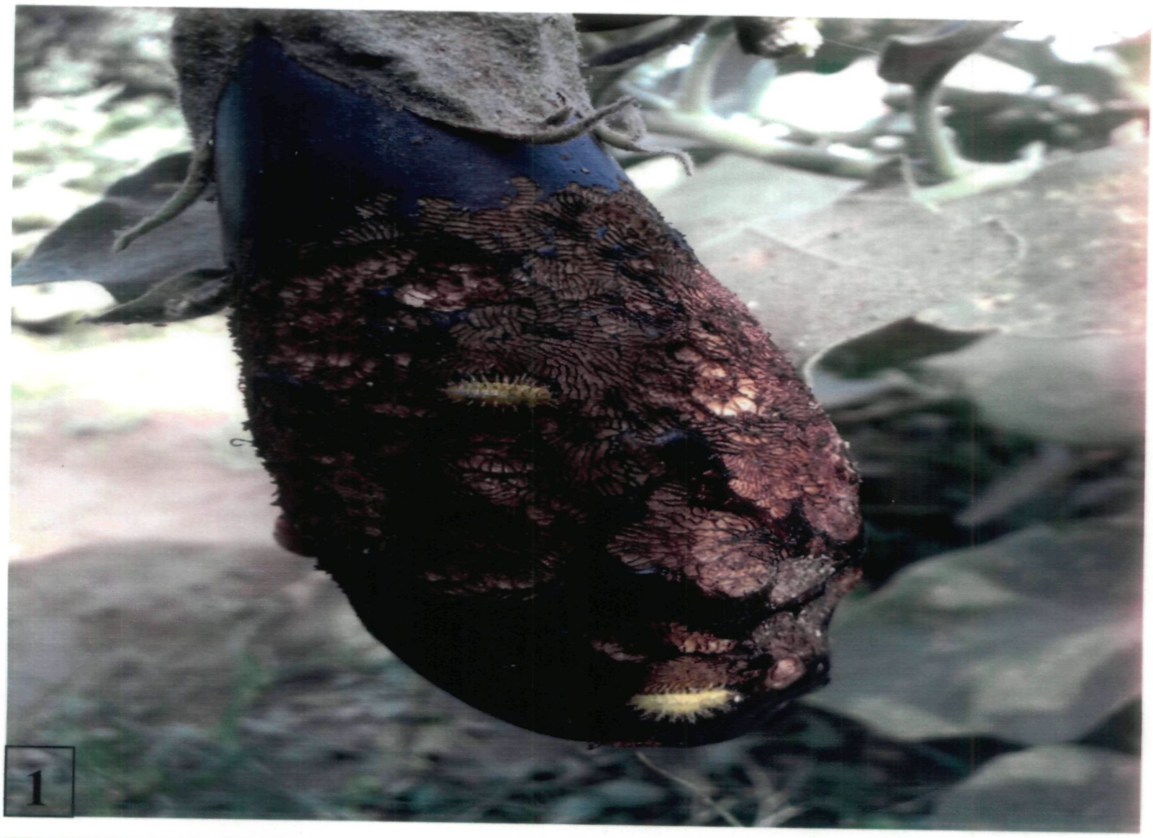

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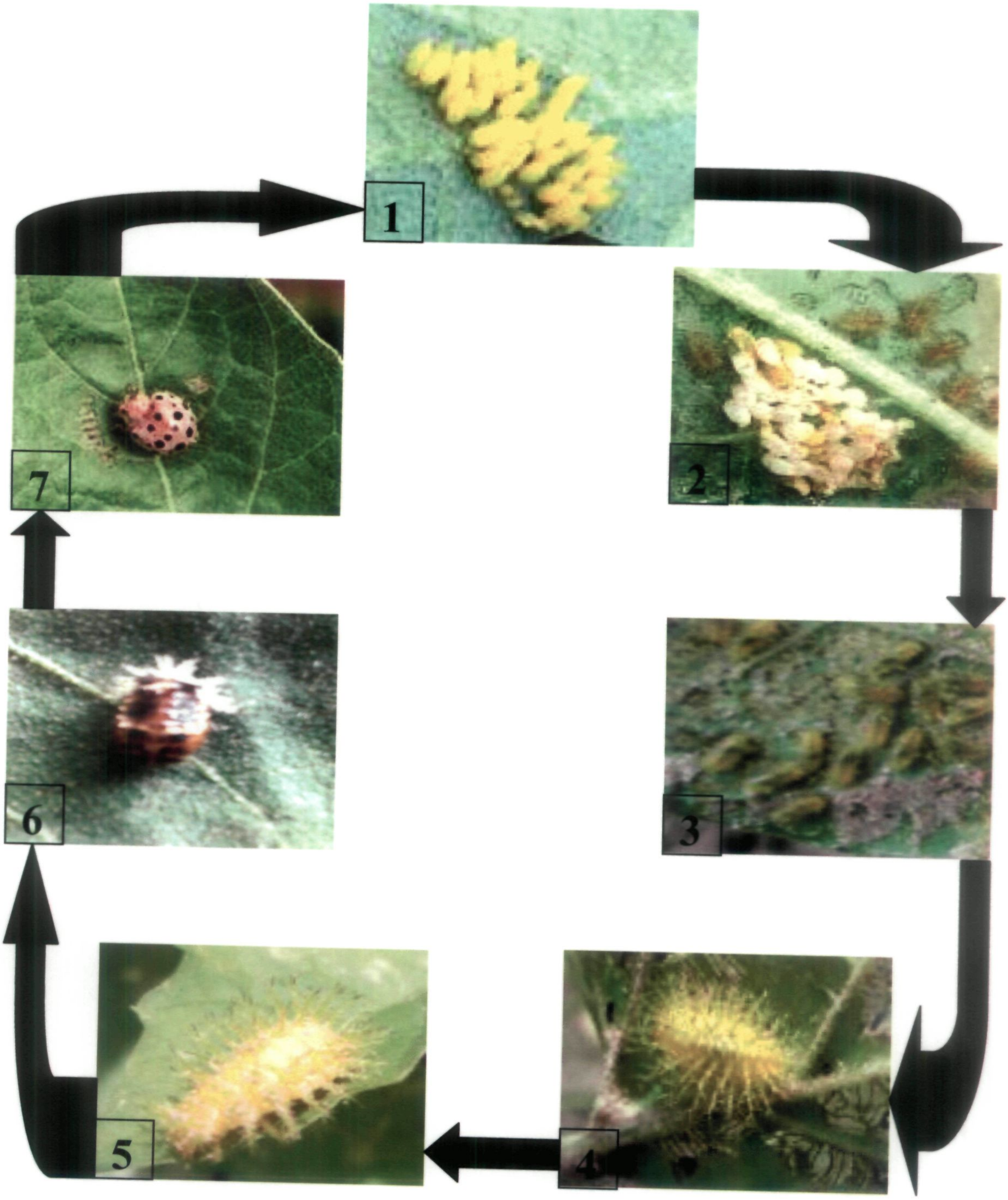

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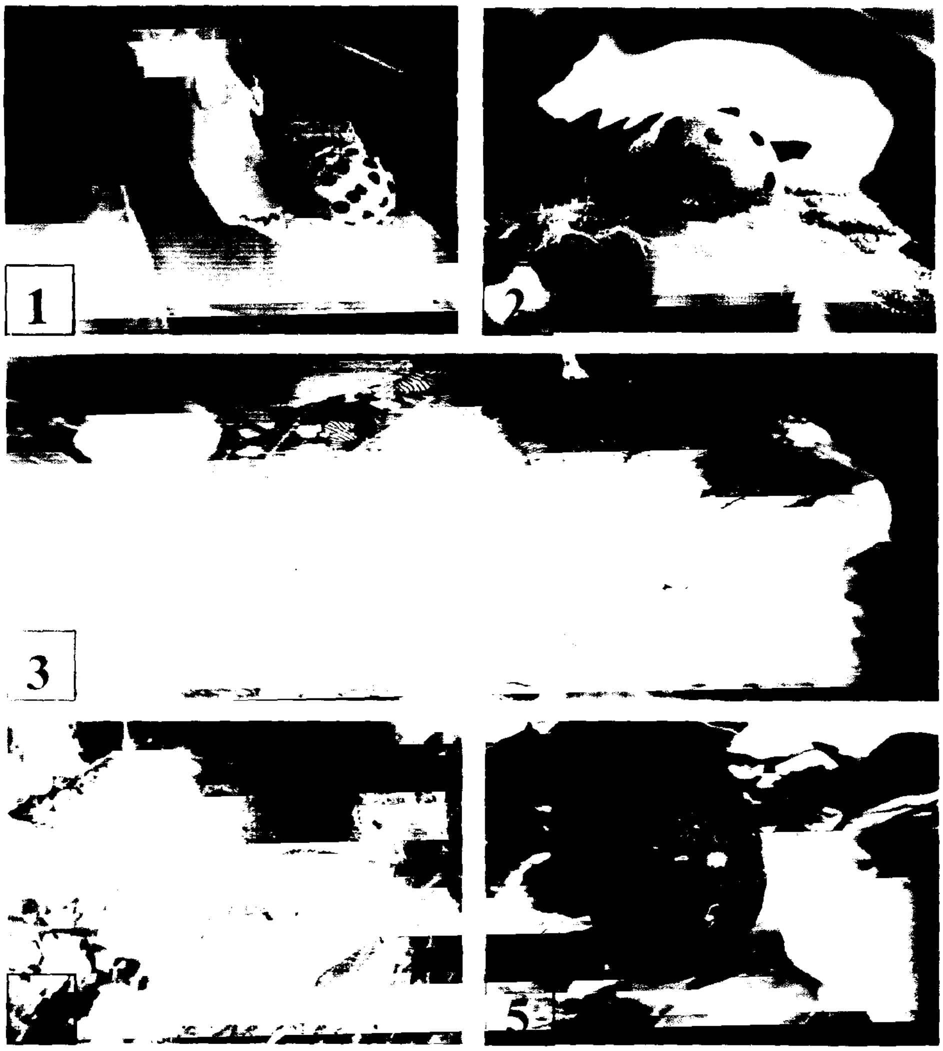

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CHAPTER-1
INTRODUCTION

India is the second largest producer of vegetables (ICC, 2011) with an annual production of 133.5 million tonnes in 2010 (http://developmentchannel.org) from 4.5 million ha of land (Sharma, 2011). Brinjal is by far the major vegetable representing some 41% by weight of all vegetables produced, occupying 19% of the land used to cultivate them. More than 4 million acres (2,043,788 hectares) are devoted to the cultivation of brinjal in the world with total production of 32, 072, 972 tonnes while, in India alone over 500,000 ha of brinjal is cultivated per annum with production of 10, 164, 700 tonnes. (NHB. 2010).

Brinjal, *Solanum melongena* L., is said to be native of India (Thompson and Kelly, 1957) with secondary centre as China (Zeven and Zhukovsky, 1975) and extensively grown in South East Asia. It is still found growing wild in India (Purewal, 1957). The name brinjal is popular in Indian subcontinents and is derived from Arabic and Sanskrit whereas the name eggplant has been derived from the shape of the fruit of some varieties, which are white and resemble in shape to chicken eggs. It is also called aubergine (French word) in Europe. It is one of the most popular and economically important vegetables among small scale farmers and low income consumers of South Asia, especially during hot-wet summers when other vegetables are in short supply. In India, it is highly cosmopolitan and principal vegetable grown as poor man's crop. It is a versatile vegetable crop adapted to different agro-climatic regions and can be grown throughout the year. It is a perennial but grown commercially as an annual crop.

Brinjal occupies an important position in every day diet due to its high nutritive, dietary and medicinal values as 100 grams of edible fruits contains 92.7 g water, 1.3 g carbohydrates, 1.4 g protein, 0.3 g fat and 0.3 g mineral matter and 4 g calcium

(Varmudy, 2011). It is low in calories and fats. It is a good source of Vitamin A, B, C and also rich in minerals like iron, phosphorous and calcium (Chandrakumar *et. al.*, 2008). It is used as a part of dietary solution to combat the early stage of type 2-diabetes. It is an appetizer, increases virility and is light, protect arteries from cholesterol damage and it cures flatulation, enlarged spleen due to malaria and employed as a cure for toothache. It contains chemicals that prevent convulsions and cancer in animals. It's green leaves are the main source of antiscorbutic vitamin C (Nadakarni, 1927). It's seed are used as a stimulant and the leaves as a narcotic but they are apt to lead to dyspepsia and constipation. It has also been recommended as an excellent remedy for those suffering from liver complaints (Shukla and Naik, 1993).

Pests are major biotic constraints to achieve self sufficeiency in quality food production. The yield losses in production of various crops after Green Revolution are manifold due to the increased complexities of pests resulting from the change in cropping patterns, intensive cultivation, higher use of fertilizers and climate changes etc. Among these, insect pests play a key role in inflicting damage to various agricultural crops resulting in appreciable losses. Total crop losses due to insect pests have been estimated to the extent of 23% (Agarwal, 2011). The extent of crop losses in vegetables varies with plant type, location, damage potential of the pest involved and cropping seasons. Vegetables are prone to insect pests and diseases due to their succulence as compare to other crops. The crop losses to the tune of 40% have been observed in vegetable crops.

Although, brinjal being one of the chief vegetable crop grown in our country, it suffers economic losses due to infestation of various pests. About 53 species of insect pests severely damage to this crop from seedling to fruiting stage affecting its growth and yield (Nayar *et. al.*, 1995). Brinjal fruit and shoot borer, *Leucinodes orbonalis* Guenee, brinjal stem borer, *Euzophera particella* Rag., brinjal lace-wing bug, *Urentius sentis*, hadda beetle, *Henosepilachna vigintioctopunctata* Fab., and *H. doecastigma* Wiedman are the insect pests occurring regularly in brinjal crop. Among these insect pests of brinjal crop. Epilachna beetle (Coleoptera: Coccinellidae) occupy a major status as a pest in South East Asia. Species of this genus exclusively feed on the leaves of plants belonging to the families Solanacae and Cucurbitacae (Rahman *et al.*, 2009). Few species attack plants of other families (Yoshihisa *et al.*, 2000). Devastating attacks by species of Epilachna have been reported from South and East Asia, Bangladesh (Austin, 1925), China (Dieke, 1947), India, Japan (Ohgushi, 1986; Fujiyama *et al.*, 2003), Pakistan (Ashrafi, 1966), Sumatra (Den'doop, 1919), Australia (Richards, 1983), East Indies (Hossain *et al.*, 2008) and United States (Dieke, 1947).

Two species of epilachna beetle *viz.*, *Henosepilachna vigintioctopunctata* (Fab.) and *H. dodecastigma* (Wied.) is fairly common and serious pests of vegetable crops (Khan *et al.*, 2000) having a wide host range. They are found to cause extensive damage to solanaceous (*e.g.*, brinjal, tobacco, tomato, potato *etc.*,) and cucurbitaceous (*e.g.*, gourds, melon, cucumber *etc.*,) plants in India (Krishnamurti and Apanna, 1951; Puttarudriah and Krishnamurti, 1954; Sengupta and Panda, 1959; Mandal, 1971; Mohandsundaram and Uthamaswamy, 1973; Azam *et al.*, 1974; Haseeb *et al.*, 2009). The pest also attack wild species *Amaranthus caudatus* L. (Hameed and Adlakha, 1973) and some medicinal plants such as *Physalis* spp. (Mohandsundaram and Uthamaswamy, 1973), *Datura* sp., *Solanum* spp. and *Withania somnifera* Dunal (Mathur and Srivastava, 1964; Venkatesha, 2006) in India.

It is one of the major pests of brinjal crop; both adult beetles and grubs are injurious and feed on the epidermal tissues of the leaves by scrapping. Sometimes it is called a leaf scrapping coccinellid beetle (Immura and Ninomiya, 1998). They eat up regular areas of the leaf tissue, leaving parallel bands of uneaten tissue in between. The leaves, thus, present a lace like appearance (Atwal and Dhaliwal, 1976). Consequently the plants may completely dry up due to extensive infestation by the growing population. As a result, growth and development of the plants are greatly hampered and their yield is markedly reduced (Alam, 1969).

The nature of damage by the larvae is some what distinct from that of adults. The grubs confine their attack to the lower surface of the leaves and adults usually feed on upper surface of the leaves (Prodhan *et al.*, 1990). The third and fourth instar grubs are more destructive and voracious (Hossain *et al.*, 2008). Epilachna beetles feed actively in the morning and evening hours and feeding declines rapidly in the middle of the day and after midnight (Tilavov, 1981).

Rajgopal and Trivedi (1989) reported that epilachna beetle may damage up to 80% of plants depending on place and season with variations of prevailing environmental conditions. Bhagat and Munshi (1997) reported 80% loss in yield due to this pest. Bhalla and Pawar (1977) also observed this beetle to cause up to 65% loss in vegetative stage of brinjal. Rai *et al.*, (1975) and Sinha and Sahini (1978) have reported that grubs and adults feed on fruits of brinjal causing characteristic injury. In severe cases even calyx of the fruit may also be infested. The increasing pest status of *H. vigintioctopunctata* and its abundance in brinjal fields has raised a number of questions regarding the factors responsible for its population development under natural conditions.

Pest-population studies are helpful in pinpointing the factors that bring about numerical changes in the natural population and also in understanding the functioning of the life system of the past species. Pest-populations are governed by their innate capacity to increase and influenced by various abiotic and biotic factors. Among the abiotic factors, it is primarily the physical components such as temperature, moisture, and light that have a direct influence on pest populations. Such factors also influence pest populations indirectly by modifying the biotic factors. The biotic factors include food and other populations, primarily the natural enemies of pests. Environmental variability and unpredictable resources are of paramount importance in insect population dynamics (Wilbur *et al.*, 1974; Southwood *et al.*, 1974; Roff, 1974; Levin, 1976; Southwood, 1977; May, 1979; Hassell, 1980). The role of temperature, relative humidity on life studies is important to assess pest status and its natural enemies. Some authors have emphasized the role of abiotic and biotic factors in the abundance of organisms in a biotic community, and calculated in the form of life table thereby focusing their population dynamics (Huffaker, 1971 and Varley *et al.*, 1973).

Life table is one of the conceptual and analytical tools of ecological study which is used to generate simple yet more informative statistics that provides the most comprehensive data on description of the survival, development, reproduction (Kivan and Kilic, 2006), mortality and mortality factors of an organism (Morris and Miller, 1954; Harcourt, 1969) under natural conditions. Multiple sets of life table data can be analyzed to identify key mortality factors or critical stages or periods, which can increase understanding of the dynamics of an insect population and at the same time, reveal the most appropriate period of management (Harcourt, 1969; Southwood, 1978).

The interaction between pest activity and abiotic factors helps in deriving at predictive models that aids in forecast of pest incidence. The pest incidence and damage varied from place to place and from year to year due to variation in prevailing environmental conditions. Hence, a continuous monitoring of all important pests and their natural enemies under field conditions is essential for timely prevention of sudden outbreaks of epidemics and for devising the suitable pest management strategies (Haseeb *et al.*, 2009).

Brinjal assumes a special significance among vegetables, as it gives better return over investment to the farmers. Under sustainable farming, brinjal provides regular daily income to meet the day-to-day expenditure like wages for the labour, service charges for the machinery etc. Vegetable growers by and large depend on chemical pesticides to counter the problem of insect pests. It is one of the most consumed and most sprayed vegetables in India. Chemical control is widely used means of managing insect pests in brinjal. Indiscriminate use of pesticides has led to severe ecological consequences like, destruction of natural enemy fauna, effect on non target organisms, residues in consumable products including packed pure and mineral water and ultimately development of resistance in insect pests to the pesticides, to which we solely rely (Dadmal *et al.*, 2004).

These limitations in synthetic insecticides have been the impetus for the scientists to search for alternate techniques for the management of insect pests (Abudulai *et al.*, 2001; Isman, 1995). The higher degree of persistency of insecticides and toxic substances (pesticides) in consumable plant parts renders pest management in brinjal more sensitive and challenging. Because of these limitations, in recent years there has been considerable pressure on consumers and farmers to reduce or eliminate synthetic pesticides in agriculture. This concern has encouraged researches to look for safe, effective and economical alternatives to synthetic pesticides, to overcome these health hazards and environmental problems in the cultivation of brinjal.

Selection of crop variety has always been a number one priority in crop protection, especially in developing disease and pest resistant varieties. Management practice involving plant varieties resistant to insect pests are an important approach along these times. Insect resistance in crop plants is an important component of IPM and it is considered as non-monetary input at farmers end. It contributes helpfully in two ways:

reduces the quantum of insecticides and improves performance of natural enemies in plants. Even a low level of tolerance in plants has dramatic effect, which in fact reduces the need of insecticides (Srivastava, 1993). Hence, to combat with this notorious beetle, utilization of plant resistance could be a meaningful tactic. Screening of brinjal cultivars against insect pests has been attempted by several workers elsewhere in India. However, the cultivars available in particular region need to be screened and efforts to be made to determine the biochemical basis of resistance in selected brinjal entries against Epilachna beetle.

Besides, host plant resistance use of organic sources of nutrients (FYM, Poultry manure, oil cakes), is emerging as a new viable option (Suresh *et al.*, 2008). The inorganic fertilizers provide the nutrients in appreciable quantities for a shorter period to the plants. Thereby the plants are endowed with luxuriant growth which offers adequate food to the insects leading to heavy insect population build up. The organic manures act as a slow release fertilizer providing balanced nutrition to the plants and ensure balanced growth, thereby making them less prone to pest incidence. Induced resistance is the qualitative and quantitative enhancement of plants defence mechanisms which is non heritable resistance where host plants are induced to impart resistance to tide over pest infestation (Heinrichs, 1988; Dilawari and Dhaliwal, 1993; Panda and Khush, 1995). Through the addition of organic sources of nutrients and amendments the production of defensive chemicals in plant increases. So, organic farming provides an eco-technological stability in pest management and is a vital component of sustainable agriculture. The integration of organic nutrients can play a vital role in creating unfavourable environment to the herbivores by the mechanism of induced resistance either by antibiosis or antixenosis. The application of organic matter in soil for crop improvement by farmers have been practiced since the advent of agriculture, but beneficial effects of organic amendments against this beetle became known recently (Chandrakumar, *et al.*, 2008).

Another alternative is the use of botanicals, which would minimize adverse effects of synthetic insecticides and for which there is a growing interest among the entomologists the world over. For the past 30 years, many studies on plant extracts against insect larvae have been conducted around the world in an effort to develop alternatives to conventional insecticides but with reduced health and environmental impacts (Jacobson, 1989; Chandel *et al.*, 2009). Plant derived pesticides were the earliest recorded insecticides used in farming (Mc Laughlin, 1973; Whitehead and Bowers, 1983). A number of botanical insecticides like pyrethrin, rotenoids, nicotine, natural isobulaholamides, quiassia, sabadilla, hellebore and ryania enjoy extensive use in pest management (Alkofahi *et al.*, 1989). Grainge *et al.*, (1985) provided an extensive list of plants with pest control properties and reported that 384 species have antifeedant activity, 297 species have insect repelling activity and 31 species have growth inhibiting properties. Indeed prior to the development and commercial success of synthetic insecticides beginning in the 1940s, botanicals were major weapons in the farmer's arsenal against crop pests and have been widely used in the management of agricultural pest (Choudhary *et al.*, 2010). The search for compounds of plant origin is currently a topic of scaring discussion after a number of environmental related issues raised due to indiscriminate use of synthetic toxic pesticides.

Some developed and developing countries have started taking interest in the plant chemicals to use them as pesticides. Among botanicals, neem has become a centre of interest for the scientific community all over the world during the last two decades. The interest in Neem in the developed world is attributed to the diverse modes of action of neem based pest control products. A number of neem products are ovicidal, larvicidal and when topically applied on adults, cause death, while other cause morphogenetic abnormalities on adults. These neem products are not only effective against pests but also inherently safer, less persistent in the environment and less prone to the problem of pest résistance than the synthetic insecticides. Today, the technical grade neem active ingredient principally Azardirachtins fetch the highest price with the continued robust growth of the global biopesticide market, Azardirachtin is uniquely positioned to become a key insecticide. The consumption of neem based bio-products has raised from 83 metric tonnes in 1994-95 to 1235 metric tonnes in 2008-09 in India (Agarwal, 2011).

Though subtle, effects of neem, such as repellence, feeding and oviposition deterrence, growth inhibition, mating disruption, chemosterilization *etc.*, are now being considered far more desirable than quick knock down in IPM programme as they reduce the risk of exposing pest's natural enemies to poisoned food or starvation (Swaminathan *et al.*, 2010).

Brinjal is one of the important vegetable crops grown in Western Uttar Pradesh including Aligarh and surrounding areas. This crop is grown in small plots and as intercrops both for cash and domestic consumptions by the farmers. However, farmers of this region are facing challenges from ravages caused by insect pests leading to colossal losses to this crop affecting its productivity, as experienced in the recent past (Sharma, 2009). This polyphagous beetle (Epilachna) has acquired major status in brinjal cultivation in this region, inflincting damage from seedling to fruiting stage. This necessitates knowing the population buildup of this pest in relation to biotic and abiotic factors to have an insight into its population dynamics which vary from region to region and from place to place. Studies on this aspect will therefore be helpful in fore-casting and decision making for sustainable management of this insect pest in Aligarh conditions.

Besides, work on non-chemical means of management *i.e.*, screening of various brinjal cultivars, use of biopesticides and evaluation of nutrient organic sources, *etc.*, may provide alternative solutions to chemical application for management of this pest thereby increasing the income of farmers and saving the environment for future generations of man and his animals.

Keeping in view the above facts present studies were undertaken for with the following objectives:

1. To study the population dynamics of *Henosepilachna* spp. on brinjal
   a) To study the population fliuctuation of *H. vigintioctopunctata* and *H. dodecastigma*
   b) To study the seasonal incidence of parasitoids of *H. vigintioctopunctata*
   c) To study the seasonal abundance of *H. vigintioctopunctata* on six cultivars of brinjal
2. To study the effect of solanaceous and cucurbitaceous hosts on life table and development of *H. vigintioctopunctata* in laboratory conditions.
   a) To study the effect of solanaceous and cucurbitaceous hosts on life-table of *H vigintioctopunctata*
      a. Age specific life-table
      b. Stage specific life-table
      c. Female fertility table
   b) To study the effect of solanaceous and cucurbitaceous hosts on development of *H. vigintioctopunctata*
3. To study the differential responses of brinjal cultivars/accessions against *H. vigintioctopunctata* in field conditions.

4. To evaluate certain organic amendments against *H. vigintioctopunctata* on brinjal in field conditions.
5. To study the bio-efficacy of some botanicals against *H. vigintioctopunctata* on brinjal in semi-field conditions.

CHAPTER-2
REVIEW OF LITERATURE

The numerous research papers published so far and a number of excellent review articles appeared from time to time on diverse aspects related to the studies undertaken have been reviewed and presented below in different heads:

Population dynamics

The population dynamics, in general, is a numerical change in size, structure, age composition, reproductive behavior and growth of individuals, in a population of living organisms (Huffaker and Messenger, 1964).

Ali and Saeady (1986, a) surveyed the numbers of eggs, larvae, pupae and adults of *Epilachna chrysomelina* Fab. on cucurbit crops in Egypt at 15-day intervals from May until the end of November 1977 and observed that the hibernating adults resumed activity at the end of April and there were 3 generations which peaked in mid-July and on 1 September and 16 October. Larvae developing in August and September gave rise to adults which entered hibernation at the end of November.

Tripathi and Misra (1991) studied the population abundance of *Henosepilachna dodecastigma* in Uttar Pradesh, India and found that populations of beetles in fields of *Luffa cylindrica* (L.) increased in the 1st and 2nd generation and declined in the 3rd and 4th generations.

Sawada and Ohgushi (1994) conducted studies on population dynamics of epilachna beetle from 1975-1981 and reported that over wintering adults emerged from hibernation around early April, reaching peak numbers in late April to early May, then gradually declined in late June. New adults began to emerge in late June and quickly reached a peak in early July, thereafter decreasing in number and entering hibernation by late October.

Beyene *et al.*, (2009) conducted the field studies on the phenology of *Epilachna similis* (Thunberg), from 2003 to 2005 along two selected rivers and from 2004-2005 in two agricultural fields. Abundance of the insect was observed in barley fields every week and fortnightly along the rivers using 0.25 m^2 quadrates and insect sweep nets, respectively. They observed the adult diapause during the dry period along rivers, which terminated around mid-January, with increased feeding and initiation of mating. The adults then migrated to agricultural fields between March and April. This may be delayed because of the reduced cumulative rainfall in January and February. Termination of diapause and adult migration was found to be influenced by rainfall. The adults from the second generation migrated to rivers between September and October as they required moisture to over winter during the dry period of the year, while the majority of the first generation adults remained in the agricultural fields. The ovipositional, larval and pupal periods of both generations were recorded. Observations indicated that the duration of the developmental stages of the first generation were longer than in the second.

Seasonal abundance

This pest has been noticed since many decades in different parts of the country but pest incidence and damage varied from place to place and from year to year due to variations in the prevailing environment (Amitava and Mohasin, 2002). Suresh *et al.*, (1996) recorded the initial occurrence of epilachna beetle in the middle of May (1994-95) in Manipur while, in April, in West Bengal (Ghosh and Senapati, 2001, a) on brinjal. The epilachna beetle, *Henosepilachna vigintioctopunctata* was initially observed on the second week of October (1998-99), and on third week of November 1999/2000 on brinjal in Jorhat, Assam (Shaw *et al.*, 2004) while, it was first noticed during last week of

February, 2006 in Udaipur, Rajasthan (Suman and Swaminathan, 2007) and in third and fourth weeks of December, 2005 in Banglore (Chandrakumar *et al.*, 2008) in brinjal. Varma and Anandhi (2008), recorded the initial incidence of epilachna beetle on third week of January (2004-05) and on first week of November (2005-06) in Madhya Pradesh while, it was first appeared on third week of February 2006 in Bapatla, Andhra Pradesh (Naik *et al.*, 2008) on brinjal. Haseeb *et al.*, (2009), reported that initial incidence of the *H. vigintioctopunctata* was noticed on third week of January, 2009 in Aligarh, Uttar Pradesh. Period of infestation of *H. vigintioctopunctata* varies with region, but the peak is generally in July- August (Rajagopal and Trivedi, 1989).

Amitava and Mohasin (2002) conducted field trials during the rabi seasons of 1990-99 to determine the incidence of *Henosepilachna vigintioctopunctata* infesting potato cv. Kufri Jyota at Memari, Kalyani, Kalna and Boinchee in West Bengal, India and found that the incidence of epilachna beetle was highest in Memari and lowest in Boinchee. Foliar damage caused by the beetle was highest in Kalyani and lowest in Kalna.

Venkatesha (2006) noticed the outbreak of *Henosepilachna vigintioctopunctata* on a medicinal plant, *Withania somnifera*, in Bangalore (Karnataka, India) during 2004-05 and monitored that the population level of the pest reached its peak in August.

Haseeb *et al.*, (2009) studied the seasonal incidence of *Henosepilachna vigintioctopunctata* on brinjal in Aligarh in rabi season and noticed that the beetle population reached the peak in the third week of February thereafter; decreasing trend in population was observed from Feb. to April 2009. While, peak activity of this pest was recorded in the first week of August in Manipur (Suresh *et al.*, 1996).

Effect of abiotic factors on population abundance

Many factors both biological and environmental can influence the distribution and demography of hadda beetle population directly or indirectly, survival and development of the different life stages and fecundity of the females. The most important factor appears to be temperature, moisture, and availability of host, natural enemies and competition. Temperature and relative humidity may directly affect insect herbivores through the regulation of desication regimes and metabolic rates (Andrewartha & Birch, 1954).

The change in epilachna beetle population was found to be erratic when the minimum temperature was beyond 25°C. The population increment with increasing temperature beyond 25°C was consistent as compared to below 25°C (Jha, 2008). The rate of development decreased when the temperature was >32°C; the life cycle was not completed when the temperature was <22°C (Chen *et al.*, 1989). A temperature of 25 ^{0}C ± 1^{0}C combined with 14 hrs photo-phase proved to be the most favorable for the development of hadda beetle (Ali and Saeedy, 1980). The findings presented relate well to activity of the epilachna in the field in north-eastern Uttar Pradesh, India, where populations were high in the period from late July to late October and low in December and January (Tripathi and Misra, 1991).

Grewal (1988) studied the seasonal fluctuation of the coccinellid *Henosepilachna vigintioctopunctata* in Punjab, India, on brinjal and reported that temperature and RH affected numbers of the coccinellid although the availability of food was also an important factor determining numbers. High temperature and low RH had an adverse effect on egg hatchability, the viability of newly hatched larvae and fecundity; however, mature larvae and adults were only moderately affected.

Richards and Filewood (1993) studied the influence of seasonal variation on instar growth in *Epilachna cucurbitae* Richards, *E. vigintisexpunctata* and *E. vigintioctopunctata*. Natural day length of 9.9-14.5 h was positively correlated with immature development. Its influence on mortality was greater in autumn than in spring and summer. Fluctuating temperatures with average means of 20.0-25.7°C also affected immature growth and mortality. Temperature had a greater effect than day length on daily mortality rates. The optimum temperature for larval development in *E. cucurbitae* and pupal development in *E. vigintisexpunctata* was 24°C. That for embryonic development in *E. cucurbitae* was 24.7°C. Above and below these temperatures, growth rates decreased and mortality increased.

The results obtained from field trials conducted in Tamil Nadu, India, revealed that the *Henosepilachna vigintioctopunctata* population was greatest in February (24.2 insects/plant) and March (27.4 insects/plant) in brinjal. Significant, positive correlations with relative humidity, maximum temperature and wind velocity, and negative correlations with rainfall, minimum temperature and sunshine were observed in relation to *H. vigintioctopunctata* population dynamics (Raghuraman and Veeravel, 1999, a).

Alahmed (2001) studied the seasonal distribution of adults, larvae, and eggs of *Epilachna chrysomelina*, and the percentage of infested leaves on water melon and observed that the highest percentage of infested leaves for 1999 and 2000 seasons were 28.2% on May16 and 5.2% on May 29, respectively, and the lowest were 5.4% on June 19 and 1.2% on July 3rd, respectively. Adults and larvae were also high in 1999 season being 18.6 and 21.2/branch, both on June 6th respectively. On the other hand, the number of adults and larvae were low in 2000 season being 4/branch on July 10 and 7.6/branch on May 15, respectively. The numbers of eggs were higher in the beginning of 1999 season, they reached 42.2 eggs/ branch on May 9th then their number dropped. Eggs were found through out the season 2000 but at low density. The high density of the beetle and the high percentage of infested leaves in 1999 compared to 2000 may probably be due to the high rate of rainfall in 1999 compared to 2000. The high relative humidity because of rain helps the hibernating adults to pass winter more successfully.

Ghosh and Senapati (2001, a) conducted the studies to determine the seasonal incidence, population fluctuation and biology of *Henosepilachna vigintioctopunctata* on brinjal cv. Pusa Purple Long in West Bengal. The results showed that the highest population (8.14 beetles per plant) was observed in mid-September. Beetle population showed significant positive correlation with average temperature, relative humidity and rainfall. Life cycle duration was shortest (26.74 days) during June-July and longest (33.52 days) in September-October. The highest fecundity (272.32 eggs laid) was during March-April. Life cycle was negatively correlated with temperature and relative humidity, while fecundity was positively correlated with these weather parameters. High temperature and relative humidity during July-September shortened the life cycle duration but increased fecundity.

Muthukumar and Kalyanasundaram (2003) conducted an experiment, to study the seasonal occurrence of *Henosepilachna vigintioctopunctata* on brinjal cv. KKM in Killikulam, Tamil Nadu, India, from January to July 2002. The incidence of *H. vigintioctopunctata* was higher (21.80-27.60 beetles per three leaves) during March-April, but declined thereafter. It was positively associated with maximum temperature.

Sarvendra *et al.*, (2005) studied the effects of weather parameters on the incidence of hadda beetle, *Henosepilachna vigintioctopunctata* on brinjal (cv. Type-3) in Uttar Pradesh, India, during the kharif season. Hadda beetle was observed from the 3rd week of August until the last week of October. The highest population density (0.28 beetle per leaf, 21.10% incidence) was recorded on the 2nd week of September when the average temperature and relative humidity were 27.14^{0}C and 88.57%, respectively. Thereafter, the population of the pest declined gradually. Temperature and humidity were negatively correlated with the population of hadda beetle. High temperature and low relative humidity had adverse effects on the population of this pest.

Suman and Swaminathan (2007) recorded the peak infestation period of both adults and grubs of *Henosepilachna vigintioctopunctata* in the first week of October and in November, 2005; thereafter, the population decreased by the end of December, 2005 and reappeared in the last week of February continuing up to April, 2006. The atmospheric temperature had a significant positive correlation with the grubs and adults, while relative humidity had a negative correlation.

Kumar *et al.*, (2009) studied the seasonal abundance of *Henosepilachna vigintioctopunctata* on *Withania somnifera* and found that the most favorable period for population buildup of *H. vigintioctopunctata* was from 10th, to 12th standard week, during which highest population and activity were recorded. The beetle population of *H. vigintioctopunctata* was positively influenced with fluctuations of temperature and sun shine hours but negatively influenced with relative humidity, rainfall and number of rainy days.

Seasonal incidence of natural enemies

Romero *et al.*, (1987) studied the parasitoids and predators of the species of the subfamily Epilachninae in maize and bean crops in 1981-82. All the species of Epilachninae were found susceptible to parasitism by *Pediobius foveolatus* (Crawford), although *Malata delphinae* (Gorham) was not of adequate size for normal development of the parasitoid. Among the predators detected attacking larvae of the species of Epilachninae were 6 species from the families Pentatomidae and Coccinellidae.

Lee *et al.*, (1988) collected eggs, larvae and pupae of *Henosepilachna vigintioctomaculata* from potatoes, brinjal and black nightshade (*Solanum nigrum* L.) in Korea Republic in June-September 1983-86 and reared to the adult stage in the laboratory at 25°C and 70% RH. Three parasitoid species, the proctotrupid, *Nothoserphus afissae* (Watanabe), the chalcid, *Uga menoni* (Kerrich) and the eulophid, *Pediobius foveolatus* were recorded. *N. afissae* was reared from 2^{nd}-4^{th} instar larvae, with parasitism being highest in 3^{rd} instar larvae. *U. menoni* was reared from 3^{rd} instar larvae and pupae. The highest parasitism was however recorded in pupae. *N. afissae* and *U. menoni* occurred during June to September. *P. foveolatus* generally did not appear until September, but it was recorded in early August in southern areas. On an average, 13.8 adults of *P. foveolatus* emerged from each host mummy. Parasitism by *N. afissae* and *U. menoni* was greatest on potatoes.

Raghuraman and Veeravel (1999, b) studied the seasonal incidence of *Pediobius foveolatus*, parasitizing *Henosepilachna vigintioctopunctata* on brinjal at six locations (Annamalainagar, Kavarapattu, Vallampadugai, C. Mutlur, Sivapuri and Coleroon) in Tamil Nadu, India, during November 1995-October 1996. The average time for development of the parasitoid from egg to adult was 10-16.5 days in the laboratory, with 11.0-22.6 parasitoids emerging per host. The greatest incidence of parasitism was observed at Annamalainagar and Vallampadugai (19.43 and 19.52%, respectively). At all locations, parasitism was observed from November (6.04%), peaking during March (24.73%).

Kaur and Mavi (2002) observed the parasitoids *Tetrastichus ovulorum* (Ferriere), *Pediobius foveolatus, Uga menoni* and *Bracon* sp. on various life stages of *Henosepilachna vigintioctopunctata* during March-September 2001. *U. menoni* was observed in the last week of March and April 2001, parasitizing the pupae of *H.*

vigintioctopunctata and emerged by making a hole in the posterior region. The *P. foveolatus* population was high during June-September, and the adults emerged from the grub by making holes.

Patnaik and Mohapatra (2004) monitored the incidence of natural enemies of the spotted leaf beetle, *Henosepilachna vigintioctopunctata* on brinjal, during the 2003 kharif season, in Orissa, India, by collecting and rearing the egg masses from field until the emergence of grubs or adult parasitoids. The egg parasitoid, identified as Omphale sp., remained active in brinjal fields parasitizing the eggs of the spotted leaf beetle from the second fortnight of August to the end of November. Parasitization was highest (57.2%) during the second fortnight of August. The overall parasitization of the egg masses was 25.1% during the cropping period with 4.1 to 14.8% eggs per egg mass being parasitized.

Raju and Maheswari (2004) studied the natural enemies associated with spotted leaf beetle, *Henosepilachna vigintioctopunctata* infesting brinjal and recorded egg parasitization by *Tetrastichus* sp. (37.6-38-8%) during November and December, while pupal parasitization by *Pediobius foveolatus* recorded 52.50% during December. In addition, *Rhynocoris fuscipes* (Fab.) consumed about 4 grubs and 2-3 adults per day. *Mermis* sp. was also recorded as an endoparasite of the 4th instar grub of the spotted leaf beetle.

Varma and Anandhi (2008) conducted field studies to determine the seasonal incidence of *Henosepilachna vigintioctopunctata* on brinjal during 2004-05 and 2005-06 in Madhya Pradesh, India. The incidence of the beetles was first noticed from the 20th week after transplanting (third week of January) with an average population of 0.27 brinjal hadda/plant in 2004-05. In 2005-06, the incidence started earlier, i.e. first week of November, with an average population level of 2.85 brinjal hadda/plant. Population of hadda beetle reached its peak in the third week of February in 2004-05. It attained its peak in the third week of November during 2005-06. The beetle incidence showed negative correlation with the maximum and minimum temperatures and was positively correlated to all other abiotic factors. In the subsequent years, the pest population was positively correlated to the maximum relative humidity and wind velocity while negatively correlated to all other abiotic factors. The activities of all the parasitoids (*Tetrastichus* sp., *Pediobius foveolatus* and *Brachymeria* sp.) were highest during February. Egg parasitoids were positively correlated to the maximum relative humidity, rain, wind velocity and sunshine hours in the first year and negatively correlated to temperature, relative humidity and rain during the subsequent year. Grub parasitoid occurrence was significantly correlated to the wind velocity in the first year and was non-significant with all other abiotic factors during the following year. The incidence of the pupal parasitiods was negatively correlated to wind velocity and sunshine hours.

Naik *et al.*, (2008) recorded the incidence of *Henosepilachna vigintioctopunctata* in terms of grub's population in Bapatla, Andhra Pradesh, India, during the third week of February 2006, which showed a non significant relationship with temperature and rainfall, but significant relationship with coccinellid predatory beetles as well as spiders.

Pediobius foveolatus was able to parasitize all larval stages of *Henosepilachna vigintioctopunctata* but preferred to parasitize later instars of the host larvae with the fourth instar larvae being the most suitable for *P. foveolatus* (Wang, 2002). Female wasps parasitized an average of 6.21 larvae and produced 74.57 offspring, some by thelytoky, when provided with 4^{th} instar larvae. In the field, the maximum natural parasitism of *H. vigintioctopunctata* by *P. foveolatus* occurred in June on potatoes (28.47%) and in July on *Solanum nigrum* (64.5%). High temperature in July caused high mortalities of both pest and parasitoid, resulting in a dramatic decline in parasitism rate (Sheng and Wang, 1992).

Although *Henosepilachna vigintioctopunctata* was parasitized throughout the year, the maximum percentage parasitization was recorded during August 1993 (49.5%), November 1994 (49.1%) and September 1993 (47.1%). Percentage parasitization was highest in fourth-instar larvae. It was concluded that *Pediobius foveolatus* is a potential biological control agent of *H. vigintioctopunctata* (Rajendran and Gopalan, 1997, a).

Life-table

Some authors have emphasized the role of abiotic and biotic factors in the abundance of organisms in a biotic community, and calculated population in the form of life-table thereby focusing their population dynamics (Huffaker, 1971 and Varley *et al.*, 1973).

Life-tables provide an ecological tool to measure survivorship, mortality and mortality factors of an organism under natural conditions (Morris and Miller, 1954; Harcourt, 1969). Multiple sets of life-table data can be analyzed to identify key mortality factors or critical stages or periods, which can increase understanding of the dynamics of an insect population at the same time, reveal the most appropriate period of management (Harcourt, 1969, and Southwood, 1978).

Pearl and Parker (1921) were the pioneers who studied the life-table of insect population targeting *Drosophilla melanogaster* (Meigen). Later on, Leopold (1933) for the first time recognized the value of life-table in the study of natural population. Leslie and Ranson (1940) extended the concept of life-table to study life expectancy of small animals. A comparative mortality of animal life table in natural population was extensively studied by Deevy (1947). However, Birch (1948), Leslie and Park (1949) studied life-table against insects. Later, Ito (1959), Slobodkin (1962), Morris (1963), Harcourt (1969), dealt with life-tables and the importance of key-factors providing means of identifying the potential role of parasitoids and predators in regulating the pest population. Subsequently, various workers have also used this approach to study the natural population of economically important insect pests of agricultural and horticultural significance (Atwal and Bains, 1974; Southwood, 1978). Since then, life-table has also been used for the study of natural population of insect pests and has been discussed comprehensively by various workers.

Nakamura (1976) constructed life-tables of *Henosepilachna vigintioctopunctata* (F.) on the basis of results of studies conducted in 1970-72 on potato near Kyoto, Japan. Overwintered females laid their eggs mainly in potato fields, and the adults of the first generation emerged in late June or early July. Egg mortality was 27% and was attributable mainly to physiological causes and cannibalism by larvae. Starvation was the main cause of death in the larval stage. Total mortality from egg to adult emergence was 90%. After the potato crop was harvested, the number of adults that dispersed to egg-plant and other solanaceous crops was so large that there was a severe shortage of food resulting in dispersal and a reduction in fecundity. Egg mortality in the second generation reached 40-60%, due to large measure to cannibalism by the adults. Total mortality was 94-99.7% and a few adults emerged in early August. It is concluded that some density-dependent mechanisms such as the regulation of fecundity, egg cannibalism, and competition for food among the larvae, and adult dispersal play an important role in the population dynamics of this beetle.

Varley *et al.*, (1976) carried out 3 experiments under semi-field and laboratory conditions to evaluate the role of intraspecific regulatory mechanisms, an account to part of a series on the population dynamics of *Henosepilachna vigintioctopunctata* (F.) in Japan. Adults were introduced into field cages at different densities. Results of evaluation of effect of parental densities on reproduction revealed that fecundity of beetle decreased and egg cannibalism by adults increased. During the larval stage, mortality was due mainly to food shortage. The number of progeny per female was thus dependent on density. Application of the graphical key-factor method of analysis described by G. C. Varley & G. R. Gradwell showed that the density-dependent regulation mechanisms acting during the adult stage (reduction in fecundity and increase in egg cannibalism) were the key factors governing variations in total survival rates in these experiments.

Nakamura and Ohgushi (1981) studied the population dynamics of *Henosepilachna pustulosa* (Kono) on the thistle *Cirsium kagamontanum* (Nakai) in Japan. Life-tables were constructed for 1974-76. Adult fecundity varied from 51.2 to 89.5, but potential fecundity was estimated to be 200 or more. Mortality during the egg stage (54.5-64.4%) was mainly due to predators, especially an earwig, a staphylinid and 2 carabids. Egg mortality also included cannibalism by adults and larvae. The larval mortality from the 1st to 3rd instar was 83.9-92.8%, presumably due to arthropod predators. Parasitism by *Watanabeia afissae* (Watanabe) and *Pediobius foveolatus* was 3.8-9.7% of 4th instar larvae. Since the beginning of feeding damage by larvae never reached a level where food-plants were seriously depleted, mortality due to starvation rarely occurred. Results of key-factor analysis indicated that the stabilization of population size was attained through density-dependent regulatory processes operating in inter-patch dispersal and in oviposition by overwintered adults. The demographic characteristics of *H. pustulosa* are contrasted with those of the potato pest *H. vigintioctopunctata*.

Abbas and Nakamura (1985) studied the population dynamics of a species of Epilachna (possibly *E. implicata* Mulsant) bitter cucumber, *Momordica charantia* L. in Sumatra, Indonesia, in 1982. The coccinellid colonized the food-plants soon after they became established, and each of 3 study periods ended with the death of the plants due to defoliation by larvae and adults. Life tables indicated that egg mortality ranged from 17.8

to 53.9%, and a parasitic species of the eulophid genus *Tetrastichus* caused 41.1-64.2% of the egg mortality. Another species of *Tetrastichus*, with *Pediobius foveolatus*, killed 1.2-19.4% of 4^{th} instar larvae, and *P. foveolatus* killed up to 59.1% of pupae. Parasitism and starvation by overcrowding, contributed most to total mortality, which ranged from 89.4 to 99.5%.

Ohgushi (1986) studied population dynamics of *Henosepilachna niponica* (Lewis) from 1976 to 1980 and constructed life-tables for five generations at the two sites along the River Ado in Central Japan. Predatory arthropods were the most important cause of mortality of eggs and larvae. A high level of predation was responsible for the low adult density of one of the populations. Seasonal adversity (heat stress in mid-summer, and autumn flood) decreased the survival of newly-emerged adults but from then on adult survival up to the reproductive stage was assumed more likely to be size and sex-dependent. Seasonal changes in the causes of major mortality factors coupled with deteriorating food resources profoundly affected the demographic features and individual success from egg to the reproductive stage of the lady beetle.

Shirai (1987) studied two populations of *Henosepilachna vigintioctomaculata* feeding on wild thistle (*Cirsium* spp.) in different habitats in Sawai and Kashio, Nagano Prefecture, Japan, in 1978-80. Both populations were characterized by high mortality (95-97%) during the immature stages due to egg cannibalism by adults and predation of eggs, larvae and pupae by polyphagous arthropods. The reproductive rate (number of newly emerged females per overwintered female) was low in both populations over the 3-year study. The reproductive rate in the Sawai population was more stable (0.9-1.8) than that in the Kashio population (1.3-5.4). The variation in the number of eggs laid per female was the major factor responsible for the variation in the reproductive rate seen in Sawai. The reason for this difference in variation pattern between the 2 populations was obscure.

The variation in the number of eggs laid per female also seemed to play an important role in stabilizing the densities of both populations.

Nakamura *et al.*, (1988) studied the population dynamics of *Henosepilachna vigintioctopunctata* on brinjal in Indonesia in 1981-82. After planting, adult coccinellids soon colonized and oviposited massively, resulting in rapid population growth for 1-2 months; thereafter, the population increase slowed down due to defoliation. Three to four months thereafter the plants recovered their leaves, but leaf quality was less suitable for the coccinellid and, as a result, the population remained at a low level during the rest of the study period. Adult population size fluctuated 7 to 8 fold during the study period. The estimated mean duration of residence of adults was 16.5 days for males and 15.2 days for females. Elytral spot pattern was variable. A life table showed that parasitism, and starvation by overcrowding, contributed most to mortality in the immature stages. Two species of *Tetrastichus* parasitized the eggs, and *Pediobius foveolatus* parasitized the pupae. Four species of coccinellids are reported as possible predators on *H. vigintioctopunctata.*

Colunga and Vera (1990) studied the mortality of the coccinellid *Epilachna varivestis* on beans, *Phaseolus vulgaris* L. under field conditions in Mexico. Mortalities for eggs, larvae and pupae were 63, 77 and 57%, respectively. Principal mortality factors for eggs were heavy rainfall, low temperatures and infertility, while those for larvae were heavy rainfall, low temperatures and parasitism. The main mortality factors for pupae and adults were exposure to sunlight and low temperatures, respectively. The period in which development of the coccinellid was initiated affected survival. The tachinid parasitoid *Aplomyiopsis epilachnae* (Aldrich) was encountered in one pupa.

Adu and Morimoto (1997) conducted a field experiment, to study the effect of spatial distribution pattern (one large clump or several small clumps) on immature

Epilachna vigintioctomaculata and the impact on the associated predator fauna in 1992-93 at Shinsu University farm, Japan. The role of predators in the mortality of immature *E. vigintioctomaculata* was also examined in an experiment in which cages were used to eliminate natural enemies in the field. Mortality of *E. vigintioctomaculata* was higher in the small clumped distribution than in the large clumped one in both years. Overall mortality of *E. vigintioctomaculata* immature stages was significantly higher under the field conditions than in the cages in both distribution patterns, and the mortality due to predation (mainly by spiders, ants, coccinellids, bugs and mantids) was about 40% for each stage up to the 3rd stadium. Egg mass sizes varied widely with an average of about 27. Since predation was the major mortality factor, and this was contingent on prey distribution, predation probably acted with varying intensities in the plots supporting the 2 different spatial distribution patterns.

Beyene *et al.*, (2007) carried out studies on the population dynamics of tef epilachna in Southern Ethiopia, in Wolaita Zone for 2 years (2004 and 2005) at three locations, Boloso Sore, Damot Gale and Sodo Zuria, to find out the key mortality factors. Mortality of eggs and early larval stages was higher at all locations when compared to the later stages. The highest rate of mortality on the eggs was caused mainly by the egg parasitoid, *Oaencyrtus epulus* Annecke (Encyrtidae). The parasitoids, *Pediobius foveolatus* (Eulophidae) and *Mesopolobus* spp. (Pteromalidae), were the main causes of the pupal mortality. The mortality of the larval stages was supposed to be due mainly to the many predators present, namely as *Chlaenius* sp. (Carabidae), ladybird beetles (Coccinellidae), larvae of hoverflies (Syrphidae) and green lacewings (Chrysopidae), assassin bugs (Reduviidae), earwigs and spiders. A fungal entomopathogen (*Beauveria* spp.) was also found on adults. The egg parasitoid *O. epulus* and the pupal parasitism caused by the *P. foveolatus* and *Mesopolobus* spp. were the key mortality factors in the population dynamics of the tef epilachna. The egg and pupal parasitism was density dependant at two and one locality, respectively.

Varma and Anandhi (2008) studied that several mortality factors i.e., biotic and abiotic factors existing in the brinjal ecosystem, so that these factors could be exploited in IPM strategy for the management of brinjal Hadda beetle. The total generation mortality was 118.8% of which biotic factors contributed to 58.1% mainly in egg, grub and pupal stages.

Host plant resistance

Srivastava *et al.*, (1969) carried out experiment to compare the suitability of five solanaceous plants (tomato, brinjal, *Solanum insanum* L., *Datura stramonium* L. and *Physalis maxima* Mill.) as food-plants for larvae of *Henosepilachna vigintioctopunctata* in the laboratory conditions at 25-29^{0}C and 88-94.5% R.H. The average duration of the larval period ranged from 13 days on *P. maxima* to 16.35 days on brinjal. The percentage survival and the growth rate index were highest (94% and 7.23, respectively) on *P. maxima* and lowest (36% and 2.55, respectively) on tomato. It is concluded that, of the plants tested, *P. maxima* is the most and tomato the least suitable.

Pandey and Shanker (1975) determined the effect of 10 different food-plants on the development of *Henosepilachna vigintioctopunctata*, a pest of solanaceous and cucurbitaceous plants, in laboratory tests in India. Results showed that brinjal was the most favourable and pumpkin the least.

Sakurai *et al.*, (1980) studied the development of *Henosepilachna vigintioctopunctata* on 4 species of solanaceous plants viz., potato, tomato, brinjal, *Physalis alkekengi* L. and *Lycium* sp. throughout the year in the laboratory. Newly hatched larvae were provided with the foliage of 4 species of solanaceous plants or with slices of potato tuber or brinjal fruit. The emergence rate, pupal weight and adult head-width were greater for individuals developing on potato and *Physalis* foliage than for those on tomato or *Lycium*. The developmental period was prolonged and the pupal weight, adult head-width and oviposition diminished when the larvae were provided with sliced potato or brinjal, but two generations were reared on potato and 3 on brinjal. The emergence rate of first and second generation adults was the same on brinjal as on potato or *Physalis* foliage, so that brinjal can be used as an alternative food for laboratory rearing.

Borah and Saharia (1981) carried out laboratory studies to determine the effect of 10 species of cucurbitaceous plants on the development of *Henosepilachna vigintioctopunctata* in India. On the basis of the leaf area consumed, both larvae and adults preferred *Momordica cochinchinensis* (Lour.), *M. charantia, Luffa cylindrica, L. acutangula* and *Cucumis* sp. On the basis of parameters such as larval and pupal weight, percentage larval and pupal survival and percentage adult emergence, *M. cochinchinensis* was shown to be the most suitable food-plant for *H. vigintioctopunctata*.

Ganga and Chetty (1982) carried out laboratory studies in India on the fecundity, life-cycle and survival of the brinjal pest *Henosepilachna vigintioctopunctata* on various other solanaceous plants viz., *Solanum nigrum, Solanum torvum* (Dunal), tomato, *Physalis minima* L. and *Datura fastuosa*. Results revealed that naturally occurring solanaceous plants could maintain the pest population throughout the year. This supported field observations at Madurai that whenever insecticides were applied the pest became scarce on the main crop but could be found on these other plants. The greatest potential for maintaining the pest was shown by *P. minima*, which had the highest survival, shortest life-cycle and highest fecundity.

Ganga and Nagappan (1983) carried out laboratory studies in India to relate statistically the differences in the feeding activities of adults of *Henosepilachna* *vigintioctopunctata* on 4 solanaceous plants, eggplant, and tomato and the wild plants *Datura fastuosa* and *Physalis minima*, and the differences in the nutritive values of the plants. The rates of feeding, assimilation and conversion by the beetle were determined for each plant. The assimilation efficiency was very high (>98%) on all 4 plants. The net conversion efficiencies ranged from 1.59 to 20.68%. There were significant relationships between leaf protein content and both ingestion and assimilation and between secondary substances and conversion. The data indicated that the damage potential of the pest was significant on eggplant and that the wild plants were also suitable food-plants, *D. fastuosa* by promoting greater consumption and *P. minima* by promoting greater net conversion.

Vasantha *et al.*, (1984) studied the preference of 3rd and 4th instar larvae of *Henosepilachna vigintioctopunctata* for the leaves of solanaceous plants in the laboratory. Brinjal was the preferred food-plant, followed by tomato, *Datura fastuosa, Physalis minima* and *Solanum nigrum.* Continuous feeding was not observed on *S. torvum.* Assimilation efficiency was generally greater than 95% on all the preferred food-plants. Third instar larvae which were reared on tomato leaves were of small size and often died before reaching the 4th instar.

Ali and Saeady (1986, b) tested the feeding activity, growth rate and preference of *Epilachna chrysomelina* for cucumber, squash, watermelon and snake cucumber (*Trichosanthes ovigera* Blume) in the laboratory. Both larvae and adults consumed the largest amount of food when provided with watermelon leaves and the smallest amount when provided with cucumber leaves. *T. ovigera* supported the fastest larval growth and watermelon the slowest. Adults preferred *T. ovigera* to squash, watermelon and cucumber.

Gajendra *et al.*, (1987) studied the food plant range, survival and development of *Henosepilachna dodecastigma* and *H. vigintioctopunctata*. Larvae of *H. dodecastigma* did not feed on Pteridophyta or gymnosperms. Of the 9 orders of the Lignosae group of dicotyledons, only species of the Cucurbitales were accepted. No species of Herbaceae were accepted as food. Monocotyledons were also rejected. Contrary to earlier reports, *E. dodecastigma* could not survive on 4 species of Solanaceae (including aubergine and *Capsicum annuum* L.). However, newly hatched larvae of *H. vigintioctopunctata* survived and developed well on Solanaceae but failed to survive on cucurbits.

Marinoni and Ribeiro (1987) studied the bionomics of *Henosepilachna paenulata* (Germar) in the laboratory conditions at 20°C, LD 12:12 and 65% RH, on *Cucurbita pepo* L., *Lagenaria vulgaris* (Molina), *Cucumis sativus* L. The effects of host-plant on adult and larval food ingestion, mortality and development were examined. The beetle completed its larval development on *Cucurbita pepo, L. siceraria* and cucumbers. *C. pepo* provided the best conditions for larval and adult development. *S. edule* caused 100% larval mortality but did not affect the adults.

Shirai (1987) reared three species of *Henosepilachna* in the laboratory on potato and on their native wild host plants in Japan. The increase per generation of *H. vigintioctomaculata* reared on potato was 6 times that of beetles reared on the wild host *Scopolia japonica* (Maxim.), which was due mainly to greater fecundity (225±111 eggs/female on potato as compared with 40±53 on *S. japonica*. Population increase of *H. niponica* on potato was one-sixth that on its normal host, *Cirsium nipponicum* (Maxim.), which was due to lower fecundity and larval survival, with 48 and 158 eggs/female and 38 and 77% larvae surviving on potato and *C. nipponicum*, respectively. Fecundity of *Henosepilachna yasutomii* was greater and thence its increase per generation on potato was about twice that on its normal hosts, *S. japonica* and *Caulophyllum robustum*. There were no clear differences in larval survival of *H. yasutomii* among the 3 food plants.

Richards and Filewood (1988) carried out feeding experiments in the laboratory on the 3 pest species of the *Henosepilachna vigintioctopunctata* complex occurring in Australia. Marrow was the preferred food plant of the cucurbitophagous *H. cucurbitae*, while potato was preferred by the 2 solanivorous species *H. vigintisexpunctata vigintisexpunctata* and *H. vigintioctopunctata.* The species *H. vigintisexpunctata vigintisexpunctata* could survive for long periods on weeds, often with reduced fecundity. Plant family influenced the duration of the preoviposition period, whereas plant species influenced the length of the oviposition period. The development rate was faster and mortality was higher in *H. cucurbitae* than in the other 2 species. *H. vigintioctopunctata* was the more successful of the 2 solanivorous species; the hatch rate, fecundity and generation time were greater in both species than in *H. cucurbitae*. *H. cucurbitae* had a development rate and preoviposition and oviposition periods similar to all other cucurbitophagous epilachnine species outside Australia, but a longer lifespan and higher fecundity. Of all epilachnine species studied, the 2 Australian solanivorous species had the slowest development rate, longest preoviposition, oviposition and postoviposition periods, longest lifespan and highest fecundity.

Ramzan *et al.*, (1990) carried out field studies on the developmental behaviour and seasonal abundance of *Henosepilachna vigintioctopunctata* on various solanaceous food plants in Ludhiana, India, in June 1976. The coccinellid completed its life cycle most quickly on *Solanum nigrum* (22.4 days) and the highest numbers of the pest were found on *S. xanthocarpum*, reaching a maximum of 526.3/10 plants in March.

Dhamdhere *et al.*, (1990) reared *Henosepilachna vigintioctopunctata* in the laboratory on 6 food plants viz., Tomato, brinjal, *Solanum nigrum, S. xanthocarpum and Physalis minima*. Tomato and brinjal were found to be the most suitable and *Datura alba* the least.

Lal (1990) studied order of preference for adults of *Epilachna ocellata* Redenbacher, infesting 10 vegetable crops in Himachal Pradesh, India, in 1983 and 1984. The descending order of preference for adults was potato, tomato, brinjal, okra, cucumber, radish, Capsicum, French bean (*Phaseolus vulgaris*), green gram (*Vigna radiate*) and black gram (*V. mungo*). Adults always preferred the host plants on which they lived as larvae, and adult females, though fed on various hosts, deposited their eggs on the preferred host plants.

Parjhar *et al.*, (1997) tested suitability of 6 solanaceous plants as host plants for *Henosepilachna vigintioctopunctata.* Brinjal and potato were shown to be superior with regard to survival and duration of larval development. The other plants tested were *Solanum nigrum, Nicandra physaloides, Withania somnifera* and tomato.

Shirai and Katakura (1999) studied the host plants of *Henosepilachna vigintioctopunctata* in the Southeast Asia region. Larval survival and development of *H. vigintioctopunctata* on Solanaceae, Cucurbitaceae and Fabaceae were examined for seven local populations from Japan, Thailand, Malaysia and Indonesia. All populations showed the highest emergence rate and largest adult body size when reared on plants of the genus *Solanum* (Solanaceae). On *Cuccinia indica* (Cucurbitaceae), the Malaysian population had an emergence rate of ca. 32% and the Thailand and two Indonesian populations each had an emergence rate of ca. 10%. However, newly emerged adults of these four populations were not able to produce the next generation when reared on *C. indica* because of very low fecundity and hatchability. On *Centrosema pubescens* (Fabaceae), the Malaysian and two Indonesian populations each had an emergence rate of ca. 30%. Newly emerged adults of these three populations showed 62 to 72% hatchability when reared on *C. pubescens.* It is concluded that the major host plants of *H.*

vigintioctopunctata in Southeast Asia are solanaceous plants and this species is unable to complete its life cycle solely on cucurbitaceous plants.

Khan *et al.*, (2000) conducted experiments to study the larval life table of *Henosepilachna dodecastigma* and their growth on six different host plant species: ribbed gourd (*Luffa acutangula*), tomato, sweet gourd (*Cucurbita moschata*), watermelon, teasel gourd (*Momordica cochinchinensis*) and brinjal, under laboratory conditions. The egg mortality of *H. dodecastigma* was highest (20%) on ribbed gourd and lowest (5%) on watermelon. The highest larval survival rate was recorded on watermelon and the lowest on sweet gourd at the age of 10 days. The larval life expectancy was highest on tomato followed by sweet gourd and the lowest on brinjal and watermelon. Total larval duration was highest on sweet gourd followed by tomato and lowest on brinjal. The highest pupal duration was observed on watermelon and the lowest on brinjal. The highest number of adults emerged on watermelon and the lowest on sweet gourd. The total food consumption by the larvae for 10 days was highest on watermelon and lowest on sweet gourd.

Patel and Purohit (2000) conducted laboratory studies to determine the preference of the *Henosepilachna vigintioctopunctata* between brinjal and tomato as hosts. The effect of the host plants were compared based on larval and pupal period, weight of full-grown larva and pupa, and adult longevity. Larval and pupal period were not significantly affected by brinjal and tomato. The average number of days required to complete the entire larval stage, was slightly longer (15.95 ± 0.86 days) on tomato leaves than brinjal leaves (15.60 ± 0.73). Adult longevity was higher on tomato compared to brinjal. Larvae grew faster and obtained heavier weight when fed with brinjal leaves (27.55 ± 0.51 mg) than with tomato leaves (23.40 ± 0.65 mg). The brinjal leaves also enhanced the development and body weight of adults. The results indicated a preference for brinjal leaves by larvae and adults, which supported shorter period of development and also helped in gaining heavier weight of both the damaging stages.

Shirai and Katakura (2000) evaluated the host suitability of the weed *Centrosema pubescens* within two sympatric populations of *Henosepilachna vigintioctopunctata* feeding on Solanaceous plants and *C. pubescens* in Malaysia (Kuala Lumpur) and Indonesia (Bogor and Padang). In the Bogor and Padang populations, *Centrosema* strains had a significantly higher emergence rate than sympatric Solanum strains. In Kuala Lumpur, there was no significant difference in emergence rates between the two strains. When *Centrosema* strains from Kuala Lumpur and Padang were reared and maintained solely on Solanum plants, the emergence rate on *C. pubescens* gradually decreased with successive rearing generation and resulted in 0% in the 7^{th} or 20^{th} generations. The findings suggested that the current host suitability of *C. pubescens* depended on the previous experience of each population with the use of this plant as a host. However, it was not demonstrated from laboratory selection that Solanum strains increase the host adaptation to *C. pubescens* because every Solanum strain became extinct in the third generation when reared solely on *C. pubescens*.

Fujiyama and Katakura (2002) investigated the host plant suitability of the solanaceous wild herb, *Solanum japonense* as an alternative larval food for the three species of the *Epilachna vigintioctomaculata* complex, namely *E. niponica, E. pustulosa*, and *E. yasutomii*, under laboratory conditions. Three larval developmental traits (eclosion rate, developmental duration, and body size) were recorded together with the leaf area consumed throughout the developmental stages. All three ladybird species showed sufficient performance on *S. japonense*, although the suitability of *S. japonense* for larval development appeared to be highest for *E. pustulosa* and lowest for *E. yasutomii*. The measurements of leaf consumption revealed that *E. niponica* and *E. pustulosa* consumed a significantly larger leaf area of *S. japonense* than did *E. yasutomii* during the developmental stages.

Abe and Matsuda (2000) carried out an experiment to investigate feeding responses of adults and larvae of *Henosepilachna admirabilis*, *H. boisduvali*, *H. vigintioctomaculata*, and *H. vigintioctopunctata* to four cucurbitacins (B, E, I and E-glucoside). Both adults and larvae of *H. admirabilis*, which mainly feeds on the genus *Trichosanthes* (Cucurbitaceae), were strongly stimulated to feed by these cucurbitacins, especially by cucurbitacin E-glucoside. *H. boisduvali* feeds on *Diplocyclos palmatus* (Cucurbitaceae). Larvae of this species were stimulated to feed by all four cucurbitacins, especially by cucurbitacin I, and adults were stimulated to feed by cucurbitacin B only. *H. vigintioctomaculata* and *H. vigintioctopunctata*, which usually feed on solanaceous plants, were also stimulated to feed by cucurbitacins. They were not stimulated to feed by solanine and tomatine, which are usually contained in solanaceous host plants.

Koji *et al.*, (2004) examined the differences between the two populations of *Henosepilachna niponica* on several closely related thistle species and varieties, under laboratory conditions. Observations were taken on adult feeding acceptance, adult feeding preference, and larval performance. In the Asiu population, adult beetles clearly avoided the host of the Yuwaku population, *Cirsium kagamontanum*, and none of the larvae were able to complete their development, whereas in the Yuwaku population, adults accepted and even preferred it to some other thistle species evaluated, and about 10% of first instar larvae became adults. This indicated that the Yuwaku population evolved its feeding preference and physiological adaptation to *C. kagamontanum* through a utilization of this low-ranked host under natural conditions. Apart from *C. kagamontanum*, the two populations showed a similar host susceptibility pattern, indicating that this ladybird beetle has a conserved hierarchy in feeding preference and growth performance. Adult leaf choice behavior was also observed when given different thistle species, and results indicated that the difference in biting rate after palpation determined the leaf areas consumed, implying that factors on the leaf surface played an important role in the choice.

Shinogi *et al.*, (2005) carried out study to determine the process of host/non-host interactions of *Henosepilachna vigintioctopunctata*, a specialist herbivore of solanaceous plants, with various plant species. On host plants (tomato and egg plant) the ladybird beetle started feeding within 5 minute. On red pepper, another solanaceous plant, it also started feeding within 5 minute, but did not continue the feeding as vigorously as on tomato or eggplant. Results suggested that the ladybird beetle recognized red pepper as a host plant but did not overcome its constitutive resistance. On Chinese cabbage, the ladybird beetle did not start feeding as quickly as on the host plants, but once started, it continued feeding as vigorously as on the host plants. Results also suggested that the ladybird beetle did not recognize Chinese cabbage as a host plant but overcome its constitutive resistance. Subsequently, the effect of induced resistance in a host (tomato) and non-hosts (Chinese cabbage and Arabidopsis) was evaluated.

Abdullah and Abdullah (2009) studied the behavior of fifty one 12-spotted ladybird beetles *Henosepilachna indica* on ten black nightshade *Solanum nigrum* in the field at Ulu Kelang, Selangor, Malaysia. Leaf disc choice bioassay showed that *H. indica* preferred to feed on both *Solanum melongena* and *S. nigrum* leaf discs. In the laboratory, 72 h continuous observation on ten beetles showed that the leaf area consumption of *S. nigrum* was 1.202 ± 0.085 mm^2 per hour for one beetle. This study indicates that *S. nigrum* is a potential trap plant for pest management of the economically important egg plant *S. melongena*.

Differential responses of cultivars/accessions against *Henosepilachna* sp.

Screening is the experimental testing of different varieties/ cultivars in the field to record their resistance/ susceptibility against a particular insect, causing immense losses to the crop in question. Once a variety is confirmed to be resistant to the pest then growing such variety becomes the cheapest method for control of the pest as no extra amount is invested on pest management. Resistance of a variety varies from one agro-climatic zone to another. Therefore, its efficiency is to be tested in different regions. Many workers have tested different varieties to confirm their resistances to *Henosepilachna sp.*, some of these efforts have been summarized below

Sambandam *et al.*, (1972) tested 114 brinjal accessions to determine the resistance for *Henosepilachna vigintioctopunctata.* Apple-Green Flesh and Pusa Purple Round were found to be moderately resistant to *H. vigintioctopunctata.* The search for sources of resistance among 30 non-tuberous, wild *Solanum* spp., resulted in locating 3 highly resistant spp., viz., *Solanum torvum, S. mammosum* and *S. khasianum.*

Elden *et al.*, (1974) screened more than 350 soyabean lines for resistance to *Epilachna varivestis* Muls. in field and laboratory experiments in the United States in 1971 and 1972. Entries with low feeding damage scores in the field were screened in the laboratory in a larval antibiosis test and an adult seedling-preference test. Entries that performed well in both the field and laboratory studies were retested and subjected to a third laboratory test, the larval leaf-disc test. Laboratory studies confirmed the moderate levels of resistance found in the field in the lines P.I. 90481, P.I. 96089, P.I. 157413, V-21 and V-156. Antibiosis and non-preference were the two mechanisms responsible. The performance of several selected lines in both field and laboratory studies indicated that the laboratory methods were effective for selecting lines with resistance and identifying in some instances the mechanism of resistance.

Raju *et al.*, (1987) screened 8 varieties of brinjal for resistance to *Henosepilachna vigintioctopunctata*. Punjab Chenakate (PC), SM204 and SM195 showed moderate resistance to the pest. Low amounts N, K and Zn and high amounts of P, Ca, Mg, Fe, Mn, Cu, total carbohydrates and phenols detected in the leaves of PC, SM204 and SM195 are considered to be related to the resistance shown by these varieties. SM204 gave the highest fruit yield (18.4 t/ha).

Rajendran and Gopalan (1997, b) developed an improved method for screening and grading brinjal accessions for resistance to *Henosepilachna vigintioctopunctata*. The screening procedure combined both the incidence and intensity of damage in the field. The damage index (D.I.) was calculated by multiplying pest incidence and intensity/100. Grading was divided into three categories: resistant (R, D.I. = 0.0-0.10), moderately resistant (MR, D.I. = 0.11-0.30), and susceptible (S, D.I. = _ 0.31). Using this technique, 78 brinjal accessions, 15 hybrids and 10 wild *Solanum* spp. were screened during 1993-94. Among the hybrids, EP 24x65 was moderately resistant. All the wild accessions were resistant except *Solanum macrocarpon,* which was moderately resistant. Among the 78 accessions screened, none were resistant, but 15 were moderately resistant to *H. vigintioctopunctata.*

Gangopadhyay *et al.*, (1997) screened out 27 brinjal accessions, both commercial varieties and local types, and 2 wild *Solanum* species for resistance to *Henosepilachna vigintioctopunctata* at Mondouri, Nadia, West Bengal, in 1993. Makra, Altapati, Gourkajli, Brinjal 72, Puni, Chicon Long, *S. incanum* and *S. macrocarpon* were relatively resistant to the pest. Muktakeshi, Kamdebpur Local, Eknakuli, Nischintapur, Brinjal 15, Brinjal 17, Green Brinjal Round, Light Purple Round and Banaras Giant White were highly susceptible. Contrary to earlier reports, Arka Shirish failed to restrict infestation by the pest.

Rajendran and Gopalan (1998) conducted a field trial to assess the resistance against *Henosepilachna vigintioctopunctata* on 103 accessions of brinjal including several wild relatives, *Solanum integrifolium, S. khasianum, S. aethiopicum, S. microcarpum, S. gilo* and *S. macrocarpum* during 1993-94. Assessment was carried out 60-70 days later following extensive damage to susceptible control cv. Annamalai. The mean percentage of leaves affected in each entry and the mean leaf area damaged by the beetle in 24 h (determined using caged plants) were used to derive a damage index which was used to grade entries as resistant, moderately resistant or susceptible. Only 9 entries were rated as resistant, 17 as moderately resistant and 77 as susceptible. Of the hybrids tested, only EP24/65 alone was moderately resistant. All the wild accessions were resistant except *S. macrocarpum*, which was rated as moderately resistant.

Mandal *et al.*, (2000) evaluated varietal resistance against *Henosepilachna vigintioctopunctata* on brinjal cultivars. Nine brinjal varieties were screened under field conditions. None of the varieties under trial was completely resistant to the epilachna beetle. However, on the basis of injuries PBr-129-5, NDB-25 and K-314 were comparatively less susceptible while KT-4 variety was more susceptible to the beetle.

Nayak and Rath (2001) conducted a study to ascertain the relative degree of resistance of 39 aubergine cultivars (plus one control cultivar, KB White) to the Epilachna beetle, *Henosepilachna vigintioctopunctata* during the kharif season of 2000 in Orissa, India. Cultivars CHBR 3 and DPLB 5 had the highest pest incidence (59.8 and 58.5%, respectively). Cultivar CHBS 309 recorded the highest intensity (7.8 cm2). The damage index ranged from 0.04 to 3.11 in different cultivars, with 0.80 in the susceptible control. Of the 40 cultivars, eight were resistant (Pipili 5, BB46-13, CHBR1, Bhanjanagar Local, SM 6-6, Shyamala, BB 99 and BB 60-C). Twenty-four were susceptible and 8 were moderately resistant to the pest.

Rath *et al*., (2002) conducted laboratory experiments to study non-preference mechanism in selected brinjal cultivars against Epilachna beetle, *Henosepilachna vigintioctopunctata* at the Department of Entomology, College of Agriculture, University of Agriculture and Technology, Bhubaneswar, India. Results revealed that high trichome density and longer trichome were responsible for non-preference mechanism of resistance in resistant/moderately resistant brinjal varieties. The cultivars used were: resistant varieties Pipili 5, Bhanjanagar local and BB 60-C; moderately resistant BB-26, Banki Local and BB 44; and the susceptible control KB White. Based on trichome characteristics and possibly olfactory stimuli, Epilachna beetle discriminated between the resistant and susceptible varieties. Egg sterility was found to be higher on resistant varieties than on susceptible ones.

Gill (2003) screened four melon cultivars viz,. Punjab Sunehri, MM-28, Punjab Rasila and Hara Madhu under field conditions in Punjab, India, against hadda beetles, *Henosepilachna dodecastigma and H. vigintioctopunctata*. The lowest adult populations of both hadda beetles were recorded on MM-28, and the highest on Punjab Rasila and Hara Madhu. Damage due to feeding by hadda beetles was observed at the early stage of plant growth in all the cultivars, but subsequently the plants grew well.

Bhagat and Munshi (2004) evaluated six commercial cultivars of brinjal namely Pusa Purple Long, Pusa Purple Round, Pusa Hybrid-6, Pusa Kranti, Supriya and Nisha, in May for susceptibility to the spotted leaf-eating beetle, *Henosepilachna vigintioctopunctata* under 'open choice' conditions in the field in Jammu, Jammu and Kashmir, India. There was a steady increase in infestation level from 27th standard week (SW) onward and it reached a peak between 32nd and 33rd SW in all the cultivars after which the count declined steadily. The maximum average population (19.33 grubs and adults/5 plants) was recorded in Pusa Purple Long. Based on the seasonal incidence of the pest, Pusa Purple Long was categorized as the most susceptible while all others were categorized as susceptible cultivars.

Rath (2005) conducted laboratory studies on the antibiosis mechanism of resistance in selected brinjal cultivars against Epilachna beetle, *Henosepilachna vigintioctopunctata*. Results showed that resistant cultivars such as Bhanjanagar Local, Pipili 5 and BB 60 accounted for increased egg, grub, pupal and adult duration than moderately resistant cultivars such as, BB 26, Banki Local and BB 44. Male:female sex ratio was higher in both resistant and moderately resistant cultivars than the susceptible control KB White. The control cultivar did not favour egg, grub, pupal and adult development and caused more female forms and accounted for comparatively higher population build-up with higher growth index.

Elanchezhyan *et al*., (2008) conducted a field experiment in 2006 in Madurai, Tamil Nadu, India, to study the influence of cultivars/hybrids/germplasm of brinjal to *Henosepilachna vigintioctopunctata* and their natural enemies. The hybrid, Sweta was the best in reducing the population of spotted leaf beetle to 8 numbers/3 leaves. Hybrids Bejo Sheetal and Pusa hybrid-6 recorded high population of coccinellids, syrphids and spiders.

Organic farming

Organic farming claims to have the potential to provide benefits in terms of environmental protection, conservation of non-renewable resources, improved food quality, reduction in output of surplus products and the reorientation of agriculture towards areas of market demand (Lampkin, 1990). Many workers have evaluated certain organic nutrients against *Henosepilachna vigintioctopunctata* in brinjal and other host plants, some of these efforts have been reviewed below

Singh (2002) carried out an experiment on French bean cv. Contender during the summer season of 1997 and 1998 in sandy loam soil in Palampur, Himachal Pradesh, India, with nine treatments comprising combinations of three fertilizers, i.e. farmyard manure + dense organic manure, biofertilizer + dense organic manure, recommended chemical fertilizers; and three pesticides, namely Neemax at 1.0 kg/ha, garlic extract at 10 l/ha and endosulfan at 1.2 l/ha. Recommended NPK was applied at 30, 80 and 60 kg/ha, with different sources of nutrients according to their treatments. The treatment combination of farmyard manure + dense organic manure and Neemax gave higher yield, higher protein and vitamin C content with prolonged shelf life under ambient storage conditions, than the other treatments. However, nitrate content which caused health hazards was low in treatment having biofertilizer + dense organic manure. Neemax controlled the bean beetle, *Epilachna varivestis* effectively compared to endosulfan.

Zadda *et al.*, (2007) conducted an experiment to evaluate certain organic nutrients against *Henosepilachna vigintioctopunctata* in brinjal. Application of organic sources of nutrients and amendments (Farm yard manure, poultry manure, neem cake, mahua cake, pungam cake and biofertilizers i.e. *Azospirillum*, phosphobacteria and silica solubilizing bacteria) significantly enhanced the production of defensive chemicals viz., silica and phenols and thus exhibited induced resistance in terms of antibiosis by means of reduction in feeding rate, oviposition, longevity and population buildup and prolonged the nymphal duration of brinjal pests. Brinjal plants, which received organics, registered less quantity of reducing sugars, proteins and leaf chlorophyll when compared to NPK as straight fertilizer applied plots, thus making the plants less prone to insect attack.

Suresh *et al.*, (2008) conducted a field experiment in farmer's holding at Vinayagapuram village of Melur Taluk, of Madurai District, Tamil Nadu to adopt various eco-friendly measures to control spotted beetle damage in Brinjal. Farm Yard Manure (FYM), Biofertilizers, Poultry manure, Neem cake and Mahua Cake were used as organic sources of nutrients for the management of beetle damage in brinjal. From the study conducted, the treatment involving FYM + biofertilizers + neem cake recorded high per cent reduction of beetle infestation over NPK as inorganic form. Next to this was FYM + biofertilizers + mahua cake treatment. The highest fruit yield of (16.65 t/ha) was also noticed in the promising treatment.

Ravikumar *et al.*, (2008) conducted field studies to determine the effect of various organic amendments in inducing resistance to *Henosepilachna vigintioctopunctata* on Ashwagandha in India. The results revealed that farmyard manure (FYM) at 12.5 t/ha + Azophos (2 kg/ha) + neem cake (1000 kg/ha) was very effective in reducing the damage of spotted leaf beetle by 69.79%. The FYM + Azophos + neem cake combination was less preferred for oviposition, which recorded 62.00 ova /plant, coupled with a minimum feeding area of 6.75 cm^2.

Botanicals

Schmutterer and Rembold (1980) carried out laboratory studies to determine the effect of fractions of neem seeds from West Africa on *Epilachna varivestis* in the German Federal Republic. Results showed that 4 pure fractions had strong to very strong growth disruption effect on *E. varivestis* Muls., while fifth one had a lesser effect. After uptake of the neem seed ingredients by feeding on treated bean leaves, various more or less typical symptoms were observed in fourth-instar larvae, depending on the individual fraction, resulting in death or failure to moult. Only one fraction exhibited obviously repellent properties.

Lange and Schmutterer (1982) carried out a laboratory study in German Federal Republic which showed that the synergist piprotal (Tropital) increased the growth-disrupting effect of a methanolic neem kernel extract (ratio 1:2) in 4^{th} instar larvae of *Epilachna varivestis* about 6 fold. Sesamex (sesoxane) also increased the effectiveness of the extract, but not significantly so. Piperonyl butoxide and 1,1'-oxybis[2,3,3,3-

tetrachloropropane] (S-421) had neither a synergistic or antagonistic effect. In 1st instar larvae of *E. varivestis*, piprotal also increased the effectiveness of the extract but to a lesser extent than in 4th instar larvae.

Mishra *et al.*, (1989) conducted laboratory study to determine the effect of neem oil on the ovipositional behaviour of *Henosepilachna sparsa*. Females of coccinellid *H. sparsa* were fed with brinjal leaves treated with 0.025 and 0.05 per cent neem oil to determine its effect on ovipositional behaviour. The pre-ovipositional period of females fed with leaves treated with 0.05 per cent neem oil was 21.09 per cent longer than that of insects fed with untreated leaves. Female fed with leaves treated with either concentrations of neem oil had a shorter ovipositional period, a reduced number of eggs laying, a smaller size of egg masses/female and a smaller number of eggs/female in comparison to the untreated controls.

Jeyerajan and Babu (1990) studied the efficacy of certain azadirachtin rich neem seed fractions on *Henosepilachna vigintioctopunctata.* Results showed that Nem-75, (1000ppm) was the best anti-feedant for grubs in which only 370.33 mm^2 leaf area was fed while in case of NK-100, the fed area was 371.67 and in case of Nemidin, it was 435.00 mm^2 in case of adults, NK-100 (1000ppm) was most effective having feeding area 388.67^2, the next best was Nemidin (1000ppm) and V-74 (1000ppm) where the fed area were 655.0 and 639.33 mm^2, respectively.

Mishra *et al.*, (1990) studied the effect of neem oil on the growth and development of *Henosepilachna sparsa.* Feeding of *H. sparsa* on brinjal leaves treated with 0.025 and 0.05 per cent neem oil increased the duration of life stages in the subsequent generations. Neem oil also reduced the weight of treated insects compared with the untreated control

Rao *et al.,* (1992) tested the insecticidal properties of petroleum ether extracts of leaves of 4 selected plants against *Henosepilachna vigintioctopunctata* in the laboratory.

Results revealed that after 24 hrs, 100% mortality was achieved at 0.2 and 0.5 per cent concentrations of *Bougainvillea spectabiliis* and *Parthenium hysterophorus*, and 0.5 per cent concentration of *Azadirachta indica*.

Schmutterer and Doll (1993) studied insecticidal properties of Philippine neem tree, *Azadirachta excelsa* against *Henosepilachna indica* and *Epilachna varivestis*. Bioassays of leaf, bark and of seed extracts of both species *H. indica* revealed greater bioactivity for *A. excelsa*, which contains azadirachtin as well as marragin, a new compound closely related to azadirachtin, in its seed kernels. Marragin was more toxic than azadirachtin to *E. varivestis*.

Sreedevi *et al.*, (1993) compared the toxicity of plant extracts to *Henosepilachna vigintioctopunctata* with that of 4 conventional insecticides in a greenhouse on brinjal. Carbaryl gave the greatest mortality (81.47%), followed by fenvalerate and phosalone (80.36 and 79.31%, respectively). The plant products Repelin, Neemicide, Vapenik, Neknool and Wellgro caused 83.35, 80.05, 76.65, 73.30, and 70.00% mortality, respectively.

Mehta *et al.*, (1995) evaluated anti-feedant action of petroleum ether extracts of 3 plants (*Ageratum, Lantana camara* and *Eupatorium*) against larvae and adults of *Henosepilachna vigintioctopunctata* in the laboratory. A 1% extract of each of *Ageratum* and *Lantana* gave complete protection to brinjal leaves against feeding by 1^{st}, 2^{nd} and 3^{rd} instar larvae. In adults, the greatest antifeedant effect was observed with a 1% *Lanatana* extract, followed by *Eupatorium* (1%). The remaining 2 concentrations (0.5 and 0.25%) of each of the 3 plant extracts were effective as anti-feedants but to a lesser extent compared with the 1% concentration.

Haque *et al.*, (1996) tested the effect of neem oil (0.25, 0.50, 1.0 or 2.0 per cent) on the food consumption and survival of 1^{st} and 3^{rd} instar larvae and adults of

Henosepilachna dodecastigma in a laboratory. All the 1st instar larvae were killed at all the tested concentrations before feeding. The feeding activity in 3rd instar larvae and adults decreased with increasing oil concentration. Highest larval mortality was recorded at the 2 higher oil concentrations.

Bhuiyan *et al.*, (1996) tested the efficacy of neem oil as an antifeedant and growth inhibitor to the beetle *Henosepilachna dodescastigma.* It was observed that food consumption by the test insect was significantly reduced and growth inhibition indicated by mortality was 100 per cent in the 1st- 3rd instars. However, few grubs with dark spots and low body weight pupated at lower concentrations but failed to emerge as adults. Some emerged as deformed ones with rippled hind wings. Oviposition was significantly reduced. The study indicated that neem oil served as a potential antifeedant and growth inhibitor of *H. dodescastigma* beetle.

Rajendran (1998) carried out field studies to evaluate the effects of neem oil on the fecundity and egg hatchability of *Henosepilachna vigintioctopunctata* on brinjal in 1993-94 in Tamil Nadu. Neem oil at 4% concentration reduced fecundity by 62.8% over control. Neem oil 2% + endosulfan 0.035%, reduced oviposition by 74.7%. Egg hatchability was also reduced.

Kumar and Babu (1998) observed the toxicity and growth regulatory effects of Neem Azal-T/S (1% azadirachtin) and Neem Azal-F (5% azadirachtin) against the pupae and adults of *Henosepilachna vigintioctopunctata.* Neem Azal formulations caused no pupal mortality, but endosulfan (0.07%) caused 40% mortality. However, Neem Azal formulations affected the normal emergence of adults, 1 ml/litre of Neem Azal-F resulting in 35% emergence. It is concluded that the 2 Neem Azal treatments had adverse effects on the fecundity and moderate growth regulatory effects on *H. vigintioctopunctata.*

Mehta *et al.*, (1999) tested leaf extracts of *Ageratum houstonianum, Artemisia brevifolia* and leaf and drupe extracts of *Melia azedarach* against *Henosepilachna vigintioctopunctata,* at 1, 2, 4 and 6 % concentrations each. Feeding the adults with brinjal treated leaves resulted in substantial prolongation in development of their progeny. Treatment with leaf extract of *M. azedarach* delayed the total life cycle by 6 days. Adults emerging from treatments with 4 and 6% concentrations of leaf extract of *M. azedarach* and *A. houstonianum* were found to be deformed. Substantial reduction in weight of fourth instar larvae was also observed. *M. azedarach* drupe extract resulted in maximum reduction in larval weight at all the tested concentrations.

John (1999) determined the efficacy of acetone extracts of *Parthenium* and water hyacinth, *Eichhornia crassipes* against *Henosepilachna vigintioctopunctata.* All extracts were effective against eggs of *E. vigintioctopunctata* in laboratory. In the field, 11% *Parthenium* extract reduced populations of *H. vigintioctopunctata* on brinjal by 35.60% twenty four hours after treatment.

Shanmugappriyan and Kingsly (2001) evaluated Neem oil and neem cake extract for their phagodeterrent effect on the grubs and adults of *Henosepilachna vigintioctopunctata.* The data indicated that feeding inhibition by neem oil (0.25 to 2.50%) varied from 97.64 to 99.01% in second instar and from 88.86 to 96.54% in the third instar. At a similar concentration range, the feeding inhibition by neem cake extract ranged from 89.13 to 97.08% in second instar and from 78.82 to 90.45% in third instar. In the fourth instar, however, the average leaf area protection varied between 72.80 and 92.33% in neem oil and between 66.71 to 90.71% in neem cake extracts (concentration range of 0.25 to 5.50%). At a similar concentration range, the feeding deterrent effect against adults varied from 65.61 to 89.90% with neem oil and from 61.70 to 84.84% with neem cake extract. Treatments of synthetic insecticides at insecticides at 0.025%

concentration resulted in feeding inhibition to the maximum level of 96.19 per cent with endosulfan in second instar; 90.97 per cent in third instar and 78.23 per cent in adults with Quinalphos and, 84.76 per cent in fourth instar with Malathion.

Karmarkar and Bhole (2001) tested the efficacy and persistent toxicity of some neem products viz; Nimbecidine, Neemark and Nimbitor at 1 and 2% neem concentrations against adults of *Henosepilachna dodecastigma*. The treaments with Nimbecidine and Neemark at 2 per cent concentration gave mortality of 90.69 and 71.90%, respectively, after 48 and 72 hours post-treatment. The treatment with 0.05% endosulfan recorded the highest mean per cent protection (up to 8 days) followed by 2% Neemark (up to 6 days).

Santhakumar *et al.*, (2002) tested antifeedant activities of aqueous extracts of *Calotropis gigantea, Eichhornia crassipes, Lantana camara, Pongamia pinnata, Solanum surattense* (*S. xanthocarpum*), *S. trilobatum and Tribulus terrestris* leaves against *H. vigintioctopunctata* on brinjal. Leaf extracts of *C. gigantea*, showed the highest antifeedant activity, and followed by extracts from *P. pinnata.*

Thakur and Mehta (2004) evaluated insecticidal potential of *Ageratum houstonianum, Artemisia brevifolia and Azadirachta indica* against fourth instar larvae and adults of *Henosepilachna vigintioctopunctata* in laboratory. The petroleum ether extract of the plants proved significantly superior in causing mortality of larvae (69.44%) as well as adults (48.05%) compared with the alcoholic (25.27 and 27.92%, respectively) and aqueous (32.77 and 25.27%, respectively) extracts. *A. indica* leaves and *A. houstonianum* were superior against fourth instar larvae with mean mortality of 55.55 and 45.18%, respectively. In adults, *A. indica* drupes revealed mean maximum mortality (35.55%) followed by *A. indica* leaves (29.98%).

Sankaraiyah and Lakshminarasimhan (2007) tested efficiency of partially purified fraction (methanol, ethyl acetate and petroleum ether) of seeds of *Croton tiglium* and *Strychnos nux vomica* against various stages of *Henosepilachna vigintioctopunctata.* LC_{50}/EC_{50} values of methanol fraction of *S.nux vomica* ranged between 0.074-0.108 per cent concentrations. The 3^{rd} instar and adults were more deterred from feeding on treated surface. Methanol fraction of *S.nux vomica* propounds more effective for select parameters in comparision with other fractions of *S.nux vomica* and *C. tiglium.*

CHAPTER-3
MATERIALS AND METHODS

The present studies were carried out under controlled conditions in the Department of Plant Protection and at the experimental fields of Faculty of Agricultural Sciences, AMU, Aligarh, (India) during 2009 - 2011.

Location

Aligarh is located in the western part of the state of Uttar Pradesh at a distance of about 126 km from Delhi, the capital of India. It spreads from $27^0$29' to $28^0$10' north latitude and $77^0$29 to $78^0$38' east longitude. The greatest width from west to east is about 116 km and the maximum length from north to south is about 72 km. Rest spreads over 5024 sq. km, but area changes slightly due to change of course of the rivers Ganges and Yamuna.

Climate and weather

The climate in Aligarh is of subtropical type having three well-defined seasons; winter, summer and monsoon. Winter season starts from November and continues up to first fortnight of April, whereas, summer sets in May. Months of May and June are the hottest wherein maximum day temperature plummets to 48^0C. The second half of December and January are usually the coldest period. Monsoon normally starts in the first week of July and continues with appreciable amount up to the first week of September. Annual rainfall of Aligarh district averages 315mm of which 75-80% is received from second half of July to first week of September.

Soils

The soil of the experimental fields is illitic fine sandy loam. The physico-chemical properties of the soil include sand- 61%, silt- 25%, clay- 14% and organic matter 0.41%. The soil water ratio is 1:2.5 and pH 7.3 to 8.1.

Fertilizer management

Brinjal is heavy feeder of fertilizers. Fertilizers were given @ 50 kg N_2, 25 kg P_20_5 and 40 kg K_2O/ hectare. Half of N_2 and total amount of P_20_5 and K_2O were well incorporated into the soil as basal dressing, through urea (46% N), DAP (18% N_2, 46% P_20_5) and MOP (60% K_2O). The remaining half of N_2 was top dressed at 30 days after sowing.

Irrigation, Weeding and Harvesting

First irrigation was given at the time of transplanting and subsequent irrigation was given at 4-6 days interval in summer and 10-14 days in winter and three weeding were given at 30 days interval. The crop was harvested after eight months.

1. Studies on population dynamics of *Henosepilachna* spp. on brinjal

1. A. Studies on population fluctuation of *H. vigintioctopunctata* and *H. dodecastigma* and seasonal incidence of parasitoids on *H. vigintioctopunctata* on brinjal.

Population dynamics of the two different species of hadda beetle was extensively studied on the cultivar Navkiran. Brinjal variety was raised round the year during 2010 and 2011 with recommended fertilizers and cultural practices in 3.5m x 3m plots replicated 9 times without any plant protection measures. Observations on the pest population was recorded at 7 days interval on 4 randomly selected plants from each replicated plots as number of adult beetles per plant basis through out the year. The population of egg, grub and pupa was recorded on 4 randomly selected plants in each replication to study the incidence of parasitoids. The egg batches, grubs and pupae were sampled every week and reared in the laboratory separately using Petri dishes to assess the per cent parasitism.

1. B. Linear Correlation analysis

To determine the correlation analysis of hadda beetle population and rate of parasitism with abiotic factors, weekly meterological data (minimum and maximum temperature, morning and evening humidity and rainfall) was collected from Meteorological station, Department of Physics, Aligarh Muslim University, Aligarh, India (Table-1 & 2). The data so generated from weekly observations was subjected to Pearson's correlation analysis by using the language program "R 2.12.2" unless stated otherwise.

1. C. Studies on seasonal abundance of *H. vigintioctopunctata* on six different cultivars of brinjal.

The studies on population dynamics of brinjal hadda beetle on different cultivars of brinjal were carried out during 2009-10. Among six cultivars of brinjal namely Suchitra and Pragati were oval in shape while Nageena, PPL-74, Lalat and Sweekar were long varieties. Seeds of the selected cultivars were sown in the month of October and transplanted in the month of November in 3 x 2.5 m^2 plots at a spacing of 75 x 60 cm in Randomized Block Design with three replications. Recommended agronomic practices like fertilizer application, irrigation, hoeing etc. were followed in raising the crop and remained same for all the cultivars. No plant protection measures were taken throughout the crop season. Observations on population dynamics of insect pests started as soon as their infestations were noticed and recorded till the harvesting of crop. Population density was determined by counting number of eggs, grubs, pupae and adults on twelve randomly selected plants in each variety at weekly intervals. Meteorological data on temperature, relative humidity and rainfall were obtained during the period of experimentation. Simple correlation coefficients were worked out between the weather parameters and mean population of eggs, grubs, pupae and adults on each variety.

2. Studies on the effect of solanaceous and cucurbitaceous hosts on life table and development of *H. vigintioctopunctata* in laboratory conditions

2. A. Effect of solanaceous and cucurbitaceous hosts on life table of *H. vigintioctopunctata.*

Insect rearing and experimental conditions

Different solanaceous crops viz. brinjal, black nightshade, winter cherry, tomato and a cucurbitaceous crop viz. bitter gourd were raised in an experimental field in Randomized Block Design in summer season of 2011 (Table-3). The seedlings of all crops were sown in plot size 3x3 m. All these crops were monitored regularly so as to assess the attack of hadda beetle. Eggs were found in clusters on the underside of the leaves in all the crops except in tomato, where eggs were not found.

The stock culture of *H. vigintioctopunctata* was maintained under laboratory conditions. For this purpose eggs were collected from respective crops in the field except in tomato, where larvae were directly collected from field and kept in Petri plates (10 cm) over the filter paper and placed in BOD incubator calibrated at 27^0C coupled with 80±5% Relative Humidity. 100 newly hatched healthy larvae were selected and reared in Petri plates lined with moist filter paper along with respective food plants. Food in the form of leaves was provided daily to the grubs till pupation. Fresh food from respective crop was supplied to the grubs and filter paper was changed daily to maintain hygienic conditions. Progeny of laboratory reared *H. vigintioctopunctata* was used in the experiments.

Effect of different host plants on age specific life table

Freshly emerged adult males and females were sorted out from the stock culture and kept in glass jars (25x15 cm) provided with fresh leaves of respective food plant with their petioles dipped in water in plastic containers (10x12 cm) for oviposition by females.

The eggs laid by females were counted and kept in petriplates (10 cm) in batches of 10 and replicated 10 times for construction of life table (100 cohort). The number of alive and dead out of 100 grubs were recorded daily every 24 h on all respective host plants and dead were removed from petriplates. After a series of molts, the grubs pupated; the deformed pupae were counted and discarded. The data obtained was analyzed for age and stage specific life tables as per suggestion of Birch (1948) and Southwood (1978).

Effect of different host plants on female fertility table

One female and two males, all newly emerged, of *H. vigintioctopunctata* were transferred in the respective food plants into glass jars (25 x 15 cm). A new male was added whenever another male died. Thus, females have alternative males for mating during lifetime. Adults on all respective foods were observed daily for longevity and egg laying. Fertility tables were constructed based on Birch (1948) and Southwood (1978).

Data analysis

These procedures necessitated for complete study of various life parameters of *H. vigintioctopunctata* for construction of life tables. Three types of life table as proposed by Deevy (1947), Brich (1948) and Southwood (1978) were constructed as given hereunder.

a. Age specific life-table
b. Stage specific life-table
c. Age specific survival and fertility table

a. Age Specific Life-Table

The following assumptions were used in the construction of age specific life-table.

x = Age of the insect in days

l_x = Number surviving at the beginning of each interval x out of 100

d_x = Number dying individuals during the age interval x out of 100

e_x = Expectation of life or mean life remaining for individuals of age x

Life expectation was calculated using the equation; $e_x = T_x / I_x$

To obtain e_x two other parameters L_x and T_x were also computed as below

L_x = the number of individuals alive between age x and x+1 and calculated by the equation

$$L_x = I_x+1\ (x+1) / 2$$

T_x = the total number of individual of x age units beyond the age x, and obtained by the equation,

$$T_x = I_x + (I_x+1) + (I_x+2) \ldots\ldots\ldots +I_w$$

Where,

I_w = The last age interval.

b. Stage Specific Life Table

A stage specific life table was constructed to see the effect of various host plants on the survival and mortality of different stages of *H. vigintioctopunctata.* Data on stage specific survival for eggs, larvae, pupae and adults were recorded from the age specific survival and mortality life table. The data obtained from such table was used for computing various life parameters as given below:

Apparent Mortality

This is measured mortality and gives the information on number dying as percentage of number entering that stage and was calculated by using the formula:

$$\text{Apparent Mortality} = d_x / l_x \text{ X } 100$$

Stage Specific Mortality (S_x)

Data obtained on apparent mortality was used for the calculation of the stage specific survival fraction (S_x) of each stage by using the equation:

S_x of particular stage = [I_x of subsequent stage] / [I_x of particular stage]

Mortality Survival Ratio (MSR)

It is the increase in population that would have occurred if the mortality in the stage, in question had not occurred and was calculated as follows:

MSR of particular stage = [Mortality in particular stage] / [I_x of subsequent stage]

Indispensable Mortality (IM)

This type of mortality would not be there in case the factor (s) causing it is not allowed to operate. However, the subsequent mortality factors operate. The equation is,

IM = Number of adults emerged x M.S.R. of particular stage

K- Values

It is key factor, which is primarily responsible for increase or decrease in number from one generation to another and was computed as the difference between the successive values for "log I_x". The total generation mortality was calculated by adding the k- values of different development stages of the insect, which is designated /indicated as "K" (Varley and Gradwell, 1960; Southwood, 1978).

$$K = k_0 + k_1 + k_2 \ldots\ldots k_n$$

Where, k_o, k_1, k_2,.....k_n are the k- values at egg, first instar, second instar, third instar, fourth instar, pupal stages.

c. Age specific Survival and Fertility–Table

The fertility was constructed with the following assumptions:

a) The survivorship rates were assumed to be the same for both the sexes, as it was not possible to identify the sexes prior to adult stage.

b) The sex could not be identified at the egg stage. Therefore a sex ratio of 1:1 was considered in each batch of eggs.

The table was constructed with the suggestions made by Birch 1948 and Southwood (1978). It consisted of following columns:

x = Pivotal age of class in days.

I_x = Number of females alive at the beginning of the age interval x (as fraction of initial population of one).

m_x = Average number of eggs laid per female in each age interval assuming 50:50 sex ratio and computed as:

$m_x = N_x / 2$

Where, N_x = Total natality per female off springs in each age.

Besides 'm_x' total number of female off springs in each age interval i.e., female lay eggs in an age interval (x), I_x. m_x was also computed by multiplying the column Ix with m_x. This is also termed as 'Reproductive expectation'.

A number of the parameters were computed from the age specific survival and fertility life table of female these include:

Net Reproductive or Replacement Rate (R_o)

This is also referred to as the "carrying capacity" of the average insect under defined environmental conditions. The information on the multiplication rate of a population in one generation is obtained from it. It is denoted as,

$$R_o = I_x m_x.$$

Potential Fecundity (P_f)

It expresses the total number of eggs laid by an average female in her total life span. It is obtained or calculated by summing up the age specific fecundity column,-

$$P_f = \sum m_x$$

Mean Length of Generation (T)

It is defined as the mean period between the birth of the parent and the birth of their off springs. This period is a weighed approximate value since the progeny is produced over a period of time and not at a definite time. Calculation followed the method suggested by Dublin & Lotka (1925)

$$T_x = \sum [I_x.m_x.X] / \sum [I_x.m_x]$$

Intrinsic Rate of Increase (r)

It is also denoted by 'r' or 'r_m' or 'r_{max}' and called as 'biotic potential'. It is defined as the instantaneous rate of increase of a population in a unit time under a set of ecological conditions (Birch, 1948). A rough estimate of the intrinsic rate of increase (r) can be calculated by using the following equation:

$$r = [\log e\ R_o] / T$$

Where, R_o represents net reproductive rate, which is calculated by multiplying I_x and m_x i.e., $R_o = I_x.m_x$.

'T' represents mean length of the generation. For an accurate estimate of 'r' Birch (1948) introduced some approximation to the method to minimize the experimental errors in the formula suggested by Lotka (1925). This is as under:

$$\sum e^{-rx}\ I_x m_x.d_x = 1 \qquad \text{Lotka (1925)}$$

$$e^{-rx}\ I_x.m_x = 1 \qquad \text{Birch (1948)}$$

Finite Rate of increase (λ)

It provides the information about the frequency of the population multiplication in a unit of time (Birch, 1948). It is denoted as-

$\lambda. = e^r$ taking log on both sides we get; $\log_e \lambda = \log_e e^r$

Where, λ = Antilog e^r

This was used for computing the rate of increase of population per year.

Doubling Time (DT)

It is defined as the time required for the population to double itself and is calculated as follows:

$$DT = Log\, e\, 2 / r$$

Annual Rate of Increase (ARI)

It can be calculated from the intrinsic rate of increase(r) or finite rate of increase (λ) or the doubling time (DT) or the net reproductive rate (Ro) assuming that the rate of increase was constant throughout the year.

$$ARI = 365 = e^{365r} = 2^{365/DT} = R_o^{365/T}$$

2. B. Effect of solanaceous and cucurbitaceous hosts on development of *H. vigintioctopunctata*

Development of immature stages

To test the effect of host plants on the duration of development, insects were taken from field collected population. The population was reared for a generation on each host plant to eliminate the effect of food reserves in the eggs and its effect on emerging larvae, before starting the experiment. Twenty leaf discs (5 cm diameter) of brinjal, winter cherry, black nightshade, tomato and bitter gourd respectively were cut and placed individually in twenty Petri dishes, each dish containing one leaf disc lined with moistened filter paper. On each leaf disc, one neonate larva was released and each petriplate was designated as a replicate. Larval food was changed every day and duration of development of different larval instars, total larval development period, pre-pupal period, pupal period, total development period (egg to pupa) were recorded. The data obtained in the experiment were subjected to ANOVA followed by Tukey-HSD test for multiple comparisons.

Development of adult stage

A newly emerged female and two males of *H. vigintioctopunctata* reared on each food type were placed together in glass jars (25 x 15 cm) provided with leaves of host plants with their petioles dipped in water in plastic containers as food for adults. A new male was added whenever male died. Adults on all respective food plants in 25 replications were observed daily for adult longevity and fecundity, pre-oviposition, oviposition and post-oviposition. For this purpose, all 25 females from each food source were offered the same oviposition substrate. Differences in fecundity, longevity and development time were tested by ANOVA. If significant differences were detected, the mean values were compared using Tukey-HSD test

3. Studies on differential responses of brinjal cultivars/accessions against *H. vigintioctopunctata* in field conditions.

A field experiment was conducted in Randomized Block Design (RBD) with three replications in an area of 400 m^2. Ten brinjal varieties screened against *H. vigintioctopunctata* is presented in Table-4. Forty- day old seedlings were transplanted in the well prepared field, with spacing of 75 x 60 cm. The cultural practices except plant protection measures were followed as per the crop production guide for horticultural crops. They were planted by maintaining twelve plants per replication and total of 36 plants per entry. Five plants per replication were tagged at random and observed for the incidence of *H. vigintioctopunctata* in each brinjal variety at weekly interval at the age of 130-140 days when susceptible check ‘ Navkiran’ was completely damaged by beetle. All the leaves in which the insects had scrapped more than one cm^2 area were classified as damaged. The mean percentage of leaves affected was then arrived with the total number of leaves versus affected leaves. The intensity of leaf damage was judged by cage studies in the field. For each entry, three plants were taken and the middle leaf from the terminal end was inserted through a muslin cloth sleeve attached to one end of transparent mylar film cage. It measured 8 cm in diameter and 10 cm in length and was secured to the plant. Through a slit in the mylar film cage, a newly emerged beetle starved for six hours was introduced into the cage. The leaf area scrapped in 24 h by single beetle was then measured using the graph sheet technique (Sambandam *et al.*, 1972). The outline of the area scrapped was marked on transparent butter paper and then measured by using graph sheet. The mean area fed by one beetle in 24 h was then arrived.

Assessment of damage index and grading

The mean per cent of leaves affected in each entry and the mean leaf area damaged by a beetle in 24 h were taken as the criteria for resistance. Based on these data, the damage index was computed by multiplying percentage of leaves affected and leaf area damage and then divided by 100. Based on the damage index, grading was assigned as follows:

Incidence = percentage of leaves affected

Intensity = leaf area damage in 24 h by one beetle

Damage Index = incidence x intensity/ 100

Damage index	***grade of susceptibility***
0.0 – 0.10	less susceptible
0.11 – 0.30	moderately susceptible
> 0.31	highly susceptible

This method involved only three grades of resistance assigned with the damage index, as per the modified scoring procedure (Rajendarn and Gopalan, 1997, b).

4. Studies on the evaluation of certain organic amendments against *H. vigintioctopunctata* on brinjal in field conditios.

Experimental design and treatments

The field trial was conducted for evaluation of certain organic nutrient sources against *H. vigintioctopunctata* on brinjal in 2011. All other agronomic practices were adopted uniformly for all the treatments. Treatments were taken as detailed in Table-5.

The treatments were replicated in Randomized Block Design, the variety being Navkiran. Farmyard manure (FYM) and Poultry manure with computed quantity was applied basally at the time of main field preparation in the respective treatments. The biofertilizer @ 2kg/ ha was incorporated to the soil in the respective treatments. Half of the dose of the total requirements of other organic amendments viz. neem cake and mahua cake were applied as basal and remaining half as top dressing in two equal splits at 20 days interval. Inorganic fertilizers in the form of Urea and DAP were applied. Fifty per cent of total N and entire P and K were applied as basal and the rest of 50 per cent N was applied in two equal splits as top dressing at 20 days interval. The neem oil @ 3% and Malathion (2ml/litre) were sprayed in the respective treatments at 30, 45 and 60 days after transplanting.

Pest incidence was assessed from ten randomly selected plants per plot. The total number of leaves and the number of scrapped leaves per plant were counted to work out the per cent leaf damaged (incidence). The observations were recorded at ten days interval commencing from 15^{th} to 75^{th} DAT besides a pre-treatment count.

Assessment of marketable yield and the Cost: Benefit Ratio

The yield of healthy fruits taken at each picking in each treatment were added as average yield/plant and converted into marketable yield (quintal/ha) by multiplying with respective number of plants/ha at adopted spacing between plant to plant and row to row. The Cost: Benefit Ratio was worked out from the yield of brinjal fruits and the cost of treatments incurred in the application, in order to find out an economically viable treatment for the management of *H. vigintioctopunctata* in brinjal. The market price of brinjal fruits, government rate of biopesticide, bio-fertilizers, fertilizers and manures, labor cost, and biopesticide spray charges were taken into account to compute the Cost: Benefit Ratio using the following formula:

Cost: Benefit Ratio = Value of yield over the control (Rs./ha)/ total cost of plant protection (Rs./ha)

Statistical analysis

Data were subjected to analysis of variance (ANOVA) by using Statistical package R, version 2.12.2. The means were separated through the pair wise comparison procedure by using the (Tukey's test). These procedures were done so that the evaluation of different treatments against *H. vigintioctopunctata* could be compared to each other and their relative efficacy could be adjusted.

5. Evaluation of bio-efficacy of some botanicals against *H. vigintioctopunctata* under semi-field conditions.

For this study a pot culture trial was carried out in CRD with three replications during 2010-11 crop seasons (Rabi season) in the faculty of Agricultural Sciences, AMU, Aligarh (U.P). Brinjal was transplanted on 16^{th} February 2011 in earthen pots containing mixture of soil and well rotten farm yard manure. Ten 4^{th} instar larvae of *H. vigintioctopunctata* reared in laboratory were released on potted plants. Each pot was covered by muslin cloth bag to prevent the escape of larvae. Treatments were taken as detailed in Table- 6.

Desired concentrations of various botanicals viz. neem leaf extract, *Calotropis* leaf extract, garlic extract, *Annona squamosa* seed extract, neem cake extract, *Parthenium* leaf extract and neem excel was prepared. The plants were sprayed in the evening hours with the help of hand atomizer. A control set was also run simultaneously with similar number of larvae but treated with only water and adjuvant. Before each treatment, the sprayer was rinsed thoroughly with water. Polythene sheet was used as a screen so as to avoid the drift of various formulations. The effectiveness of treatment was based on percentage mortality in larvae. For this purpose cumulative per cent mortality was calculated from data of 1^{st}, 3^{rd}, 5^{th}, and 7^{th} day and data after transformation was subjected to one-way analysis of variance. Efficacy of different treatments was compared on 5 per cent level of significance.

Preparation of crude extracts of test insecticides

Neem leaf extract:

One kilogram of fresh, tender neem leaves were plucked and put in a glass container and one litre of lukewarm water was added. The leaves were allowed to stand soaked in water for 12 hours and then macerated in a mixer-grinder. The extract was filtered through a muslin cloth and collected in a glass jar. This extract was considered as 100 per cent solution for which the desired concentrations were made (Swaminathan *et al., 2010*).

***Parthenium* leaf extract:**

One kilogram of fresh, tender *Parthenium* leaves were plucked and put in a glass container and one litre of lukewarm water was added. The leaves were allowed to stand soaked in water for 12 hours and then macerated in a mixer-grinder. The extract was filtered through a muslin cloth and collected in a glass jar. This extract was considered as

100 per cent solution for which the desired concentrations were made (Swaminathan *et al.*, 2010).

***Calotropis* leaf extract:**

One kilogram of fresh, tender *Calotropis* leaves were plucked and put in a glass container and one litre of lukewarm water was added. The leaves were allowed to stand soaked in water for 12 hours and then macerated in a mixer-grinder. The extract was filtered through a muslin cloth and collected in a glass jar. This extract was considered as 100 per cent solution for which the desired concentrations were made (Swaminathan *et al.*, 2010).

Garlic bulb extract:

2 Garlic bulbs were soaked in water for whole night. It was ground and made into paste. This paste was kept in muslin cloth bag and squeezed thoroughly for 5-10 minutes. Finally the suspension were collected and added with 4 cups of water to make desirable concentration. (Brooklyn Botanic Garden, 2000).

Neem cake extract:

100 gm of neem cake is required for 1 litre of water. The neem cake is put in muslin pouch and soaked in water. It is soaked overnight before use in the morning. It is then filtered and emulsifier is added at the rate of 1 ml of 1 litre of water (http://somphyto.com)

***Annona squamosa* seed extract:**

Seeds were taken and dried under shade. When well dried, their seed coats were removed and they were ground with mixer grinder. Then calculated quantity of well powdered *Annona squamosa* seeds were soaked in water and kept over night. Stirring was done frequently. Then the material was filtered through clean muslin cloth. This clear filtrate was considered as 100 per cent and was mixed with water to make desireable concentration (Murugesan and Murugesh, 2008).

Table 1: Meteorological data March-November, 2010

Standard week	Max. Temp. (°C)	Min. Temp. (°C)	Max. R.H.	Min. R.H.	Rainfall (mm)
11th	34.17	18.15	66.50	40.00	0.00
12th	38.24	20.94	56.80	30.14	0.00
13th	38.27	21.45	46.50	24.14	0.01
14th	39.90	21.65	35.14	16.57	0.00
15th	43.08	25.42	35.00	17.14	0.00
16th	41.70	26.94	36.42	20.71	0.00
17th	40.60	26.25	41.42	28.40	0.17
18th	38.40	26.15	54.28	38.85	0.00
19th	42.52	27.17	36.57	20.85	0.00
20th	42.37	28.02	36.71	22.85	0.00
21th	41.07	28.00	57.42	38.14	0.62
22th	41.17	27.82	43.71	32.00	1.45
23th	38.17	25.75	51.57	40.00	0.00
24th	41.41	28.28	46.42	28.71	0.00
25th	42.54	29.44	58.85	32.42	2.88
26th	37.88	27.50	66.42	53.28	1.90
27th	35.52	27.42	79.14	73.14	4.22
28th	35.71	27.28	79.28	66.28	1.54
29th	32.62	26.64	86.57	78.28	7.22
30th	31.74	26.55	85.42	77.85	4.54
31th	33.11	28.68	92.42	72.71	2.50
32th	34.22	27.25	86.28	71.71	8.97
33th	32.17	26.57	90.14	82.85	4.02
34th	32.61	26.44	89.57	77.71	8.31
35th	31.60	26.00	92.00	88.71	7.88
36th	31.71	26.12	88.70	88.42	6.88
37th	30.52	25.24	92.14	86.00	10.62
38th	29.30	23.71	91.28	82.42	1.02
39th	33.88	23.08	78.00	56.71	0.00
40th	33.71	23.22	75.41	52.57	0.00
41th	33.85	21.98	71.00	55.85	0.00
42th	32.97	22.18	77.14	54.42	0.00
43th	30.68	16.11	69.00	43.00	0.00
44th	29.81	15.88	79.00	52.85	0.00

Table 2: Meteorological data, February -October, 2011

Standard week	Max. Temp. (°C)	Min. Temp. (°C)	Max. R.H.	Min. R.H.	Rainfall (mm)
6th	25.88	11.34	83.28	54.57	0.00
7th	22.20	12.37	89.00	70.00	0.00
8th	24.14	12.11	90.42	59.57	0.00
9th	25.05	12.77	83.42	61.28	0.30
10th	27.97	13.85	77.85	47.00	0.00
11th	32.02	18.26	84.29	48.70	0.00
12th	33.28	17.60	67.40	37.85	0.00
13th	33.57	16.40	68.85	44.14	1.40
14th	34.57	18.08	48.85	26.28	0.00
15th	35.77	21.40	54.00	30.20	8.20
16th	36.74	20.44	53.42	24.42	7.80
17th	39.62	24.74	44.71	31.00	0.00
18th	39.65	21.48	58.42	34.85	18.0
19th	41.82	26.74	44.71	31.71	0.20
20th	40.08	26.54	55.70	34.71	10.4
21th	39.05	25.74	58.71	39.57	9.00
22th	39.51	25.54	55.85	35.71	1.80
23th	38.60	26.94	64.20	46.85	13.0
24th	35.62	25.25	81.14	61.28	31.2
25th	35.68	27.80	70.85	57.00	19.4
26th	33.97	25.71	84.42	76.00	23.4
27th	33.62	26.54	84.14	76.85	61.6
28th	32.20	26.22	91.28	78.85	45.8
29th	32.54	26.40	89.28	79.71	35.2
30th	32.48	26.25	89.00	78.71	109
31th	33.57	26.85	87.00	74.29	7.50
32th	31.42	26.17	88.00	80.14	35.0
33th	31.00	25.42	91.14	77.85	99.6
34th	32.94	26.85	90.28	75.71	57.4
35th	33.60	27.25	82.14	70.85	19.2
36th	33.51	26.00	87.00	73.71	10.5
37th	32.82	25.85	85.00	73.00	46.0
38th	33.62	24.25	82.42	57.57	0.00
39th	33.80	23.37	68.28	53.14	0.00
40th	33.88	22.97	72.57	49.14	0.00
41th	33.71	20.54	68.50	41.85	0.00
42th	32.48	18.80	70.00	43.14	0.00

Table 3: List of host plants used in various experiments

S. No.	Host plants	Scientific name
1.	Brinjal	*Solanum melongena*
2.	Winter cherry	*Withania somnifera*
3.	Black nightshade	*Solanum nigrum*
4.	Tomato	*Lycopersicon esculentum*
5.	Bitter gourd	*Momordica charantia*

Table 4: List of cultivars used in the experiment

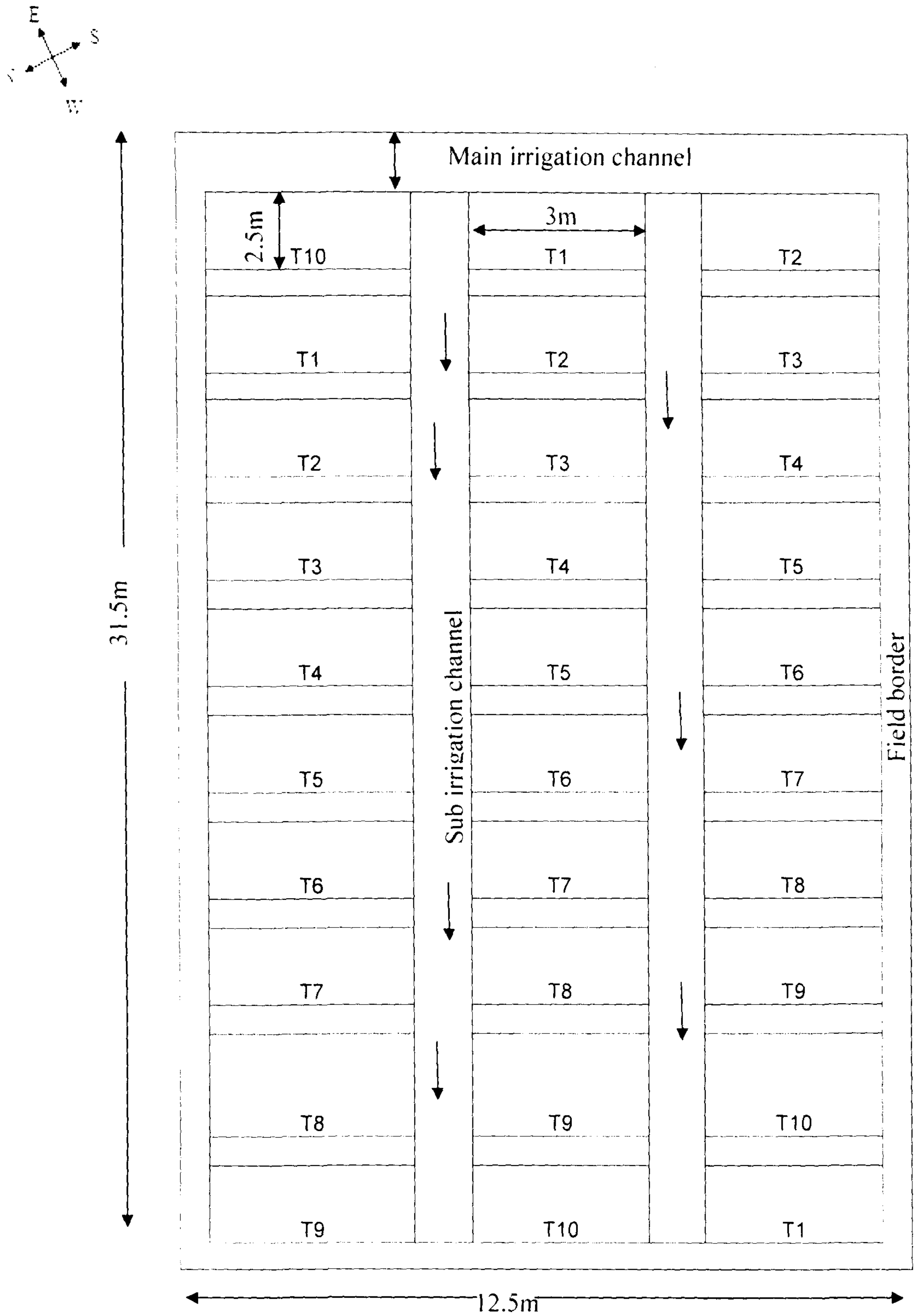
Cultivars	Shape of the fruit	Name of the company
Suchitra	oval	Indam seeds Pvt. Ltd.
Nageena	long	Doctor seeds Pvt. Ltd.
PPL- 74	long	Sungro seeds Pvt. Ltd.
Lalat	long	Century seeds Pvt. Ltd.
Pragati	round oval	Sungro seeds Pvt. Ltd.
Sweekar	long	Golden seeds Pvt. Ltd.
Pusa purple round	round	Mahyco Pvt. Ltd.
Pusa purple long	long	Mahyco Pvt. Ltd.
Navkiran	round	Mahyco Pvt. Ltd.
BR- 112	round	Sungro seeds Pvt. Ltd.

Table 5: List of the treatments used in the management of *Henosepilachna vigintioctopunctata* on brinjal

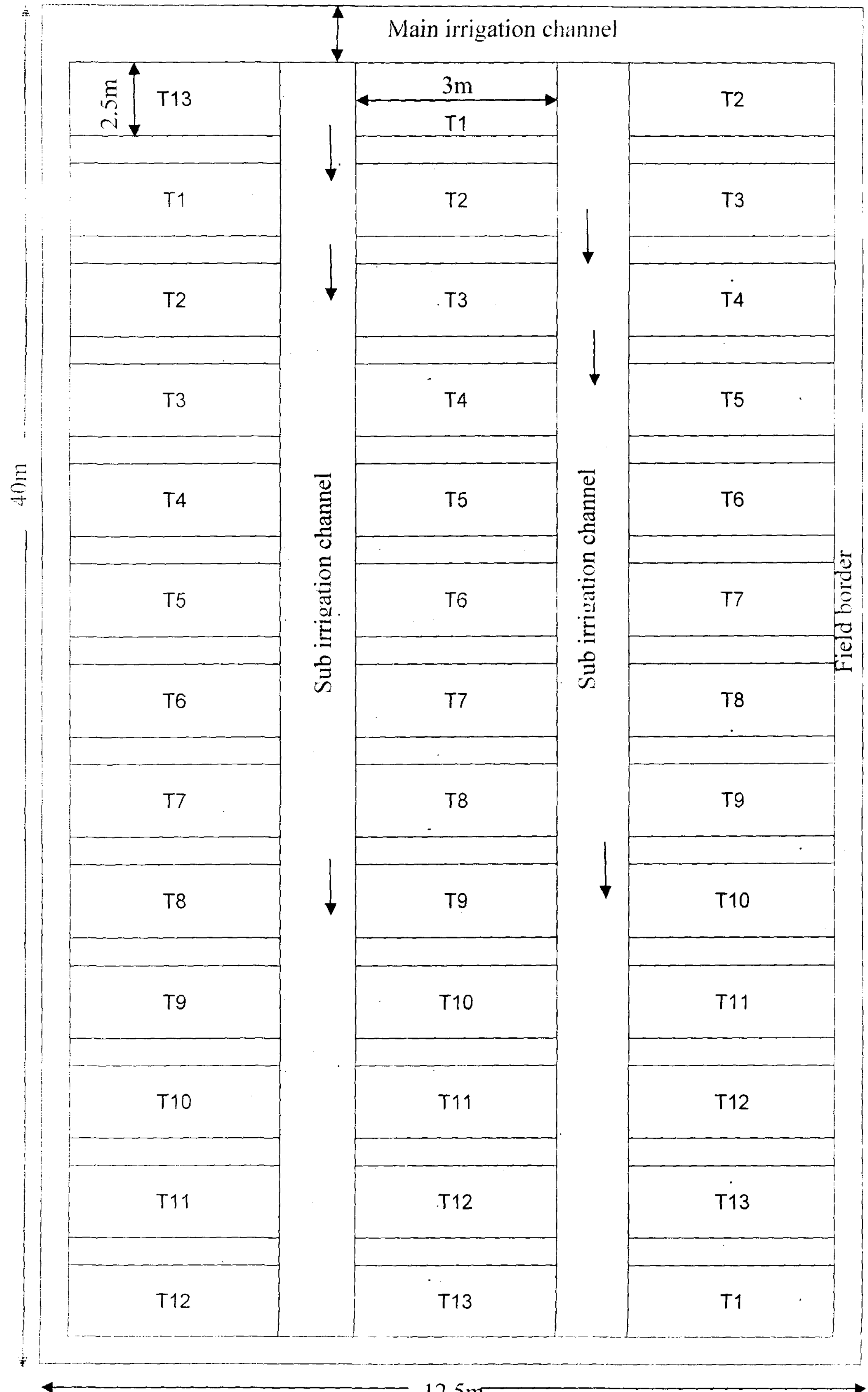
S. No	Treatments
T_1	FYM (12.5 t/ha) + Azophos (2 kg/ha) + Neem cake (800 kg/ha)
T_2	FYM (12.5 t/ha) + Azophos (2 kg/ha) + Mahua cake (1000 kg/ha)
T_3	FYM (12.5 t/ha) + Azophos (2 kg/ha) + Neem cake (800 kg/ha) + Ozoneem (3%)
T_4	FYM (12.5 t/ha) + Azophos (2 kg/ha) + Mahua cake (1000 kg/ha) + Ozoneem (3%)
T_5	FYM (6.25 t/ha) + Azophos (2 kg/ha) + Neem cake (400 kg/ha) + NPK(50%)
T_6	FYM (6.25 t/ha) + Azophos (2 kg/ha) + Mahua cake (500 kg/ha) + NPK (50%)
T_7	FYM (6.25 t/ha) + Azophos (2 kg/ha) + Neem cake (400 kg/ha) + NPK(50%) + Ozoneem (3%)
T_8	FYM (6.25 t/ha) + Azophos (2 kg/ha) + Mahua cake (500 kg/ha) + NPK (50%) + Ozoneem (3%)
T_9	FYM (12.5 t/ha)
T_{10}	Poultry manure alone (3 t/ha)
T_{11}	NPK (90:50:50 kg/ha) + Ozoneem (3%)
T_{12}	NPK alone (90:50:50 kg/ha)
T_{13}	Untreated control

Table 6: List of botanicals used in the management of *Henosepilachna vigintioctopunctata* on brinjal.

S.No.	Botanicals	Concentration	Plant part used
T_1	Neem leaf extract	5.0%	Leaves
T_2	*Calotropis* leaf extract	5.0%	Leaves
T_3	Garlic extract	5.0%	Cloves
T_4	*Annona squamosa* seed extract	5.0%	Seeds
T_5	Neem excel	0.3%	Seeds
T_6	Neem cake extract	5.0%	Seeds
T_7	*Parthenium* leaf extract	5.0%	Leaves
T_8	Control	-	-



Layout plan of experiment on differential responses of brinjal cultivars accessions against *H. vigintioctopunctata*, conducted during 2010.



Layout plan of experiment on evaluation of certain organic amendments against *H. vigintioctopuncta* in brinjal conducted during 2011.

CHAPTER-4
RESULTS

1. Studies on population dynamics of *Henosepilachna* spp. on brinjal

1. A. Population fluctuation of *H. vigintioctopunctata* and *H. dodecastigma*

Seasonal abundance of *H. vigintioctopunctata* and *H. dodecastigma* were determined on brinjal from March 2010 to November 2010 and February 2011 to October 2011 at Faculty of Agricultural Sciences, A.M.U, Aligarh (Table- 7 & 8). The initial infestation of *H. vigintioctopunctata* and *H. dodecastigma* occurred in 3rd week of March (11SW) and 4th week of March (12SW) with an average population level of 1.7 and 0.25 beetles per plant, respectively in 2010 (Fig. 1 & 2). During this period the temperature fluctuated from 18.15 to 38. 24^{0}C and relative humidity was between 30.14 and 66.5 per cent with 4.9 mm rainfall. While, the initial appearance of *H. vigintioctopunctata* and *H. dodecastigma* was noticed in 2nd week of February and 3rd week of February (8SW) with an average population level of 0.34 and 0.29 beetles per plant in 2011, respectively. Through this period the temperature ranged between 11.34 and 25.88^{0}C with relative humidity of 54.57 to 89 per cent.

The population of *H. vigintioctopunctata* and *H. dodecastigma* gradually increased and a significant increase was observed in 3rd week of May with an average population of 5.25 and 2.75 beetles per plant, respectively in 2010 and in 4th week of May with an average population of 5.75 and 3.2 beetles per plant, respectively in 2011. During this period temperature ranged from 28.02 to 42.37^{0}C with relative humidity of 22.85 to 36.71 per cent in 2010 and 25.74 to 39.05^{0}C and relative humidity of 39.57 to 58.71 per cent and a very scanty rain of about 9mm in 2011.

Further, the population of both the species declined steadily up to 1st week of July and then abruptly increased and reached the peak in 1st week of August in both the years.

Peak populations of *H. vigintioctopunctata* and *H. dodecastigma* were found to be 13.9 and 8.7 beetles per plant, respectively at temperature fluctuating between 26.55 to 31.74^{0}C with relative humidity of 77.85 to 85.42 per cent and total rainfall of 31.78mm in 2010 and 15.7 and 9.1 beetles per plant, respectively at temperature of 26.25 to 32.48^{0}C and 78.71 to 89 per cent relative humidity and rainfall of about 109 mm in 2011. Thereafter, population of *H. vigintioctopunctata* and *H. dodecastigma* declined gradually and completely disappeared in 2nd week of November in 2010 and 3rd week of October in 2011.

Seasonal abundance of *H. vigintioctopunctata* and *H. dodecastigma* were subjected to Pearson's correlation test that showed a positively significant/non-significant reaction with environmental conditions. The data (Table-9) indicated that in 2010 the population of *H. vigintioctopunctata* and *H. dodecastigma* exhibited a highly significant positive correlation with minimum temperature (r= 0.460) and (r= 0.486), respectively whereas, maximum temperature showed non-significant positive correlation with the adult population of *H. vigintioctopunctata* and *H. dodecastigma* ie. r= 0.68 and 0.69, respectively. While the population of *H. vigintioctopunctata* and *H. dodecastigma* showed highly significant positive correlation with minimum relative humidity (r= 0.392 and r= 0.406, respectively) and significant positive correlation with maximum temperature (r= 0.334 and r= 0.359, respectively). Rainfall exhibited highly significant positive correlation (r= 0.419 and r= 0.519) with the population of *H. vigintioctopunctata* and *H. dodecastigma*, respectively.

Whereas, in 2011 (Table-10) the population of *H. vigintioctopunctata* and *H. dodecastigma* exhibited a highly significant positive correlation with minimum temperature (r= 0.532 and r= 0.525, respectively), maximum relative humidity (r= 0.433 and r= 0.424, respectively), minimum relative humidity (r= 0.614 and r= 0.612, respectively) and rainfall (r= 0.619 and r= 0.655, respectively). While, the population of *H. vigintioctopunctata* and *H. dodecastigma* showed non-significant positive correlation with maximum tempeture (r= 0.022 and r= 0.010, respectively).

1. B. Seasonal incidence of parasitoids of *H. vigintioctopunctata* on brinjal

Egg parasitism was first noticed in mid-April while, pupal parasitism was initially noticed in first week of May in 2010 and 2011 (Table-7 & 8). Egg parasitism increased gradually and reached its peak during 3rd week of May (43.2% and 24.6 %) in 2010 and 2011, respectively. However, from 4th week of May parasitism declined until it completely disappeared in the beginning of June in both the years. Thereafter, egg parasitism reappeared in the last week of July and increased gradually and peak occurred in the 2nd week of August (43.3%) in 2010 and 1st week of September (27.6%) in 2011 and decreased gradually until it reached a negligible level in the beginning of October in 2010 and last week of September in 2011 (Fig. 3&4)

Whereas, grub parasitism was first observed in the last week of April, that increased up to first week of June in 2010 and last week of May in 2011 and then declined abruptly and completely vanished during mid June in both the years. Thereafter, grub parasitism reappeared at the end of July, which gradually increased until it peaked in the first week of September (29.5%) and (49.5%) in 2010 and 2011, respectively. However, from second week of September parasitism declined until it completely disappeared in the beginning of October in 2010 and at the end of September, 2011.

While, pupal parasitism was initially occurred at the beginning of May and tended to increase up to beginning of June and then declined suddenly and completely disappeared in the mid-June in both the years. Later, pupal parasitism recurred in the second week of September, 2010 and at the end of August, 2011, that increased gradually and peaked during third week of September (14.1% and 24.1%) in 2010 and 2011, respectively. However, after peak period parasitism decreased abruptly until it reached to zero at the beginning of October, 2010 and end of September, 2011.

The rate of parasitization was correlated positively/negatively significant/nonsignificant to maximum and minimum temperature as well as maximum and minimum humidity during 2010 and 2011. Rainfall was sometimes favourable/ unfavourable for perpetuation of parasitoids during both the years of studies (Table- 9 & 10). In 2010, egg parasitism showed highly significant positive correlation with minimum humidity and rainfall (r= 0.344 0. and r= 0.631, respectively) while, significant positive correlation with minimum temperature and maximum humidity (r= 0.392 and r= 0.494, respectively). Maximum temperature exhibited non-significant negative correlation (r=-0.198) with egg parasitism. Whereas, in 2011 egg parasitism exhibited highly significant positive correlation with minimum temperature (r= 0.451) and significant positive correlation with maximum temperature (r= 0.355). While, rainfall and minimum humidity showed non-significant positive correlation (r= 0.392 and r= 0.406, respectively) and maximum relative humidity showed non-significant negative correlation (r= -0.108) with egg parasitism.

Grub parasitism exhibited highly significant positive correlation with minimum temperature (r= 0.513 and r= 0.434) and rainfall (r= 0.550 and r= 0.461) and significant positive correlation with minimum relative humidity (r= 0.395 and r= 0.379) in 2010 and 2011, respectively. While, maximum relative humidity showed non-significant correlation (r= 0.211 and r= 0.243) in 2010 and 2011, respectively. Maximum temperature exhibited non-significant negative correlation (r= -0.67) in 2010 and non-significant positive correlation (r= 0.81) in 2011 with grub parasitism.

Whereas, pupal parasitism exhibited non significant positive correlation with maximum temperature (r= 0.162), minimum temperature(r= 0.293), minimum relative

Table 7: Population of *Henosepilachna* spp. and mean per cent parasitism (egg, grub and pupa) in 2010

Standard week	Mean no. of *H.vigintioctopunctata* beetles per plant	Mean no. of *H.dodecastigma* beetles per plant	Egg parasitism (%)	Grub parasitism (%)	Pupal parasitism (%)
11	1.70	0.00	0.00	0.00	0.00
12	1.80	0.25	0.00	0.00	0.00
13	0.33	0.75	0.00	0.00	0.00
14	0.50	0.00	0.00	0.00	0.00
15	0.00	0.25	0.00	0.00	0.00
16	0.50	0.25	3.20	11.10	0.00
17	0.50	0.20	5.60	11.50	0.00
18	0.33	0.25	12.80	13.60	3.20
19	1.20	1.35	17.09	14.50	6.90
20	5.25	2.75	43.20	16.80	9.30
21	2.15	1.30	21.90	19.00	8.20
22	1.80	1.10	6.00	21.00	11.20
23	1.60	0.85	0.00	11.30	9.50
24	1.90	1.10	0.00	0.00	0.00
25	2.10	1.30	0.00	0.00	0.00
26	2.50	1.60	0.00	0.00	0.00
27	7.60	3.30	0.00	0.00	0.00
28	8.90	4.70	0.00	0.00	0.00
29	11.3	6.90	0.00	0.00	0.00
30	13.9	8.70	11.10	18.50	0.00
31	12.2	8.30	24.20	21.42	0.00
32	4.30	6.10	43.30	21.21	0.00
33	5.40	3.20	39.80	23.00	0.00
34	2.10	2.70	36.10	27.10	0.00
35	2.40	1.10	38.70	29.50	0.00
36	2.30	1.40	37.40	18.30	11.20
37	3.90	2.70	40.10	18.00	14.10
38	5.70	2.10	28.60	14.60	3.40
39	5.30	2.90	21.30	8.30	1.60
40	5.90	2.70	0.00	5.10	0.00
41	1.30	1.80	0.00	0.00	0.00
42	1.10	1.30	0.00	0.00	0.00
43	1.00	0.90	0.00	0.00	0.00
44	0.40	0.10	0.00	0.00	0.00

Table 8: Population of *Henosepilachna* spp. and mean per cent parasitism (egg, grub and pupa) in 2011

Standard week	Mean no. of *H.vigintioctopunctata* beetles per plant	Mean no. of *H.dodecastigma* beetles per plant	Egg parasitism (%)	Grub parasitism (%)	Pupal parasitism (%)
6	0.34	0.00	0.00	0.00	0.00
7	0.14	0.29	0.00	0.00	0.00
8	0.28	1.70	0.00	0.00	0.00
9	0.16	0.80	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
11	0.17	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00
13	0.65	0.85	0.00	0.00	0.00
14	0.50	0.80	0.00	0.00	0.00
15	0.13	0.50	12.8	0.00	0.00
16	0.25	0.20	13.7	6.70	0.00
17	0.17	0.25	15.6	7.10	0.00
18	0.38	0.33	16.8	8.50	8.20
19	0.92	1.50	12.8	10.1	12.0
20	2.63	1.20	24.6	12.2	12.8
21	5.75	3.20	7.10	12.5	14.5
22	3.00	2.40	5.30	5.00	17.8
23	1.50	1.80	0.00	0.00	16.3
24	1.92	1.20	0.00	0.00	0.00
25	2.20	1.10	0.00	0.00	0.00
26	2.50	1.20	0.00	0.00	0.00
27	5.30	3.20	0.00	0.00	0.00
28	9.10	3.60	0.00	0.00	0.00
29	12.5	5.20	0.00	0.00	0.00
30	15.7	9.10	7.48	24.5	0.00
31	11.5	6.90	13.5	31.42	0.00
32	8.90	5.50	13.2	31.21	0.00
33	4.10	3.60	12.9	31.0	0.00
34	2.50	2.10	22.3	47.1	16.2
35	2.70	1.90	27.6	49.5	18.6
36	3.20	2.10	23.8	11.3	23.2
37	3.50	2.30	21.5	1.80	24.1
38	3.40	2.10	0.00	0.00	0.00
39	3.70	2.50	0.00	0.00	0.00
40	1.20	0.90	0.00	0.00	0.00
41	1.10	0.40	0.00	0.00	0.00
42	0.00	0.00	0.00	0.00	0.00

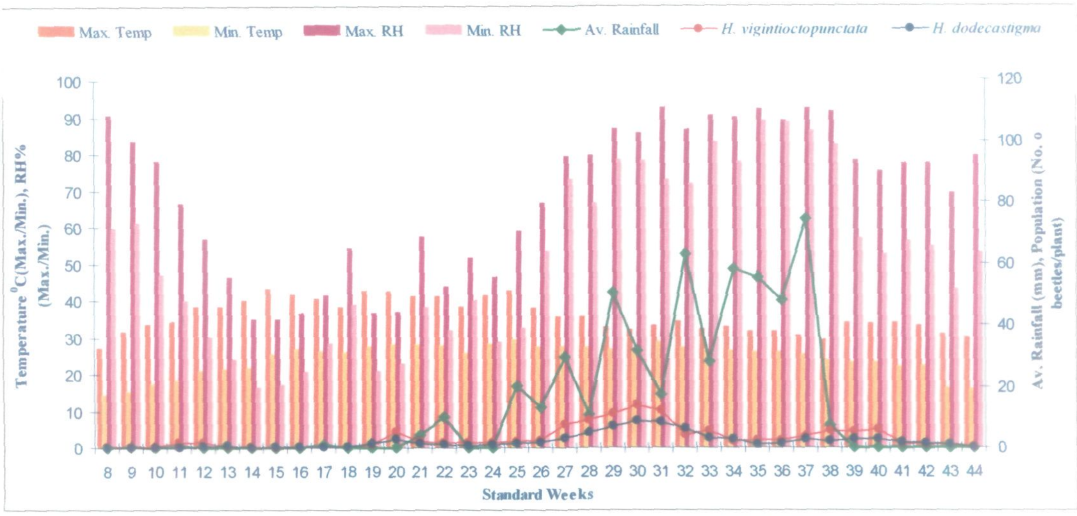


Fig. 1: Population fluctuation of *Henosepilachna* spp. on brinjal (2010)

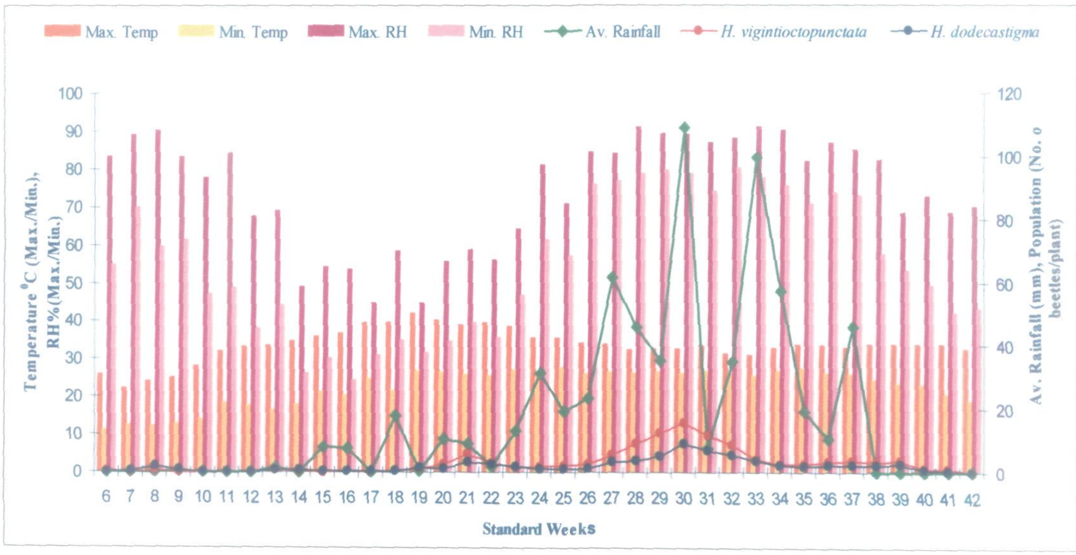


Fig. 2: Population fluctuation of *Henosepilachna* spp. on brinjal (2011)

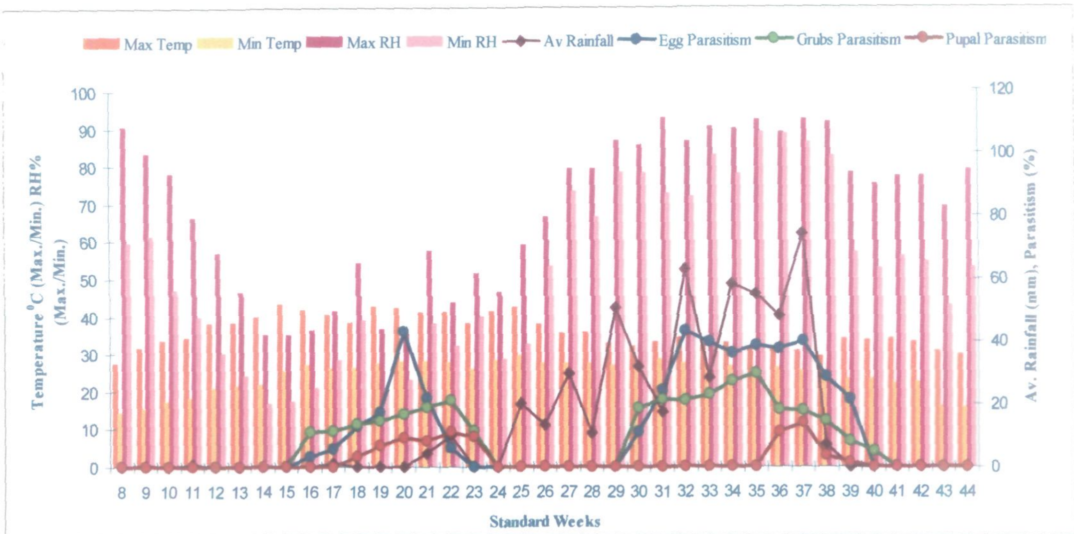


Fig. 3: Seasonal incidence of parasitoids on *Henosepilachna vigintioctopunctata* in brinjal (2010)

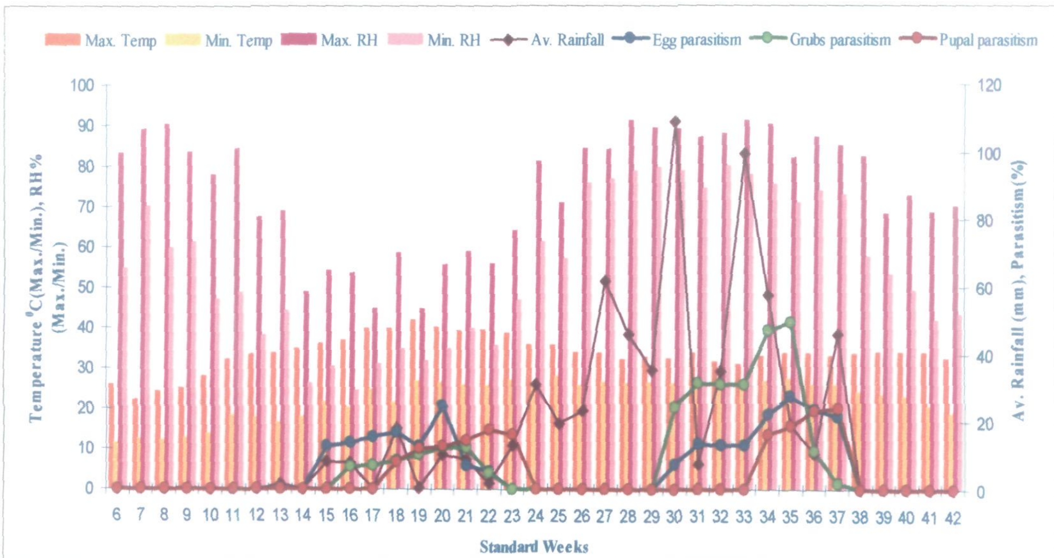


Fig. 4: Seasonal incidence of parasitoids on *Henosepilachna vigintioctopunctata* in brinjal (2011)

Table 9: Correlation of *Henosepilachna* population and its natural enemies with weather parameters (2010)

Abiotic Factors →	Max. Temp.	Min. Temp.	Max. R.H.	Min. R.H.	Rainfall
H. vigintioctopunctata population	.068ns	460**	.334 *	.392 *	.419**
H. dodecastigma population	.069ns	.486**	.359 *	.406**	.519**
Mean % parasitism (Egg)	-.198ns	.392 *	.344 *	.494**	.631**
Mean % parasitism (Grub)	-.067ns	.513**	.211ns	.395 *	.550**
Mean % parasitism (Pupal)	.162ns	.293ns	-.146ns	.012ns	.202ns

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
* Significant at 0.05% level, **Significant at 0.01% level

Table 10: Correlation of *Henosepilachna* population and its natural enemies with weather parameters (2011)

Abiotic Factors →	Max. Temp.	Min. Temp.	Max. R.H.	Min. R.H.	Rainfall
H. vigintioctopunctata population	.022ns	.532**	. 433**	.614**	.619**
H. dodecastigma population	.010ns	.525**	.424**	.612**	.655**
Mean % parasitism (Egg)	.355 *	.451**	-.108ns	.055ns	.229ns
Mean % parasitism (Grub)	.081ns	.434**	.243ns	.379 *	.461**
Mean % parasitism (Pupal)	.382 *	.421**	-.115ns	.017ns	.043ns

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
* Significant at 0.05% level, **Significant at 0.01% level

humidity (r= 0.012) and rainfall(r= 0.202) and non-significant negative correlation with maximum relative humidity (r= -0.146) in 2010. While, in 2011 it showed highly significant positive correlation with minimum temperature(r= 0.421), significant positive correlation with maximum temperature (r= 0.382), non significant positive correlation with minimum relative humidity (r= 0.017) and rainfall(r= 0.043) and exhibited non-significant negative correlation with maximum relative humidity (r= -0.115).

Tetrastichus sp. and *Pedobius foveolatus,* an egg parasitoid and larval parasitoid, respectively were emerged from the field collected *H. vigintioctopunctata* eggs and larvae that were reared in the laboratory. While, few pupae were also found parasitized by *P. foveolatus* and some pupal parasitoids were also recorded in the present study but not yet identified.

1. C. Seasonal abundance of *H. vigintioctopunctata* on six different cultivars of brinjal.

Eggs

Results of population density of hadda beetle eggs on six brinjal varieties revealed that the appearance of eggs was first noticed on 17^{th} March 2010 (11^{th} SW) on variety Nageena and Pragati with mean population density of 10.08 and 5.00 eggs per plant, respectively (Table-11). While, in other varieties viz. Suchitra, PPL-74, Lalat and Sweekar, the initial appearance of eggs were observed on 12^{th}, 15^{th}, 14^{th} and 13^{th} SW, respectively. The highest population density of 45.67, 42.75 and 37.33 eggs per plant was recorded in 17^{th} SW on Suchitra, PPL-74 and Sweekar, resp. while, on Nageena, Lalat and Pragati maximum number of eggs were found on 18^{th} SW with 37.75, 55.31 and 91.12 eggs per plant, respectively. Egg density increased from their initial appearance to 17^{th} - 18^{th} SW in all the varieties and then diminished (Fig. 5). The highest egg density was recorded on Pragati (12.50 eggs per plant) followed by Lalat, PPL-74, Sweekar, Suchitra and Nageena with 9.62, 9.35, 9.21 8.43 and 6.91 eggs per plant, respectively, after pooling the mean of egg densities on different dates. Non- significant difference was observed among cultivars on all the dates except on 18^{th} and 24^{th} SW, where significant variations in egg densities were noted among the varieties.

The correlation analysis of mean data for all varieties revealed that all the weather parameters showed non significant influence on the egg densities of *H. vigintioctopunctata* (Table-15). Among six cultivars, mean egg densities on Suchitra, PPL-74, Lalat and Sweekar exhibited positive correlation with Max. and Min. temperature while, negatively correlated with Max. RH and average rainfall. Maximum Temperature and average rainfall showed positive influence on mean egg density for Nageena and Pragati while, possessed positive correlation with all other abiotic factors.

Grubs

The peak level of larval infestation on all the varieties of brinjal reached on 19^{th} SW except Nageena and PPL-74 variety, where the peak infestation was observed early on 18^{th} week (Fig. 6). During the whole cropping season maximum numbers of larvae were harboured by Nageena, which were followed by remaining varieties. The seasonal pooled mean of larval population significantly differed among the varieties. It is evident from seasonal pooled mean that the maximum population (11.91 larvae per plant) was on Nageena which was at par with those recorded on PPL-74 and Suchitra but differed significantly with those recorded on Lalat, Pragati and Sweekar (Table-12). The minimum population was recorded on Lalat which showed significant variation with those evidenced on other five cultivars. While, Pragati and Sweekar showed intermediate population which statistically did not differ from each other but revealed significant variations with those recorded on other four varieties. Significant differences were however recorded in weekly populations of *H. vigintioctopunctata* larvae among six varieties on 12th, 13th, 18th, 19th, 20th, 21th and 24th SW out of 14 sampling dates.

The correlation coefficients between larval population and abiotic parameters could not establish significant relationship of larval population with environmental factors (Table-16). In all the varieties larval population was non- significantly positively correlated with Max. and Min. temperature while, negative non-significant correlation was found in case of Max. and Min. rainfall except in Suchitra and PPL-74, where Min. RH was found positively correlated with larval population.

Pupae

The pupal density of hadda beetle during 14 sampling dates among all the cultivars is presented in Table-13. The data in table shows that pupation was initially noticed between last week of March to 2nd week of April on cultivars Suchitra, Nageena, Lalat, Pragati and Sweekar with population density of 0.08, 0.17, 0.17, 0.08, and 0.08 pupae per plant respectively. Population disappeared abruptly from 21st April to 12th May and rapidly increased and attained its peak on 3rd week of May with population density of 14.33, 5.75, 7.0, 6.41, 22.25 and 14.91 pupae per plant on cultivars Suchitra, Nageena, PPL-74, Lalat, Pragati and Sweekar, respectively. Pupal density of the pest declined gradually till the mid of June and reached to population density of (0.00, 0.15, 0.00, 0.00, 0.00 and 0.00) pupae per plant. Weekly pupal densities of hadda beetle were found non-significantly different on all the cultivars except on 20th , 21st and 22nd SW out of fourteen sampling dates in the cropping season (Fig. 7). The pooled seasonal mean of pupal density per plant on different brinjal cultivars indicated that highest population of 2.49 pupae per plant was recorded on variety Pragati which were significantly more than the pupal density in Suchitra, Nageena, PPL-74 and Lalat with 1.58, 0.86, 0.73 and 0.58

pupae per plant, respectively. The pupal density in Pragati and Sweekar were statistically similar to each other.

Mean pupal density showed non-significant positive correlation with Max. and Min. temperature and rainfall in all the cultivars of brinjal (Table-17). Non-significant negative correlation was exhibited with Min and Max. RH in all varieties while, in Nageena and Sweekar non-significant but positive correlation was found between pupal density and Max. and Min. RH.

Adults

It is apparent from the Table-14, that hadda beetles started its initial infestation from 11th SW in variety Nageena, Lalat and Pragati while, on variety Suchitra and PPL-74, beetle infestation was first noticed on 13th SW. However, the population trend varied significantly among the varieties of brinjal. It was revealed from the data on varietal pooled mean that the variety Nageena and Pragati supported significantly higher number of beetles as compared to the remaining varieties. During the whole cropping season the population density of beetles was more on the Nageena and Pragati which was followed by remaining varieties. Variety Nageena supported relatively the higher population of beetles in the 15th, 16th, 18th, 19th and 21st SW in cropping season (Fig. 8). The variety Pragati supported relatively more number of beetles during 11th, 14th, 16th, 10th and 22nd SW in cropping season. The beetles were observed in greater numbers on variety PPL-74 during 13th, 23rd and 24th SW. Significant variations were noted among the varieties on seasonal mean basis as apparent from Fig. The population density of beetle was found relatively lower from 11th to 17th SW than the subsequent weeks as evident from pooled mean. Maximum numbers of beetles were observed during the 21th SW of crop growth, as evident from the pooled varietal means. Thereafter, it gradually declined and remained at lower level of density upto 24th SW.

Table 11: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Eggs) on six different cultivars of brinjal

Variety	Weekly observation on infestation of hadda beetle on different cultivars of brinjal														Pooled Seasonal Mean
	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun	16-Jun	
Suchitra	0a	1.67a	0a	1.25a	12.67a	26.91ab	45.67a	6.25a	0a	0a	0a	5.33b	8.08ab	10.25ab	8.43a
Nageena	10.08b	0a	0a	0a	1.5a	6.91ab	15.61a	37.75a	12.08ab	0a	0a	0a	3.08ab	10.25ab	6.91a
PPL-74	0a	0a	0a	0a	8.91a	3.63a	42.75a	28a	11.67ab	0a	0a	0a	10.25b	25.75b	9.35a
Lalat	0a	0a	0a	6.17a	3.08a	16.13ab	25.41a	55.31ab	24.75b	0a	0a	0a	0a	3.91a	9.62a
Pragati	5ab	0a	0a	0a	11.13a	24.58ab	34a	91.12b	7.88ab	1.25a	0a	0a	0a	0a	12.50b
Sweekar	0a	0a	1.25a	0a	10a	29.91b	37.33a	36.58a	12.83ab	0a	0a	0a	0a	1.08a	9.21a
Pooled Varietal Mean	2.51	0.27	0.20	1.23	7.88	18.01	33.46	42.50	11.53	0.20	0	0.88	3.56	8.54	----
LSD at 0.05	7.9	1.92	1.45	7.3	13.42	23.7	33.92	50.91	20.81	1.45	0	4.27	9.69	16.15	5.26

The values in column followed by similar letter (s) are not significantly different (P>0.05, Tukey's HSD) from each other.

Table 12: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Grubs) on six different cultivars of brinjal

Variety	Weekly observation on infestation of hadda beetle on different cultivars of brinjal														Pooled Seasonal Mean
	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun	16-Jun	
Suchitra	0a	1.5a	0.5a	0.08a	0a	0.25a	46c	28.83a	30.08a	31.41c	12.17b	0.08a	1.25a	1.75ab	10.99bc
Nageena	10.67b	6.33b	2.08b	0.08a	0a	26.83a	14.58ab	35.75ab	30.87a	31.5c	5.25a	0.25a	0.83a	1.75ab	11.91c
PPL-74	0a	0a	0a	0a	0a	1.5a	27.87bc	61.5b	50.41a	15.37b	0.75a	0.13a	0.25a	5.91b	11.69c
Lalat	0a	0.33a	0a	0a	0a	1.5a	3.58a	14.41a	24.83a	2.5a	0.58a	0.08a	0a	0a	3.42a
Pragati	8.87b	3.67ab	0.5a	0a	0a	0a	0ab	27.13a	51.38a	6.13ab	2.63ab	0.13a	0a	0a	7.17ab
Sweekar	0a	0.67a	0.16a	0a	0a	7.88a	9.75ab	20.75a	30.25a	6.33ab	3.88ab	0.13a	0a	0a	5.7a
Pooled Varietal Mean	3.25	2.08	0.54	0.02	0	6.32	16.96	31.39	36.30	15.54	4.21	0.13	0.38	1.56	-------
LSD at 0.05	7.22	3.97	1.15	0.12	0	29.76	24.89	26.96	25.71	11.55	8.89	0.32	1.43	4.13	4.13

The values in column followed by similar letter (s) are not significantly different (P>0.05, Tukey's HSD) from each other.

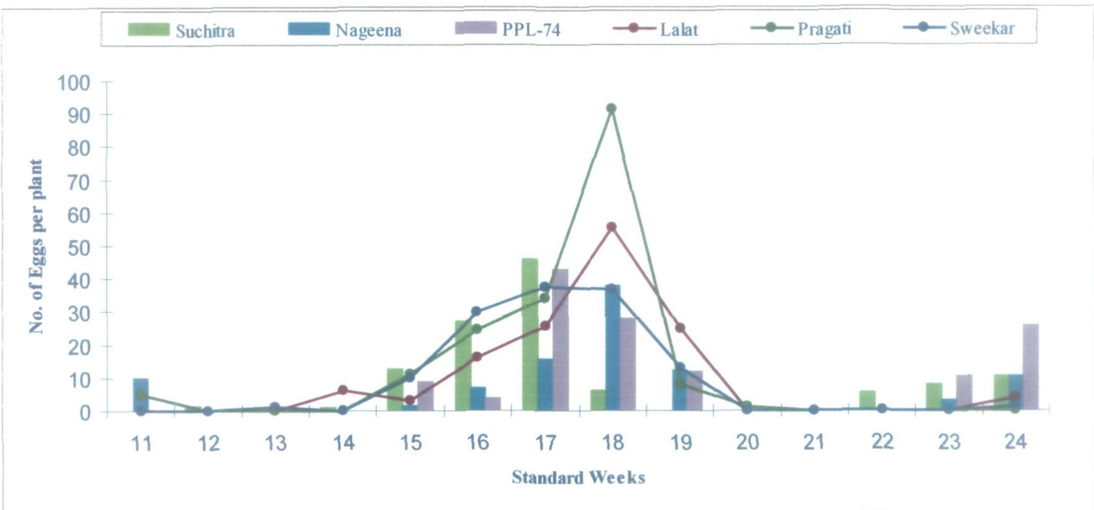


Fig. 5: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Eggs) on six different cultivars of brinjal.

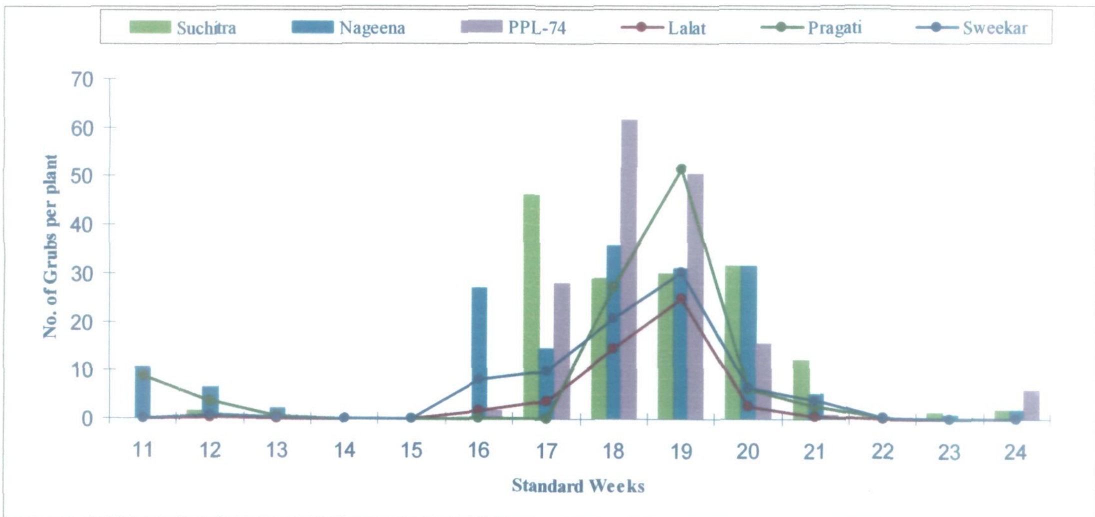


Fig. 6: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Grubs) on six different cultivars of brinjal.

Table 13: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Pupae) on six different cultivars of brinjal

Variety	Weekly observation on infestation of hadda beetle on different cultivars of brinjal														Pooled Seasonal Mean
	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun	16-Jun	
Suchitra	0a	0a	0.08a	0a	0a	0a	0a	0a	0a	14.33ab	7.5ab	0.17a	0a	0a	1.58bc
Nageena	0a	0a	0a	0a	0.17ab	0a	0a	0a	0a	5.75a	5.41ab	0.75	0.15b	0a	0.86ab
PPL-74	0a	0a	0a	0.17b	0a	0a	0a	0a	0a	7a	3a	0.25ab	0a	0a	0.73ab
Lalat	0a	0a	0a	0.08ab	0a	0a	0a	0a	0a	6.41a	1.25a	0.41b	0a	0a	0.58a
Pragati	0a	0a	0a	0a	0a	0a	0a	0a	0a	22.25b	12.25b	0.13a	0a	0a	2.49d
Sweekar	0a	0a	0a	0a	0.08ab	0a	0a	0a	0a	14.91ab	12.87b	0.33b	0a	0a	2.01c
Pooled Varietal Mean	0	0	0.013	0.041	0.041	0	0	0	0	11.77	7.04	0.34	0.02	0	----------
LSD at 0.05	0	0	0.08	0.16	0.16	0	0	0	0	14.33	7.5	0.17	0	0	0.85

The values in column followed by similar letter (s) are not significantly different (P>0.05, Tukey's HSD) from each other.

Table 14: Seasonal abundance of *Henosepilachna vigintioctopunctata* (Adults) on six different cultivars of brinjal

Variety	Weekly observation on infestation of hadda beetle on different cultivars of brinjal														Pooled Seasonal Mean
	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun	16-Jun	
Suchitra	0a	0a	0a	0.25a	0.25b	0.17b	0.08ab	0a	0a	0.33a	4.33ab	1.33ac	1.58ab	1.92c	0.73ab
Nageena	0.08a	0a	0.08a	0.17a	0.25b	0.25b	0a	0.58	0.58a	0.58ab	8.58b	2.83bc	1.33ab	1.25abc	1.18c
PPL-74	0a	0a	0.25a	0a	0a	0.25b	0a	0.13a	0.25a	0.38a	1.75a	2.38bc	2b	1.67bc	0.65a
Lalat	0.01a	0.08a	0.08a	0.25a	0a	0a	0.17b	0.17a	0.25a	0.92ab	1a	1.17ab	0.25ab	0.58ab	0.35a
Pragati	0.17a	0a	0a	0.5a	0.13ab	0.25b	0a	0.38a	2.63b	0a	5.75ab	3c	1.5ab	0.34a	1.05bc
Sweekar	0a	0a	0.08a	0a	0.25b	0.17b	0a	0.08a	0.08a	1.83b	3.88a	0.67a	0.67ab	0.75ab	0.60a
Pooled Varietal Mean	0.043	0.013	0.08	0.19	0.14	0.18	0.04	0.22	0.63	0.67	4.21	1.89	1.22	1.08	--------
LSD at 0.05	0.17	0.08	0.34	0.43	0.14	0.13	0.16	0.53	0.49	1.32	4.57	1.67	1.44	1.14	0.39

The values in column followed by similar letter (s) are not significantly different (P>0.05, Tukey's HSD) from each other.

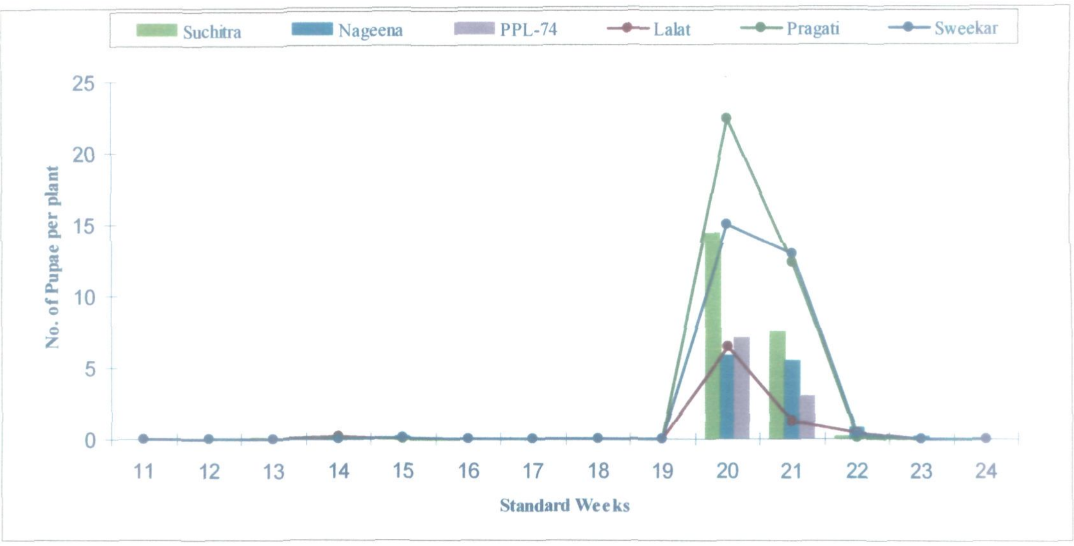


Fig. 7: Seasonal abundance of *H.vigintioctopunctata* (Pupae) on six different cultivars of brinjal.

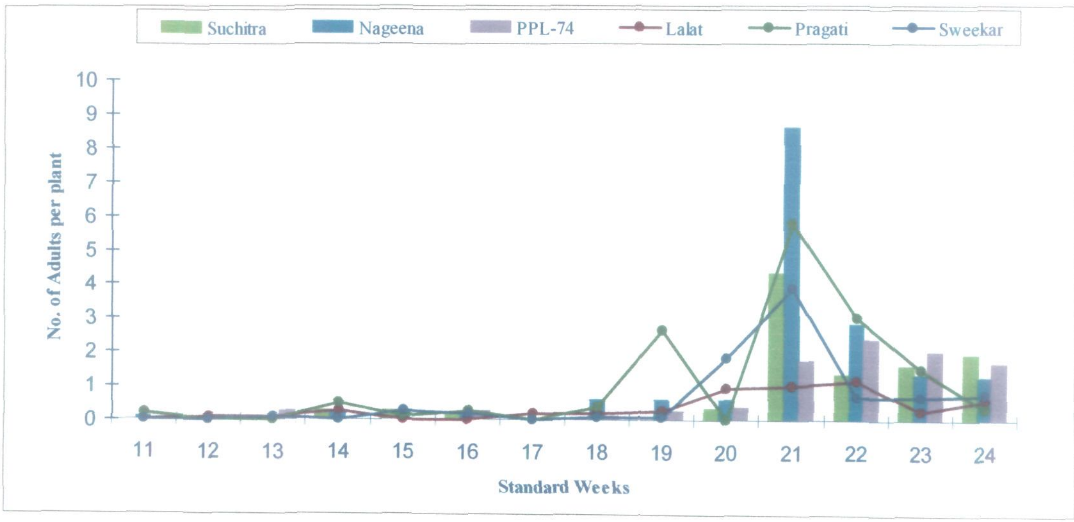


Fig. 8: Seasonal abundance of *H.vigintioctopunctata* (adults) on six different cultivars of brinjal.

Table 15: Correlation coefficients between *H. vigintioctopuncta* egg density and weather parameters

Six varieties/ cultivars of Brinjal	Weather parameters				
	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)
	Max.	Min	Max	Min	Avg.
Suchitra	0.243	0.271	-0.312	-0.138	-0.053
Nageena	-0.191	0.131	0.202	0.338	-0.237
PPL-74	0.121	0.343	-0.081	0.132	-0.192
Lalat	0.041	0.235	-0.072	0.087	-0.204
Pragati	-0.089	0.152	0.078	0.227	-0.169
Sweekar	0.149	0.264	-0.207	-0.045	-0.188

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
*Significant at 0.05% level, **Significant at 0.01% level

Table 16: Correlation coefficients between *H. vigintioctopuncta* grub density and weather parameters.

Six varieties/ cultivars of Brinjal	Weather parameters				
	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)
	Max.	Min	Max	Min	Avg.
Suchitra	0.261	0.402	-0.190	0.012	-0.110
Nageena	0.174	0.304	-0.164	-0.062	-0.287
PPL-74	0.126	0.318	-0.092	0.075	-0.193
Lalat	0.146	0.232	-0.119	-0.035	-0.159
Pragati	0.073	0.135	-0.026	-0.005	-0.189
Sweekar	0.258	0.363	-0.204	-0.073	-0.173

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
* Significant at 0.05% level, **Significant at 0.01% level

Table 17: Correlation coefficients between *H. vigintioctopuncta* pupal density and weather parameters

Six varieties/ cultivars of Brinjal	Weather parameters				
	Temperature (^0C)		Relative Humidity (%)		Rainfall (mm)
	Max.	Min	Max	Min	Avg.
Suchitra	0.309	0.353	-0.089	-0.017	0.061
Nageena	0.304	0.399	0.027	0.111	0.235
PPL-74	0.313	0.350	-0.124	-0.044	0.055
Lalat	0.304	0.313	-0.205	-0.119	0.007
Pragati	0.309	0.355	-0.082	-0.010	0.062
Sweekar	0.300	0.374	0.009	0.074	0.147

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
* Significant at 0.05% level, **Significant at 0.01% level

Table 18: Correlation coefficients between *H. vigintioctopuncta* adult density and weather parameters

Six varieties/ cultivars of Brinjal	Weather parameters				
	Temperature (^0C)		Relative Humidity (%)		Rainfall (mm)
	Max.	Min	Max	Min	Avg.
Suchitra	0.185	0.450	0.284	0.421	0.461
Nageena	0.191	0.415	0.292	0.403	0.565*
PPL-74	0.145	0.511	0.167	0.449	0.664**
Lalat	0.380	0.587*	-0.035	0.190	0.734**
Pragati	0.241	0.461	0.166	0.345	0.628*
Sweekar	0.283	0.467	0.180	0.284	0.356

Max. = Maximum, Min. = Minimum, Temp. = Temperature, R,H. = Relative humidity
* Significant at 0.05% level, **Significant at 0.01% level

Correlation analysis revealed that the population of hadda beetle was positively correlated with all the weather parameters in all the varieties except Lalat variety where it was found to be negatively correlated with Max. RH and showed significant positive correlation with Min. temperature. Mean hadda beetle population buildup showed significant positive correlation with the Average rainfall in all varieties except Suchitra and Sweekar which had positive but non-significant correlation with Average rainfall (Table-18).

2. A. Effect of solanaceous and cucurbitaceous hosts on life-table of *H. vigintioctopunctata*

a. Age-Specific life-table:

Comparative study on age specific life table of Brinjal hadda beetle on different host plants revealed that it required minimum of 50 days to complete generation on brinjal followed by 51 days on winter cherry, black nightshade, and bitter gourd and 55 days on tomato. The survivorship and expectation of life declined gradually with advancement of age (Fig. 9). However, the fluctuations of mortality parameter were seen on all the host plants (Fig. 10). The highest per cent (26) of unhatched eggs were found on tomato followed by 18% on black nightshade, 12% on winter cherry on the last day of incubation period. While on brinjal and bitter gourd, 100% hatching of eggs was recorded. It was demarcated in Fig. 10, that the early instar stages are more susceptible than late instar stages in tomato and bitter gourd. The highest mortality of the first instar (nineteen individuals) were found on bitter gourd at 5th day followed by five individuals on tomato on 7th day while the late instars (third instar stages), were found more susceptible on brinjal, winter cherry and black nightshade as evident by the mortality figures.

Pupal stages were also found susceptible and highest mortality occurred in bitter gourd, black nightshade, tomato and brinjal. On bittergourd, six and five pupae were found to have died during the middle and at the end of pupal period, respectively. The mortality at adult stages was recorded after 2 days of emergence from pupa on brinjal, whereas on other four hosts the mortality of adults began the next day of emergence from pupa and continued until the death of remaining individuals. The life expectancy declined with advancing of age. The highest life expectancy was found on brinjal in comparison to the other host crops.

b. Stage-specific life-table:

The various parameters on mortality and survival of *H. vigintioctopunctata* were calculated in the form of apparent mortality, survival fraction, mortality survival ratio, indispensable mortality, K- value and reviewed in Table-19.

1. ***Apparent mortality:***

On brinjal and bittergourd no apparent mortality of eggs was noticed. However, egg mortality was highest on tomato (26%) followed by black nightshade (18%) and winter cherry (12%). At larval instars, the highest mortality (22.2%) was noticed at second instar on tomato and lowest (5%) at first instar on brinjal. Similarly, at the pre-pupal and pupal stages, the maximum mortality (17.64 and 32.14% respectively) was observed on tomato and minimum (1.42 and 10.14% respectively) on brinjal.

2. ***Survival fraction*****:**

It was evident from the observations that maximum survival fraction at egg stage was found on brinjal and bittergourd (1.00), followed by winter cherry (0.88), black nightshade (0.82) and tomato (0.74). At different larval instars, the highest fraction (Sx) was obtained (0.95) at first instar on brinjal, whereas, lowest (0.77) at second instar on tomato. On the other hand, at pre-pupal stage maximum Sx (0.98) was found on brinjal and bitter gourd in contrast to minimum (0.82) on tomato. Similarly, at pupal stage high Sx was recorded (0.89) on brinjal and low (0.67) on tomato.

3. *Mortality Survival ratio*:

At egg stage, the highest mortality survival ratio (MSR) was obtained on tomato (0.35) as compared to lowest (0.00) on brinjal and bitter gourd. While comparing larval instars, maximum mortality survival ratio (0.29) was found at second instar on tomato and minimum (0.05) at first instar on brinjal. At pre-pupal stage, it remained high (0.21) on tomato and low (0.01) on brinjal and bittergourd. At pupal stage MSR ranged from 0.11 to 0.47 on different host plants.

4. *Indispensable mortality*:

The highest indispensable mortality (6.80) at egg stage was recorded on winter cherry and lowest (0.00) on brinjal and bitter gourd. At larval stages, indispensable mortality (IM) was noticed maximum (11.84) at first instar on bittergourd and minimum (3.26) at first instar on brinjal. At pre-pupal stage, it remained highest (4.07) on tomato followed by lowest (0.72) on bitter gourd. However, at pupal stage, maximum IM (16.00) was obtained on bitter gourd and minimum (7.00) on brinjal.

5. *K*- *value*:

At egg stage, the highest K-value was recorded (0.1308) on tomato and lowest (0.00) on brinjal and bitter gourd (Fig. 11). While comparing larval instars, the maximum 'k' (0.1091) was obtained at second instar on tomato and minimum (0.0223) at first instar on brinjal. At pre-pupal stage, the highest 'k' value (0.0843) was obtained on tomato and lowest (0.0062) on brinjal. However, at pupal stage, maximum 'k' (0.1684) was found on tomato and lowest (0.0465) on brinjal. Similarly, the total generation mortality 'K' was recorded maximum (0.7212) on tomato followed by minimum (0.2076) on brinjal.

c. Female fertility table

Total fecundity of *H. vigintioctopunctata* was significantly influenced by different host plants and was higher on brinjal than other crops (Table-20). The lowest mean fecundity (mx), 26 eggs per female occurred on tomato. Daily reproduction was also affected by different host plants in the following order: brinjal < winter cherry < black nightshade < bitter gourd < tomato. It was apparent that female ovi-posited the eggs during definite period of pivotal age. The female started to lay eggs after 8 days of the pre-ovipositional period in brinjal, black nightshade and bitter gourd, 9 days in winter cherry and 14 days in tomato. The longest duration of natality of 16 days was encountered on brinjal and black nightshade while the shortest was on tomato (7 days). The lowest mean fecundity is considerably affected by age and host plant. It is greatest in the middle of the age for all host plants and then declined with gradually with advancing age. Post oviposition was also recorded on all the host plants. Life-table indices for five different hosts are presented in Table-21. The potential fecundity was maximum on brinjal and minimum on tomato i.e. 161 and 26 days respectively. The highest net reproductive rate (R_0) was observed on brinjal (52.64), followed by black nightshade (17.77), winter cherry (16.85) and bitter gourd (15.36 females/ female/ generation). However, the smallest net

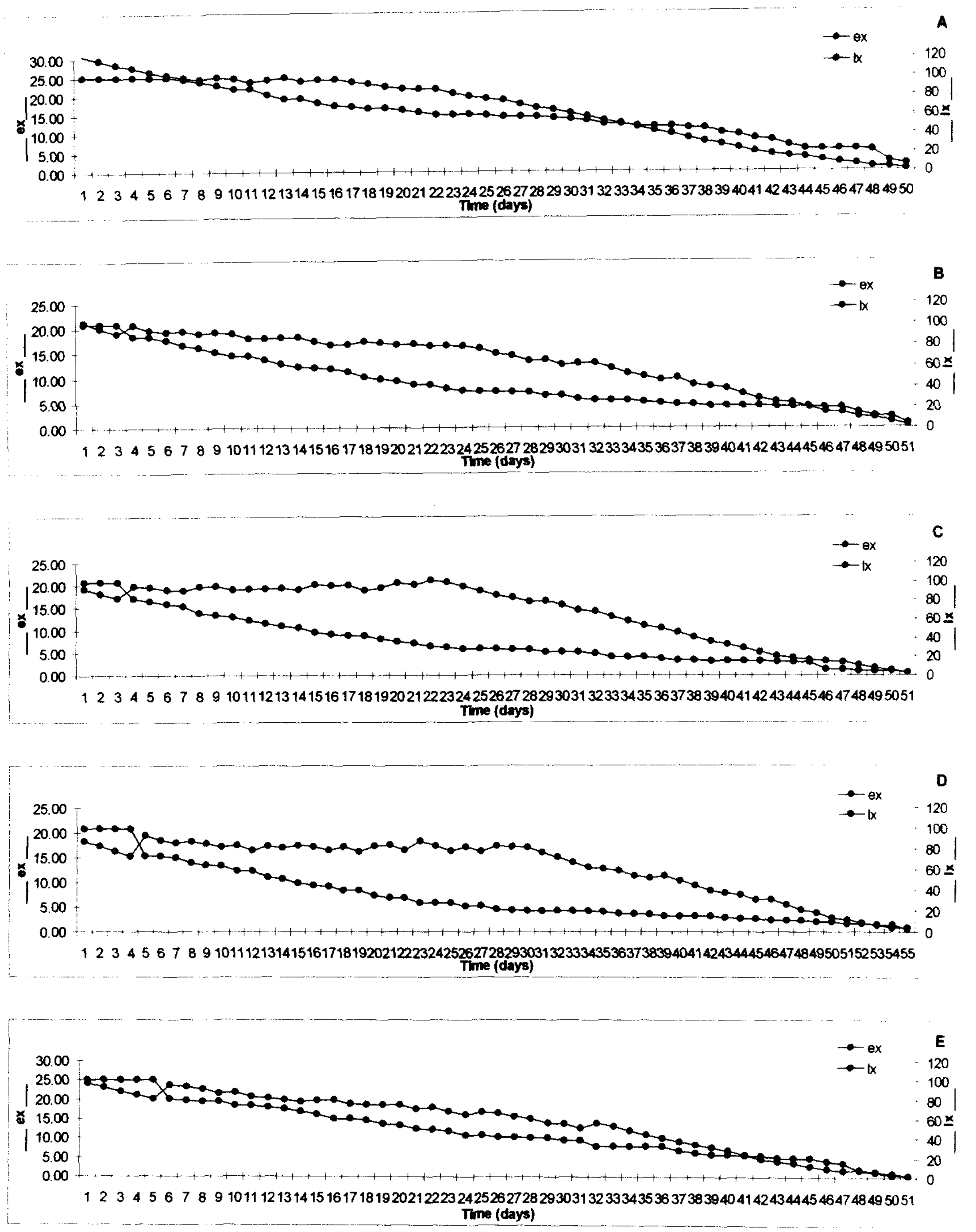


Fig. 9: Survivorship (lx) and life expectancy (ex) of *Henosepilachna vigintioctopunctata* on different host crops, brinjal (A), winter cherry (B), Black nightshade (C), tomato (D) and bitter gourd (E).

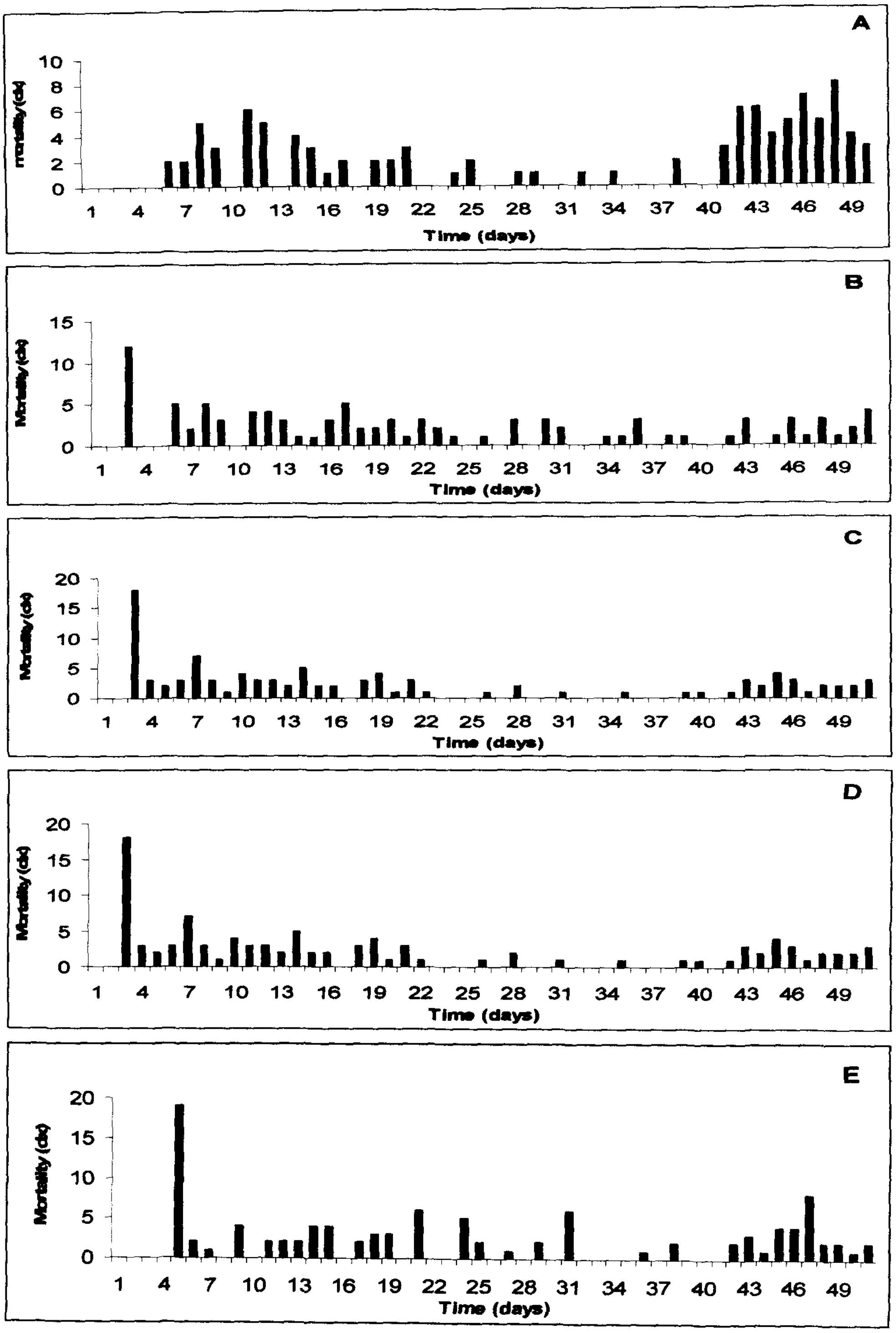


Fig. 10: Mortality (dx) of *Henosepilachna vigintioctopuncta* on different host crops, brinjal (A), winter cherry (B), black nightshade (C), tomato (D), and bitter gourd (E).

Table 19: Stage specific life table of *Henosepilachna vigintioctopunctata* on five host plants.

Stages *x*	No. surviving at beginning of stage *lx*	No. dying at Stage *Dx*	Apparent mortality *100qx*	Survival Fraction *Sx*	Mortality/ Survival ratio *MSR*	Indispensable mortality *IM*	Log *lx*	*k-values*
				Brinjal				
Egg	100	0	0.000	1.0000	0.0000	0.000	2.0000	0.0000
I instar	100	5	5.000	0.9500	0.0526	3.263	2.0000	0.0223
II instar	95	7	7.368	0.9263	0.0795	4.932	1.9777	0.0332
III instar	88	12	13.636	0.8636	0.1579	9.789	1.9445	0.0637
IV instar	76	6	7.895	0.9211	0.0857	5.314	1.8808	0.0357
Pre-Pupa	70	1	1.429	0.9857	0.0145	0.899	1.8451	0.0062
Pupa	69	7	10.145	0.8986	0.1129	7.000	1.8388	0.0465
Adult	62	62	100	-	-	-	1.7924	-
								K=0.207
				Winter cherry				
Egg	100	12	12.000	0.8800	0.1364	5.182	2.0000	0.0555
I instar	88	7	7.955	0.9205	0.0864	3.284	1.9445	0.0360
II instar	81	7	8.642	0.9136	0.0946	3.595	1.9085	0.0393
III instar	74	14	18.919	0.8108	0.2333	8.867	1.8692	0.0911
IV instar	60	8	13.333	0.8667	0.1538	5.846	1.7782	0.0621
Pre-Pupa	52	2	3.846	0.9615	0.0400	1.520	1.7160	0.0170
Pupa	50	12	24.000	0.7600	0.3158	12.000	1.6990	0.1192
Adult	38	38	100	-	-		1.5798	-
								K=0.420
				Black nightshade				
Egg	100	18	18.000	0.8200	0.2195	6.805	2.0000	0.0862
I instar	82	8	9.756	0.9024	0.1081	3.351	1.9138	0.0446
II instar	74	10	13.514	0.8649	0.1563	4.844	1.8692	0.0631
III instar	64	14	21.875	0.7813	0.2800	8.680	1.8062	0.1072
IV instar	50	6	12.000	0.8800	0.1364	4.227	1.6990	0.0555
Pre-Pupa	44	4	9.091	0.9091	0.1000	3.100	1.6435	0.0414
Pupa	40	9	22.500	0.7750	0.2903	9.000	1.6021	0.1107
Adult	31	0	-	-	-		1.4914	-
								K=0.508
				Tomato				
Egg	100	26	26.000	0.7400	0.3514	6.676	2.0000	0.1308
I instar	74	11	14.865	0.8514	0.1746	3.317	1.8692	0.0699
II instar	63	14	22.222	0.7778	0.2857	5.429	1.7993	0.1091
III instar	49	8	16.327	0.8367	0.1951	3.707	1.6902	0.0774
IV instar	41	7	17.073	0.8293	0.2059	3.912	1.6128	0.0813
Pre-Pupa	34	6	17.647	0.8235	0.2143	4.071	1.5315	0.0843
Pupa	28	9	32.143	0.6786	0.4737	9.000	1.4472	0.1684
Adult	19		-	-	-	-	1.2788	0.0000
								K=0.721
				Bitter gourd				
Egg	100	0	0.000	1.0000	0.0000	0.000	2.0000	0.0000
I instar	100	22	22.000	0.7800	0.2821	11.846	2.0000	0.1079
II instar	78	6	7.692	0.9231	0.0833	3.500	1.8921	0.0348
III instar	72	8	11.111	0.9028	0.1231	5.169	1.8573	0.0444
IV instar	65	6	9.231	0.9077	0.1017	4.271	1.8129	0.0421
Pre-Pupa	59	1	1.695	0.9831	0.0172	0.724	1.7709	0.0074
Pupa	58	16	27.586	0.7241	0.3810	16.000	1.7634	0.1402
Adult	42		-	-	-	-	1.6232	-
								K=0.376

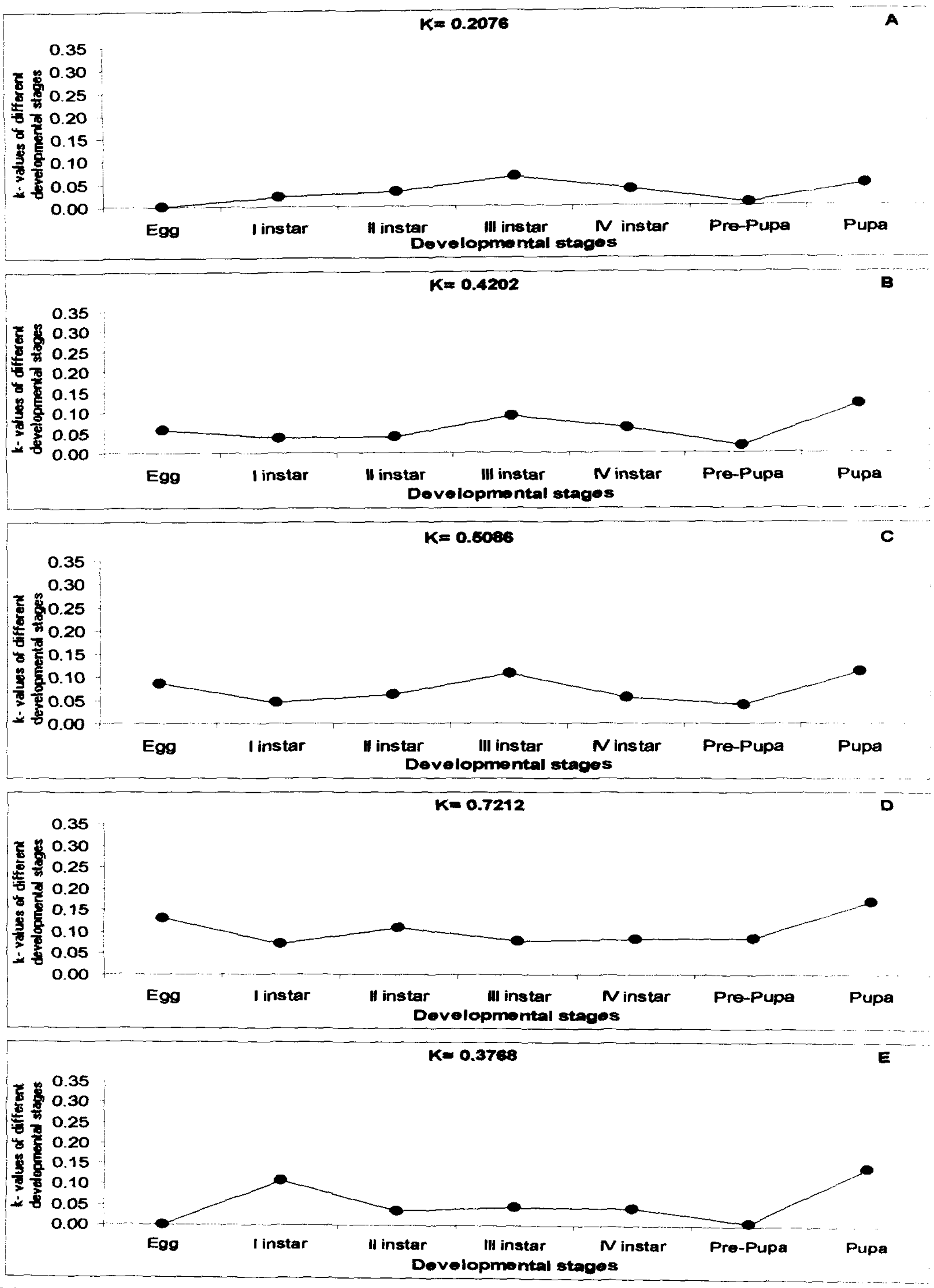


Fig. 11: *k*- values of different stages of *Henosepilachna vigintioctopunctata* on various host plants under laboratory conditions. ('K' represents total generation mortality)(A= brinjal, B= winter cherry, C= black nightshade, D= tomato, E= bitter gourd).

Table 20: Female fertility table of *Henosepilachna vigintioctopunctata* on five host plants

Pivotal age (day) x	Age-specific female survivorship l_x	Fecundity m_x	$l_x m_x$	$l_x m_x . x$	Value of $e^{-rmx} l_x m_x$	% constitution of each group towards 'r'
		Brinjal				
0.5-20.0	Immature stage					
21.5-28.5	Pre- oviposition period					
29.5	0.33	21.00	6.930	211.365	0.142	13.030
30.5	0.32	20.00	6.400	201.600	0.115	10.673
31.5	0.31	16.00	4.960	161.200	0.140	13.004
32.5	0.31	14.00	4.340	145.390	0.123	11.232
33.5	0.29	12.00	3.480	120.060	0.159	14.535
34.5	0.28	10.50	2.940	104.370	0.135	12.369
35.5	0.28	9.50	2.660	97.090	0.057	5.249
36.5	0.27	9.00	2.430	91.125	0.048	4.444
37.5	0.27	8.00	2.160	83.160	0.037	3.422
38.5	0.24	7.50	1.800	71.100	0.031	2.867
39.5	0.23	7.50	1.725	69.863	0.028	2.561
40.5	0.21	7.00	1.470	61.005	0.020	1.831
41.5	0.19	6.00	1.140	48.450	0.020	1.909
42.5	0.15	5.00	0.750	32.625	0.013	1.218
43.5	0.13	4.00	0.520	23.140	0.009	0.870
44.5	0.11	4.00	0.440	20.020	0.008	0.778
45.5	0.09	0.00	0.000	0.000	0.000	0.000
46.5	0.09	0.00	0.000	0.000	0.000	0.000
47.5	0.08	0.00	0.000	0.000	0.000	0.000
48.5	0.06	0.00	0.000	0.000	0.000	0.000
49.5	0.03	0.00	0.00	0.00	0.000	0.000
	Total	161.0	52.64	1541.56	1.00	100.00
		Winter cherry				
0.5-22	Immature stage					
23.5-31.5	Pre- oviposition period					
32.5	0.14	17.00	2.380	79.730	0.116	11.600
33.5	0.14	14.50	2.030	70.035	0.095	9.500
34.5	0.14	13.50	1.890	67.095	0.110	11.000
35.5	0.14	12.00	1.680	61.320	0.116	11.600
36.5	0.13	10.50	1.365	51.188	0.112	11.200
37.5	0.13	9.50	1.235	47.548	0.132	13.200
38.5	0.13	8.50	1.105	43.648	0.104	10.400
39.5	0.13	8.00	1.040	42.120	0.052	5.200
40.5	0.13	7.50	0.975	40.463	0.045	4.500
41.5	0.13	7.00	0.910	38.675	0.038	3.800
42.5	0.13	6.50	0.845	36.758	0.033	3.300
43.5	0.12	5.50	0.660	29.370	0.023	2.300
44.5	0.12	4.00	0.480	21.840	0.015	1.500
45.5	0.12	3.50	0.420	19.530	0.011	1.100
46.5	0.11	0.00	0.000	0.000	0.000	0.000
47.5	0.1	0.00	0.000	0.000	0.000	0.000
48.5	0.07	0.00	0.000	0.000	0.000	0.000
49.5	0.06	0.00	0.000	0.000	0.000	0.000
50.5	0.04	0.00	0.000	0.000	0.000	0.000
	Total	127.50	16.850	649.318	1.00	100.00

Continued....

Pivotal age (day) x	Age-specific female survivorship l_x	Fecundity m_x	l_xm_x	$l_xm_x.x$	Value of $e^{-rmx}l_xm_x$	% constitution of each group towards 'r'
			Black nightshade			
0.5-20 Immature stage						
21.5-28.5 Pre-oviposition period						
29.5	0.15	16.00	2.400	73.200	0.108	10.341
30.5	0.15	13.50	2.025	63.788	0.105	10.127
31.5	0.15	13.50	2.025	65.813	0.103	9.882
32.5	0.15	11.00	1.650	55.275	0.111	10.627
33.5	0.15	10.50	1.575	54.338	0.107	10.261
34.5	0.15	9.50	1.425	50.588	0.112	10.747
35.5	0.14	8.00	1.120	40.880	0.123	11.834
36.5	0.14	7.00	0.980	36.750	0.096	9.203
37.5	0.14	6.00	0.840	32.340	0.039	3.770
38.5	0.14	5.50	0.770	30.415	0.033	3.185
39.5	0.14	5.00	0.700	28.350	0.027	2.669
40.5	0.13	4.50	0.585	24.278	0.021	2.055
41.5	0.13	4.00	0.520	22.100	0.017	1.684
42.5	0.13	4.00	0.520	22.620	0.016	1.552
43.5	0.13	3.00	0.390	17.355	0.011	1.073
44.5	0.13	3.00	0.390	17.745	0.010	0.989
45.5	0.13	0.00	0.000	0.000	0.000	0.000
46.5	0.1	0.00	0.000	0.000	0.000	0.000
47.5	0.09	0.00	0.000	0.000	0.000	0.000
48.5	0.07	0.00	0.000	0.000	0.000	0.000
49.5	0.05	0.00	0.000	0.000	0.000	0.000
50.5	0.02	0.00	0.000	0.000	0.000	0.000
	Total	124.00	17.770	635.833	1.000	100.00
			Tomato			
0.5-30 Immature stages						
31.5-44.5 Pre- oviposition period						
45.5	0.06	2.00	0.120	5.580	0.079	7.900
46.5	0.06	3.00	0.180	8.550	0.117	11.700
47.5	0.06	5.00	0.300	14.550	0.194	19.400
48.5	0.06	7.00	0.420	20.790	0.269	26.900
49.5	0.06	5.00	0.300	15.150	0.190	19.000
50.5	0.06	2.00	0.120	6.180	0.075	7.500
51.5	0.06	2.00	0.120	6.300	0.075	7.500
52.5	0.05	0.00	0.000	0.000	0.000	0.000
53.5	0.02	0.00	0.000	0.000	0.000	0.000
54.5	0.02	0.00	0.000	0.000	0.000	0.000
	Total	26.00	1.560	77.100	1.000	100.000

Continued…

Pivotal age (day) x	Age-specific female survivorship l_x	Fecundity m_x	l_xm_x	$l_xm_x.\ x$	Value of $e^{-rmx}l_xm_x$	% constitution of each group towards 'r'
			Bitter gourd			
0.5-23	Immature stages					
24.5-31.5	Pre- oviposition period					
32.5	0.14	15.00	2.100	70.350	0.104	10.400
33.5	0.14	12.50	1.750	60.375	0.110	11.000
34.5	0.14	12.00	1.680	59.640	0.124	12.400
35.5	0.14	11.00	1.540	56.210	0.127	12.700
36.5	0.13	10.00	1.300	48.750	0.114	11.400
37.5	0.13	9.00	1.170	45.045	0.126	12.600
38.5	0.13	8.00	1.040	41.080	0.077	7.700
39.5	0.13	7.50	0.975	39.488	0.054	5.400
40.5	0.13	7.00	0.910	37.765	0.046	4.600
41.5	0.13	6.00	0.780	33.150	0.036	3.600
42.5	0.13	6.00	0.780	33.930	0.034	3.400
43.5	0.12	4.50	0.540	24.030	0.022	2.200
44.5	0.12	4.00	0.480	21.840	0.015	1.500
45.5	0.12	3.50	0.420	19.530	0.011	1.100
46.5	0.11	0.00	0.000	0.000	0.000	0.000
47.5	0.1	0.00	0.000	0.000	0.000	0.000
48.5	0.07	0.00	0.000	0.000	0.000	0.000
49.5	0.06	0.00	0.000	0.000	0.000	0.000
50.5	0.04	0.00	0.000	0.000	0.000	0.000
	Total	116.00	15.360	578.700	1.000	100.000

Table 21- Life-table indices of *Henosepilachna vigintioctopunctata* on five host plants

Hosts	Reproductive parameters					
	net reproductive rate (R_0)	Mean length of generation (T_c)	Intrinsic rate of increase (R_m)	Finite rate of increase (λ)	Doubling time (DT)	Annual rate of increase ($A.R.I$)
Brinjal	52.460	35.20298	0.11258	1.119168	6.156930	0.70×10^{18}
Winter cherry	16.850	37.76706	0.07478	1.077647	9.269152	0.71×10^{12}
Black nightshade	17.770	35.28165	0.08155	1.084976	8.498825	0.84×10^{13}
Tomato	1.560	48.42038	0.00918	1.009226	75.47872	28.55718
Bitter gourd	15.360	37.67285	0.07250	1.075193	9.560651	0.31×10^{12}

reproductive rate (R_0), 1.56 females per female per generation, was recorded on tomato. The smallest r_m (0.009185 females per female per day) occurred on tomato which showed that *H. vigintioctopunctata* did not perform well on tomato. Infinite rate of increase (λ) is always greater than the intrinsic rate of increase (r_m). In the present study, the infinite rate of increase (λ) was similar on winter cherry, black nightshade and bittergourd and was computed as 1.08 individuals per females per day. However, the highest infinite rate of increase (λ) 1.12 individuals per females per day recorded on brinjal. There was an insignificant difference on mean length of generation (T_c) on brinjal, winter cherry, black nightshade and bittergourd, but when these data, were compared with that of tomato, a significant difference was detected. In addition, *H. vigintioctopunctata* may become double in 6.33 days on brinjal followed by 8.49, 9.26, 9.56 days on black nightshade, winter cherry and bittergourd respectively.

2. B. Effect of solanaceous and cucurbitaceous hosts on development of *H. vigintioctopunctata*

Development of immature stages

The development of *H. vigintioctopunctata* on different host plants revealed that incubation period was found significantly minimum (2.81 ± 0.41 days) on brinjal and maximum (4.45 ± 0.51 days) on tomato (Table-22). On the other hand, the significantly shortest duration (2.95 ± 0.51, 1.85 ± 0.59, 2.8 ± 0.41 and 3.15 ± 0.49 days) of larval (first, second, third and fourth) instars was recorded on brinjal and longest (5.4 ± 1.10, 4.5 ± 0.76, 4.6 ± 0.75 and 5.85 ± 0.81 days) on tomato (Fig.12). Further, the prepupal period was recorded maximum (2.4 ± 0.59 days) on tomato which showed significant difference with all other hosts. However, minimum pre-pupal period was found on brinjal showing statistically parity with black nightshade, winter cherry and bittergourd. Interestingly, pupal period was observed minimum (5.05 ± 0.69 days) on bitter gourd, revealing a significant variation with brinjal and tomato. In contrast maximum (7.4 ± 1.14 days) pupal period was recorded on tomato. Development of immature stage, from egg to pupa did not vary significantly varied on black nightshade, winter chery and bittergourd but significantly differed on brinjal (being minimum) and tomato (being maximum). The total developmental period (egg-pupa) was 20.6 days on brinjal and prolonged to 34.6 days on tomato.

Development of adult stage

The results (Table-23) showed that host plants significantly affected the adult stage of *H. vigintioctopunctata.* A significantly minimum pre-oviposition period (8.15 ± 1.04 days) was observed on brinjal and maximum (14.3 ± 0.73 days) on tomato. On the other hand, the significantly shortest oviposition period (7.05 ± 1.10 days) was recorded on tomato and longest (16.3 ± 1.48 days) on brinjal. Further, the post-oviposition period was recorded minimum (3.1 ± 0.72 days) on tomato showing significant difference with all other hosts (Fig. 13). However, maximum post-ovipositional period (5.45 ± 0.89 days) was found in bittergourd showing statistically parity with brinjal, black nightshade and winter cherry. As far as adult longevity (male and female) was concerned both sexes showed significantly minimum longevity (20.45 ± 0.69 and 23.9 ± 0.45 days, respectively) on tomato and maximum (24.1 ± 0.64 and 28.60 ± 0.69 days, respectively) on brinjal. Maximum (322.2 ± 3.74) number of eggs laid by a single female during its whole life span was observed on brinjal followed by 255.15 ± 1.60, 248.05 ± 3.53, 232.45 ± 2.74 eggs on winter cherry, black nightshade and bitter gourd respectively. In contrast, significantly minimum fecundity (51.75 ± 7.94 eggs) was recorded on tomato.

Table 22: Development time for immature stages of *Henosepilachna vigintioctopunctata* on five host plants in laboratory conditions.

Developmental Stages	Immature development time (days) on different host plants				
	Brinjal	Winter cherry	Black nightshade	Tomato	Bitter gourd
Eggs	2.80 ± 0.41^{a}	3.25 ± 0.44^{bc}	3.15 ± 0.37^{b}	4.45 ± 0.51^{d}	3.50 ± 0.51^{c}
L1†	2.95 ± 0.51^{a}	3.35 ± 0.49^{a}	3.25 ± 0.64^{a}	5.40 ± 1.10^{b}	3.10 ± 0.55^{a}
L2†	1.85 ± 0.59^{a}	3.15 ± 0.59^{b}	3.05 ± 0.51^{b}	4.50 ± 0.76^{c}	2.90 ± 0.64^{b}
L3†	2.80 ± 0.41^{a}	3.05 ± 0.60^{a}	3.10 ± 0.55^{a}	4.60 ± 0.75^{b}	3.10 ± 0.64^{a}
L4†	3.15 ± 0.49^{a}	4.20 ± 0.41^{b}	3.35 ± 0.49^{a}	5.85 ± 0.81^{c}	4.10 ± 0.55^{b}
Pre-Pupa	1.00 ± 0.00^{a}	1.20 ± 0.37^{a}	1.10 ± 0.31^{a}	2.40 ± 0.59^{b}	1.10 ± 0.31^{a}
Pupa	6.05 ± 0.60^{b}	5.15 ± 0.59^{a}	5.20 ± 0.62^{a}	7.40 ± 1.14^{c}	5.05 ± 0.69^{a}

Within rows, mean followed by different letters are significantly different to Tukey's HSD test ($P < 0.05$)

Table 23: Adult life parameters of *Henosepilachna vigintioctopunctata* on five host plants in laboratory conditions.

Parameters	Different host plants				
	Brinjal	Winter cherry	Black nightshade	Tomato	Bitter gourd
Pre-Oviposition (day)	08.15 ± 1.04^{a}	09.30 ± 0.9^{c}	08.80 ± 0.9^{bc}	14.30 ± 0.7^{d}	08.70 ± 0.7^{b}
Oviposition (day)	16.30 ± 1.5^{d}	14.20 ± 0.8^{b}	16.10 ± 1.0^{cd}	07.05 ± 1.1^{a}	14.35 ± 0.8^{bc}
Fecundity (eggs/female)	322.2 ± 3.7^{d}	255.2 ± 1.6^{c}	248.05 ± 3.5^{c}	51.75 ± 7.9^{a}	232.5 ± 2.7^{b}
Post-Oviposition(day)	04.65 ± 0.9^{b}	04.75 ± 1.0^{bc}	05.30 ± 0.8^{cd}	03.10 ± 0.7^{a}	05.45 ± 0.9^{d}
Male longevity (day)	24.10 ± 0.6^{d}	23.95 ± 0.7^{c}	23.90 ± 0.7^{bc}	20.45 ± 0.7^{a}	23.05 ± 0.9^{b}
Female longevity (day)	28.60 ± 0.6^{c}	28.15 ± 0.6^{bc}	29.50 ± 0.7^{d}	23.90 ± 0.5^{a}	27.25 ± 0.4^{b}

Within rows, mean followed by different letters are significantly different to Tukey's HSD test ($P < 0.05$)

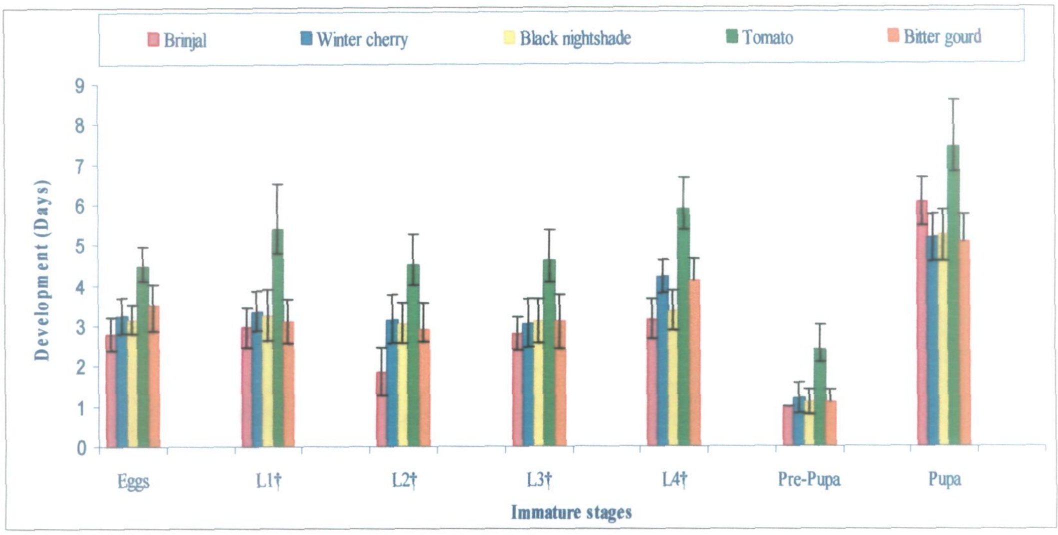


Fig. 12: Development time of immature stages of *Henosepilachna vigintioctopunctata* on five different hosts

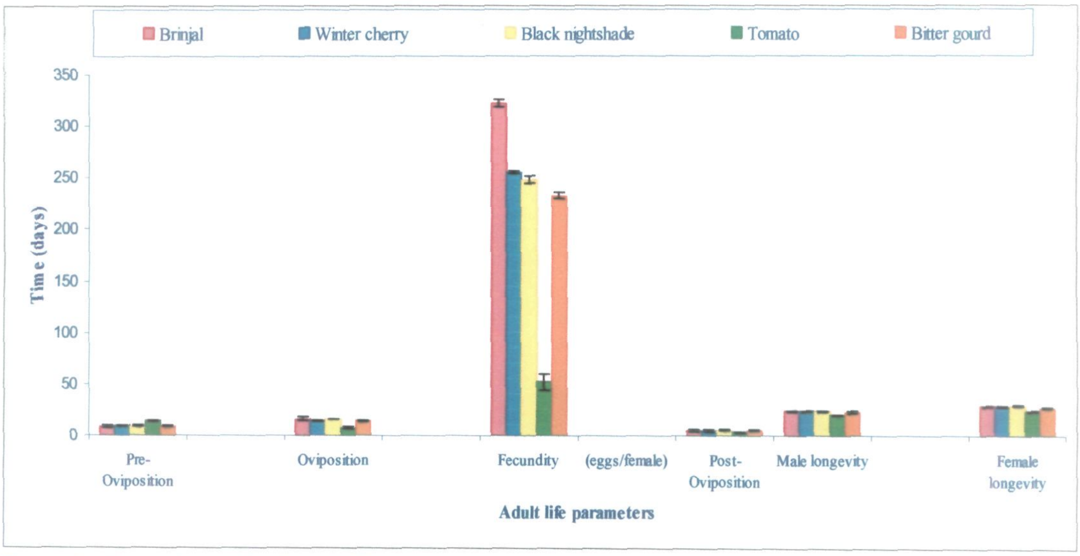


Fig. 13: Duration of adult life parameters of *Henosepilachna vigintioctopunctata* on five different hosts.

3. Differential responses of brinjal cultivars/accessions against *H. vigintioctopunctata* in field conditions.

It is apparent from the (Table-24) that the damage index ranged from 0.16 to 1.14 in different varieties with 0.83 in the susceptible check 'Navkiran'. Among the ten cultivars screened against *H. vigintioctopunctata*, two enteries were graded as moderately resistant and eight as susceptible. The mean leaf incidence in the moderately susceptible enteries varied from 30 to 40 per cent. Similarly, the mean leaf area damaged in 24h under caged studies ranged from 0.16 to 0.23 cm^2. In susceptible cultivars, the leaf incidence ranged between 67.5-95 per cent and mean leaf area damaged ranged between and 0.81-1.21 cm^2, respectively. The order of susceptibility was observed as Pragati > Nageena > Pusa purple long > Navkiran > PPL-74 > Suchitra > Sweekar > BR-112 > Lalat < Pusa purple round.

4. Evaluation of certain organic amendments against *H. vigintioctopunctata* on brinjal in field conditions.

The results of the investigations on the effect of organic sources of nutrients against *H. vigintioctopunctata* are presented in Table-25. All the treatments involving organic nutrients were proved significantly superior over NPK as inorganic form. The overall mean per cent incidence recorded throughout the period of observation, revealed that among organics imposed, the basal application of Farm Yard Manure @ 12.5 t/ha + Azophos @ 2Kg/ha + Neem cake @ 800Kg/ha with need based application of neem oil (3%) and FYM (12.5 t/ha) + Azophos (2Kg/ha) + Mahua cake (1000Kg/ha) + neem oil (3%) were found significantly effective in reducing the incidence due to *H. vigintioctopunctata* with mean per cent reduction of 82.22 and 79.64 respectively, over NPK (Fig. 14). The next best treatment was FYM (50%) + Azophos @ 2Kg/ha + Neem cake (50 %) + NPK (50%) + Neem oil (3%) which also proved significantly efficient in

Table 24: Incidence and intensity of *Henosepilachna vigintioctopunctata* on different brinjal cultivars/accessions in field conditions.

Varieties	Incidence (%)	Intensity (cm^2)	Damage Index	Grade
Suchitra	75.0	0.94	0.70	S
Nageena	90.0	1.12	1.01	S
PPL-74	67.5	1.19	0.80	S
Lalat	40.0	0.57	0.23	MR
Pragati	95.0	1.21	1.14	S
Sweekar	77.5	0.82	0.64	S
Navkiran	90.0	0.92	0.83	S
BR-112	72.5	0.81	0.59	S
Pusa purple round	30.0	0.53	0.16	MR
Pusa purple long	90.0	1.02	0.92	S

Incidence = Percentage of mean leaves affected
Intensity = Leaf Area damage in 24 h by one beetle
Damage Index = (Incidence x Intensity) / 100

reducing the incidence by 72.02 mean per cent, over NPK. Other treatments viz., FYM @ 12.5 t/ha + Azophos @ 2Kg/ha + Neem cake @ 800Kg/ha, FYM (50%) + Azophos @ 2Kg/ha + Mahua cake (50 %) + NPK (50%) + Neem oil (3%) and FYM @ 12.5 t/ha + Azophos @ 2Kg/ha + Mahua cake @ 1000Kg/ha also proved notably efficient in reducing the incidence by 71.33, 70.72 and 69.41 mean per cent, respectively, over NPK. Among all the organic amendments, the plots treated with the combination of FYM + Biofertilizer + Oil cake were proved better in reducing the beetle incidence when compared with plots treated with the FYM/ Poultry Manure alone. The treatments with FYM (12.5 t/ha) and Poutry Manure (3 t/ha) alone were found capable of reducing the incidence by beetle with mean per cent reduction of 32.04 and 25.96 respectively, over NPK.

Beside organic amendments, the treatment viz., NPK + neem oil (3%) were found significantly effective in reducing the beetle incidence with mean per cent reduction of 63.74 over NPK alone. The plants treated with NPK alone as inorganic form was recorded with highest mean per cent incidence of 11.62 per cent by hadda beetle.

Marketable yield and Cost Benefit Ratio

The highest fruit yield (169.8 q/ha) coupled with 58.1 per cent yield increase over NPK was recorded with maximum cost benefit ratio (CBR) of 1: 5.7 in the plots treated with FYM (12.5 t/ha) + Azophos (2Kg/ha) + Neem cake (800Kg/ha) + neem oil (3%) followed by FYM (12.5 t/ha) + Azophos (2Kg/ha) + Mahua cake (1000Kg/ha) + neem oil (3%) which recorded fruit yield of 167.3 q/ha with 57.4 per cent increase over NPK with the CBR of 1: 4.3 (Table- 26 & 27). The next best treatment viz., FYM (12.5 t/ha) + Azophos (2Kg/ha) + Neem cake (800Kg/ha) recorded 142.4 q/ha fruit yield with 50 per cent increase of yield over NPK with CBR of 1: 4.2 (Fig. 15) The other treatments viz., FYM (12.5 t/ha) + Azophos (2Kg/ha) + Mahua cake (1000Kg/ha) recorded 140.1 q/ha

Table 25: Effect of certain organic amendments on incidence of *Henosepilachna vigintioctopunctata* on brinjal

Treatments	Days after Transplanting															
	15		25		35		45		55		65		75		Mean	
	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK	% Incidence	% reduction overNPK
T_1	1.15^{a}	74.04	2.44^{a}	72.98	3.65^{d}	71.6	4.50^{cd}	69.49	4.90^{c}	72.13	3.84^{c}	69.88	2.84^{d}	71.4	3.33^{cd}	71.33
T_2	1.29^{a}	70.88	2.86^{a}	68.33	3.81^{d}	70.35	4.68^{d}	68.27	5.02^{c}	71.44	4.02^{cd}	68.47	3.20^{d}	67.8	3.55^{cd}	69.41
T_3	1.18^{a}	73.36	2.45^{a}	72.87	1.88^{a}	85.37	2.38^{a}	83.86	2.55^{a}	85.49	2.20^{a}	82.75	1.82^{a}	81.7	2.07^{a}	82.22
T_4	1.33^{a}	69.98	2.88^{a}	68.11	2.22^{ab}	82.72	2.74^{ab}	81.42	3.12^{ab}	82.25	2.41^{ab}	81.1	1.86^{ab}	81.3	2.37^{a}	79.64
T_5	2.08^{b}	53.05	4.16^{b}	53.93	5.72^{e}	55.49	6.27^{e}	57.49	6.85^{d}	61.04	4.77^{de}	62.59	3.83^{e}	61.5	4.81^{ef}	58.59
T_6	2.30^{b}	48.08	4.75^{b}	47.4	6.49^{e}	49.49	6.68^{e}	54.71	7.06^{d}	59.84	5.36^{e}	57.96	4.02^{e}	59.6	5.24^{f}	54.92
T_7	2.19^{b}	50.56	4.39^{b}	51.38	3.10^{cd}	75.88	3.32^{ab}	77.49	3.72^{abc}	78.84	3.84^{c}	69.88	2.20^{abc}	77.9	3.25^{bc}	72.02
T_8	2.32^{b}	47.63	4.70^{b}	47.95	3.18^{cd}	75.25	3.46^{bc}	76.54	4.00^{bc}	77.25	3.78^{bc}	70.35	2.37^{bcd}	76.2	3.40^{c}	70.72
T_9	2.98^{bc}	32.73	6.29^{c}	30.34	8.76^{f}	31.83	9.77^{f}	33.76	12.05^{e}	31.46	9.17^{f}	28.08	6.25^{f}	37.1	7.90^{ef}	32.04
T_{10}	3.15^{c}	28.89	7.00^{c}	22.48	9.35^{f}	27.24	10.45^{f}	29.15	12.89^{e}	26.68	10.35^{f}	18.82	7.03^{f}	29.3	8.60^{f}	25.96
T_{11}	4.19^{cd}	5.42	8.83^{d}	2.21	3.24^{c}	74.79	3.52^{bcd}	76.14	4.08^{bc}	76.79	3.24^{bc}	74.59	2.39^{bcd}	76	4.21^{dc}	63.74
T_{12}	4.43^{d}	-	9.03^{d}	-	12.85^{g}	-	14.75^{g}	-	17.58^{f}	-	12.75^{g}	-	9.94^{h}	-	11.62^{g}	-
T_{13}	3.64^{c}	17.83	8.18^{d}	9.41	12.16^{g}	5.37	13.38^{g}	9.29	16.18^{f}	7.96	10.68^{f}	16.24	8.08^{g}	18.7	10.33^{g}	11.1

The values in column followed by similar letter (s) are not significantly different ($P>0.05$, Tukey's HSD) from each other.

Table.26- Effect of certain organic amendments on the brinjal fruit yield.

T. No.	Treatments	Yield (q/ha)	% increase over NPK
T1	FYM + BF + NC	142.4	50.0
T2	FYM + BF + MC	140.1	49.2
T3	T1+ Neem oil	169.8	58.1
T4	T2+ Neem oil	167.3	57.4
T5	FYM + BF + (NC + NPK)	138.8	48.7
T6	FYM + BF + (MC + NPK)	137.7	48.3
T7	T5+ Neem oil	145.2	51.0
T8	T6+ Neem oil	142.1	49.9
T9	FYM alone	74.9	4.9
T10	Poultry manure alone	73.5	3.1
T11	NPK + Neem oil	98.2	27.5
T12	NPK alone	71.2	0.0
T13	Untreated control	71.5	0.4

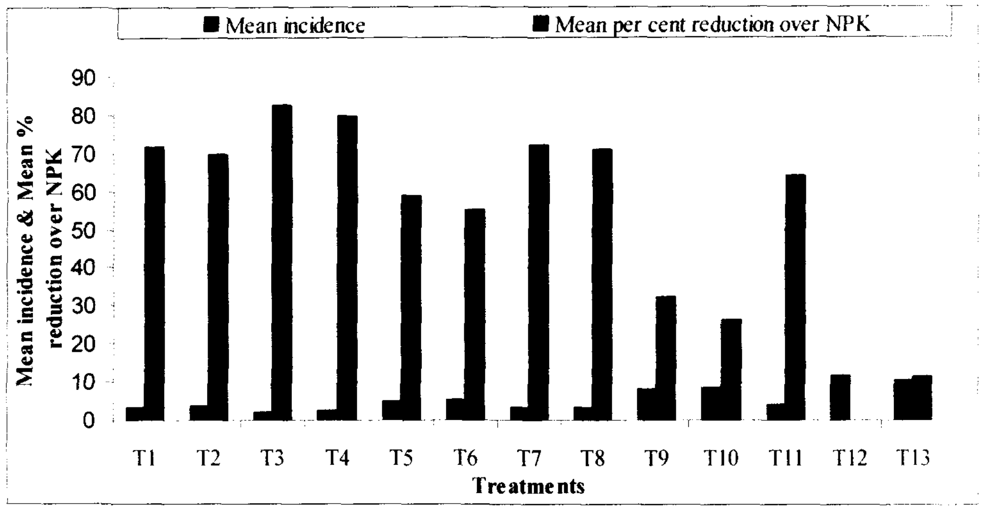


Fig. 14: Comparative efficacy of certain organic amendments on incidence of *Henosepilachna vigintioctopunctata* on brinjal under field conditions.

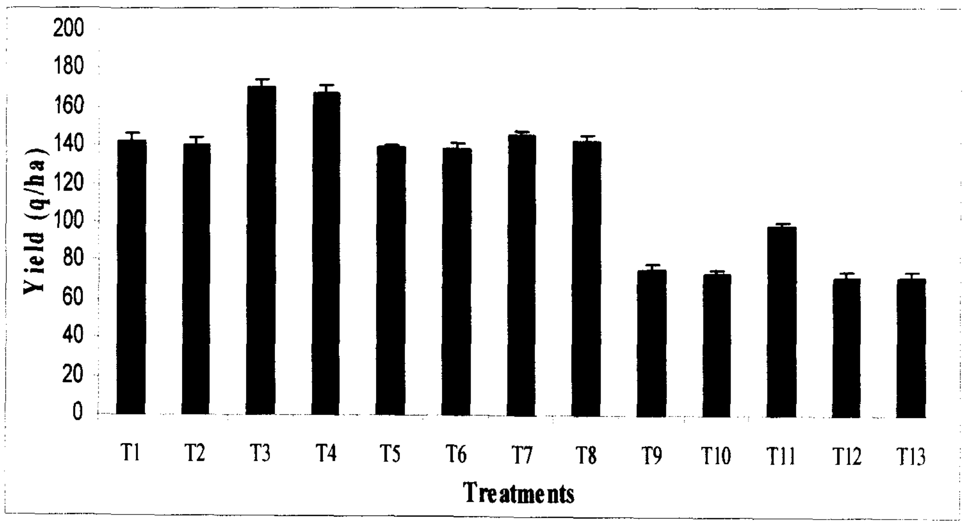


Fig. 15: Effect of certain organic amendments on yield of brinjal.

Table 27: Cost: Benefit Ratio of treatments for the management of *Henosepilachna vigintioctopunctata* on brinjal

S. No.	Treatments	Outputs			Inputs			Net profit/ha [Rs.]	Cost: Benefit ratio
		Yield of healthy fruits [q/ha]	Increased yield over the NPK [q/ha]	Price of increased yield [Rs.]	Cost of manures/fertilizers/ neem oil formulation	Labour charges [Rs.]	Total [Rs.]		
T1	FYM + BF + NC	142.4	71.2	85440	15650	660	16310	69130	1: 4.2
T2	FYM + BF + MC	140.1	68.9	82680	19650	660	20310	62370	1: 3.1
T3	T1+ Neem oil	169.8	98.6	118320	16694	990	17684	100636	1: 5.7
T4	T2+ Neem oil	167.3	96.1	115320	20694	990	21684	93636	1: 4.3
T5	FYM + BF + (NC + NPK)	138.8	67.6	81120	22285	660	22945	58175	1: 2.5
T6	FYM + BF + (MC + NPK)	137.7	66.5	79800	24285	660	24945	54855	1: 2.2
T7	T5+ Neem oil	145.2	74	88800	23329	990	24319	64481	1: 2.7
T8	T6+ Neem oil	142.1	70.9	85080	25329	990	26319	58761	1: 2.2
T9	FYM alone	74.9	3.7	4440	7500	220	7720	-3280	1: -0.4
T10	Poultry manure alone	73.5	2.3	2760	3000	220	3220	-460	1: -0.1
T11	NPK + Neem oil	98.2	27	32400	5795	990	6785	25615	1: 3.8
T12	NPK alone	71.2	-	0	4750	660	5410	-5410	-
T13	Untreated control	71.5	0.3	360	0	0	00	360	-

FYM @ Rs. 600/t, Poultry Manure @ Rs. 1000/t, Biofertilizer @ Rs. 75/Kg, Neem cake @ Rs. 10/Kg, Mustard cake @ Rs. 15/Kg, Urea @ Rs.10/Kg, DAP@ Rs. 15/Kg, MOP@ Rs.15/Kg, Ozoneem@ Rs. 232/l with 49.2 per cent yield increase over NPK with the CBR of 1: 3.1 and FYM (50%) + Azophos (2Kg/ha) + Neem cake (50%) + NPK (50%) + neem oil (3%) recorded 145.2 q/ha fruit yield with 51 per cent yield increase over NPK with the CBR of 1: 2.7 are worth mentioning. The plants treated with FYM (12.5 t/ha) and Poultry Manure (3 t/ha) alone recorded 74.9 and 73.5 q/ha with 4.9 and 3.1 per cent increase of yield over NPK with CBR of 1: -0.4 and 1:- 0.1, respectively. In addition to this, the treatment viz., NPK + neem oil (3%) recorded 98.2q/ha yield with 27.5 per cent increase in yield over NPK with CBR of 1:3.8. Among all the treatments, the minimum yield was recorded in case of plants treated with NPK as organic form alone.

5. Bio-efficacy of some botanicals against *H. vigintioctopunctata* in semi-field conditions.

Results of the experiment are summarized in the Table-28. The data on the mortality of larvae shows that in general all the treatments were highly significant over control. Data from 1st to 9th day after treatment clearly shows that there was significant difference among the treatments. Results also revealed that treatments of Neem excel at concentration of 0.3 per cent and *Annona squamosa* seed extract and *Calotropis* leaf extract at concentration of 5.0 per cent consistently gave good kill and proved significantly superior over other treatments at different duration. In decreasing order of efficacy, the various treatments were Neem excel (0.3%), *Annona squamosa* seed extract (5.0%), *Calotropis* leaf extract (5.0%), Neem cake extract (5.0%), Neem leaf extract (5.0%), *Parthenium* leaf extract (5.0%) and lastly garlic extract (5.0%) (Fig.16).

Treatment of commercial formulation of neem (Neemexcel 3.0%) consistently proved significant superior over all other treatments in giving initial killings and total mortality of 98 per cent on 7th day. Comparatively effective killing resulted at 5th and 7th day among all the treatments. Among other botanical extracts, *Annona squamosa* seed extract and *Calotropis* leaf extract at concentration of 5.0 per cent was at par with each other and registered highest mortality of 86 per cent and 80 per cent, respectively on 7th day. These studies revealed that relatively all the botanical formulations were effective against the larvae of *H. vigintioctopunctata* except garlic extract, which caused only 38 per cent mortality on 7th day. No phytotoxicity in terms of leaf injury on tips and surface, vein-clearing, necrosis, wilting and epinasty and hyponasty was noticed as observed for a period of 7 days ater spray. After uptake of the Neem ingredients by feeding on treated brinjal leaves, larvae which could develop into pupae and adults showed abnormal development, pupae resulting in failure to moult while adults were observed with typical symptoms, having rippled wings and legs with abnormal movements and behavior.

Table 28: Effect of some botanicals against fourth instar larvae of *Henosepilachna vigintioctopunctata* on brinjal in semi- field conditions

Treatments	Concentration (%)	Mean per cent mortality of *H. vigintioctopunctata* at indicated days			
		1	3	5	7
Neem leaf extract	5.0	22.00	32.00	44.00	62.00
Calotropis leaf extract	5.0	32.00	36.00	56.00	80.00
Garlic extract	5.0	10.00	18.00	32.00	38.00
Annona squamosa seed extract	5.0	34.00	38.00	58.00	86.00
Neem excel	3.0	36.00	44.00	78.00	98.00
Neem cake extract	5.0	28.00	34.00	50.00	68.00
Parthenium leaf extract	5.0	18.00	28.00	38.00	58.00
Control		0.00	0.00	0.00	0.00
CD at 5%	--------------	6.74	6.38	6.74	6.56

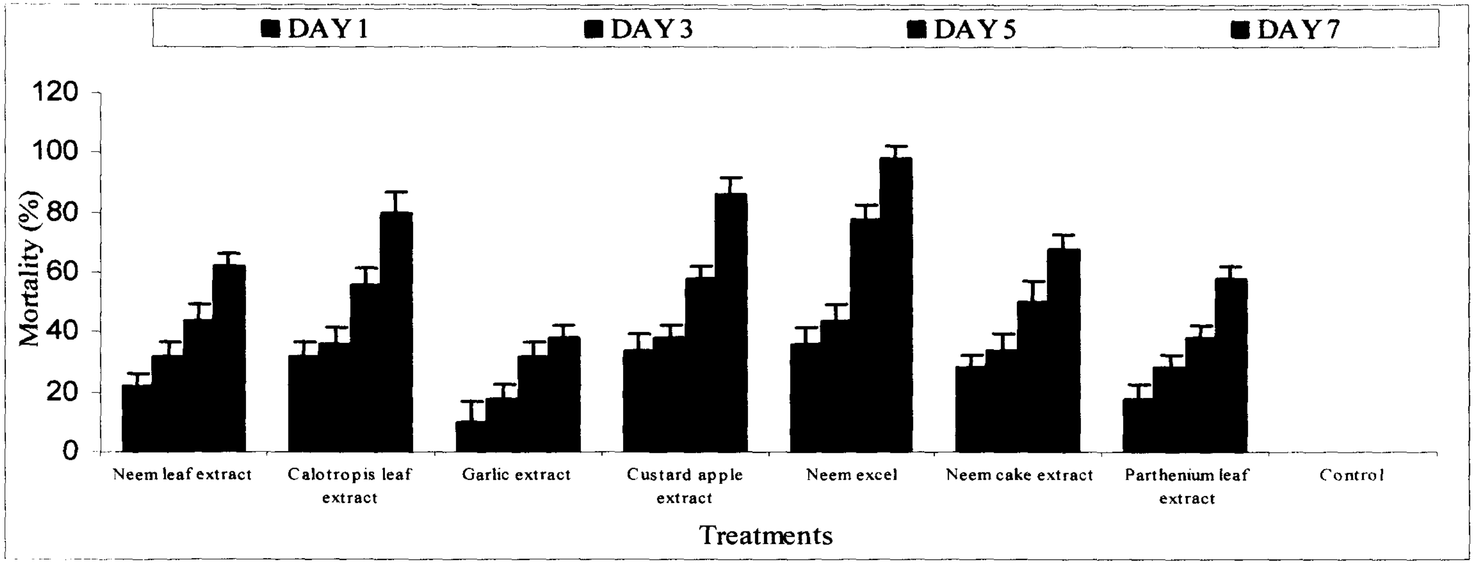


Fig. 16: Comparative efficacy of some botanicals on the mortality of fourth instar larvae of *Henosepilachna vigintioctopunctata* on brinjal under semi-field conditions.

CHAPTER-5
DISCUSSION

1. Studies on population dynamics of *Henosepilachna* spp. on brinjal

1. A. Population fluctuation of *H. vigintioctopunctata* and *H. dodecastigma*

Results of present studies revealed that, initial infestation of *H. vigintioctopunctata* and *H. dodecastigma* occurred from mid-February to mid-March, thereafter population of both the species gradually increased and reached to significant higher population in mid-May and then gradually declined in last June. Thereafter, population increased abruptly from early July and reached the peak in early August and then declined gradually and completely disappeared in last October and early November (Fig.). This was also confirmed by the results of Sawada and Ohgushi (1994), who reported that adults reached their first peak in late April to early May, and then gradually declined in late June. New adults began to emerge in late June and quickly reached a peak in early July, thereafter decreasing in number and entering hibernation by late October. Likewise, Ali and Saeady (1986, a) also observed that larvae developing in August and September gave rise to adults which entered hibernation at the end of November. Similar results were also reported by Ghosh and Senapati (2001, a) who recorded the occurrence of beetles from April to mid- October. Similarly, the population of beetles was highest during August as confirmed by results of earlier workers, Venkatesha (2006); Bhagat and Munshi, 2004; Suresh *et al.,* (1996) and Rajgopal and Trivedi (1989). In addition, Tripathi and Misra (1991) observed that adult population was high from late July to September.

The development, growth and population dynamics of an insect pest is greatly influenced by weather factors. Temperature and relative humidity affected numbers of the

H. vigintioctopunctata although the availability of food was also an important factor determining numbers (Grewal, 1988). The interaction between the populations of *Henosepilachna* spp. with minimum temperature, maximum and minimum humidity and rainfall was significant and gave positive correlations and non-significant positive correlation with maximum temperature (Table.). The results of Chen *et al.*, (1989) showed that temperature range of 24-32^{0}C favored the occurrence of *H. vigintioctopunctata.* Similar observations were made by Ghosh and Senapati (2001, a) which further confirmed the present findings. The population fluctuation of *H. vigintioctopunctata* was also influenced by the maximum and minimum relative humidity but maximum temperature had no influence (Ali and Saeady, 1986 (a); Naik *et al.*, 2008). Similarly, the positive correlation between population density of *H. vigintioctopunctata* and maximum and minimum relative humidity was also recorded by Raghuraman and Veevaral (1999, a), Varma and Anandhi (2008) and Haseeb *et al.*, (2009). In addition, Suman and Swaminathan (2007) and Chandrakumar *et al.*, (2008) worked out a positive correlation between adult population and minimum temperature. Contrary to the findings of the present studies, Sarvendra *et al.,* (2005) reported negative correlation between temperature and humidity and population of *H. vigintioctopunctata.* The possible reason for this contrary result may be attributed to the geographical population differences at a particular location or due to the extremes of weather conditions prevailing at a particular time and location or population went down due to some other natural cause.

1. B. Seasonal incidence of parasitoids of *H. vigintioctopunctata*

In the present study, egg parasitism exhibited non-significant negative correlation with maximum temperature in 2010 and with maximum humidity in 2011 but showed significant positive correlation with all other weather parameters (Table- 9 & 10). Similar results were obtained by Varma and Anandhi (2008) who reported that egg parasitoids were positively correlated to the maximum relative humidity, rain, wind velocity and sunshine hours in the first year and negatively correlated to relative humidity in subsequent years.

We found that there were two peaks of egg parasitism i.e. (43.2% and 24.6% in 2010 and 2011, respectively) during third week of May and (43.3%) and (27.6%) in the 2nd week of August and 1st week of September in 2010 and 2011, respectively. While, Grub parasitism reached to 29.5 per cent at temperature fluctuating between 26 and 31.6^{0}C with relative humidity of 77.71 to 88.71 per cent in 2010, while 49.5 per cent parasitism at temperature of 27.25 to 33.6^{0}C and humidity ranging between 70.85 to 82.14 per cent in first week of September, 2011. The present findings are in conformity with the results of Patnaik and Mohapatra (2004) who reported that egg parasitization was highest (57.2%) during second fortnight of August. The greatest parasitism occurred in pupae from June to September (Lee *et al.*, 1988). Likewise, Rajendra and Gopalan (1997, a) also reported that although *H. vigintioctopunctata* was parasitized throughout the year, the maximum percentage parasitization was recorded during August 1993 (49.5%) and September 1993 (47.1). These findings are further in conformity with the results of present studies. Kaur and Mavi (2002) also recorded the parasitization on different stages of *H. vigintioctopunctata* during March- September, 2001.

Adults of *Tetrastichus* sp. and *Pedobius foveolatus* were found to be dominant egg and larval parasitoids, respectively while, few pupae were also found parasitized by *P. foveolatus*. Parasitization of eggs of *H. vigintioctopunctata* by *Tetrastichus* sp. was also recorded by Kaur and Mavi (2002), Raju and Maheshwari (2004) and Varma and Anandi (2008). Earlier Krishnamurti and Appana (1951) recorded *P. foveolatus* parasitizing the grubs of *H. vigintioctopunctata. P. foveolatus* is known to be a potential parasitoid of various phytophagous coccinellids (Venkatesha, 2006). This parasitoid was recorded to cause up to 62% parasitism in *H. ocellata* (Dhingra *et al.*, 1986) and 80% in *H. philippinensis* (Chiu and Moore, 1993). Natural parasitism of *H. vigintioctopunctata* by *P. foveolatus* on brinjal was 35-70% (Dhamdhere and Dhingra, 1990), 48.27 to 48.46 % (Varma and Anandhi, 2008), 28.47% on potato and 64.5% on *Solanum nigrum* L. (Sheng and Wang, 1992). Similar to our results, Raju and Maheshwari (2004) also reported the parasitization of pupae of *H. vigintioctopunctata* by *P. foveolatus* on brinjal.

1. C. Seasonal abundance of *H. vigintioctopunctata* on six cultivars of brinjal

Seasonal abundance of *H. vigintioctopunctata* was non-significantly affected by temperature, relative humidity and rainfall on six different cultivars of brinjal. In the present study, the increase in population of all stages of *H. vigintioctopunctata* was found gradual in summers (March to May). The maximum population density of all stages on all cultivars was observed between 17^{th} to 21^{st} SW with in average temperature and humidity range (32.27 – 35.19^{0}C and 28.71 – 47.78%, respectively) and thereafter, it declined suddenly (Table-11, 12, 13 & 14). This sudden turn down in the population densities could be attributed to the high temperature and low RH which adversely affected the egg hatchability, the viability of newly hatched larvae, rate of development and fecundity. Similar results were obtained by Sarvendra *et al.*, (2005) who reported that high temperature and low RH had adverse effects on the population of this pest. It was further confirmed by Nava *et al.*, (1987). They recorded 32.5^0 as the upper lethal temperature for eggs and 35^0 C for larvae and pupae.

In general rain was found unfavourable for egg and larval stages as observed in the present studies. Occurrence of rain during 21^{st} and 22^{nd} SW affected larval population of *H. vigintioctopunctata* which decreased down. Similar results were obtained by Alahmed (2001) who reported that egg density was very high on 9^{th} May and then their number dropped. It might be due to the fact that rain can dislodge the larvae of this beetle from the plants and can drown the larvae in the water in the soil. Rainfall generally washed off eggs of *H. vigintioctopunctata* due to the secondary impacts from rain drop hitting the soil and ricocheting soil and water back to the leaves. However, most of the adult beetles were found sheltered themselves in cracks and crevices in trees, stones; trash etc. in order to protect them from rain. It was confirmed by Inoue *et al.*, (1993) that rainfall lowered egg hatchability and time of adult residence on host plants. Ohgushi & Sawada (1985) reported that habitat perturbations such as flood, rainfall will greatly distort population stabilization if they occur in the reproductive season when populations build up is high. As a result, the egg density remained at unusual low level after rains. Pupation took place at the main stem of the plant and hence not affected by the rainfall due to presence of rich canopy. All the weather parameters showed positive influence on adult population in present studies. These findings are in conformity with the findings of Ghosh and Senapati (2001, a).

In our present study none of the weather parameters alone was responsible for the multiplication and growth of *H. vigintioctopunctata* on different cultivars. It is assumed that for a major part of the season, the meteorological parameters remained conducive for the rapid multiplication of this pest. Moreover, the degree of infestation and rates of population change of the beetle on different varieties seemed to be governed by varietal characterstics.

2. A. Effect of solanaceous and cucurbitaceous hosts on life-table of *H. vigintioctopunctata*

Host plant availability and quality may play a role in pest population dynamics by affecting immature as well as adult performance. In the case of *H. vigintioctopunctata*, no life table studies with regard to its various host plants have been published and only a few studies have examined the effect of host plants on the developmental stages or on overall performance of this species.

The development, survival and mortality rate of specific insects can vary on various host plants; the factors determine plant suitability for herbivorous hosts (Saeed *et al.*, 2010). Although data on developmental rates and survival, provide important clues concerning the ability of the host to support a complete insect life cycle, these data should be linked to other parameters such as mortality before definitive conclusions are drawn concerning host suitability. In addition to differences in developmental period, there were marked differences in survival of larvae among different host plants because of differences in mortality of immatures Larvae fed on tomato faced considerably reduced survival rates compared with other host plants tested. In addition, low levels of larval and pupal mortality were observed on brinjal. Therefore, it is concluded that the low survival on tomato was due to the heavy mortality of immatures as observed from Table- 19, which could be attributed to the unsuitability of the host plant. Similarly, the larval host plants can have significant effect on both adult longevity and survival.

There are many factors that can affect host suitability, including nutrient contents and tissue texture. However, the highest mortality of early instars was found on tomato. It might be due to the hard tissue textures and spine-like appendages (trichomes) on leaves that would have resulted in high mortality of early instars. Furthermore, the production of chemicals, such as toxins and digestibility reducers, may interfere with the physiology of the herbivore and reduce growth and survival (Schoonhoven *et al.*, 2005). During the last instar stages, death rates decrease automatically on each host plant because the maxillae and mandibles of mouth parts get modified in these stages and larva tend to eat plant leave more easily. A low degree of mortality of larvae was also found at last stage of development, possibly due to the variation in nutritional value of host plants. Several studies supported the nutritional value of these crops. (Hsiao *et al.*, 1968; Bongers, 1970; Harrison *et al.*, 1988 and Hare, 1990). Among different host plants, another reason for the lowest mortality on brinjal may be due to choice of food supporting the survival of the beetle. In contrast, the highest mortality was recorded on tomato.

In holometabolous herbivores (Coleoptera, Lepidoptera, Diptera and Hymenoptera), the larval food is decided by the ovipositing female. Ovipositing females are thought to show a preference for host plants that support rapid larval development (Janz *et al.*, 1994; Nylin &Gotthard, 1998; Wedell *et al.*, 1997), as short development times act to reduce exposure times to predators and parasitoids (Connor 1991; Klok & Chown 1999), and facilitate rapid reproduction in growing populations (Fischer & Fiedler, 2000; Gotthard *et al.*, 1994). A female insect encountering a poor quality host plant may modify her oviposition behavior by reducing the number of eggs she lays on each plant. In the present findings very less fecundity was recorded on tomato as compared to other host plants. The reduction in egg production was due to secondary compounds in the leaf, and presumably to the sharp spine like projections on the foliage (Shirai, 1999). Casagrande (1982) pointed out two factors, secondary metabolic compounds in the leaf and trichome like projections on the foliage, regarding the mechanism of solanaceous plant resistance to *Leptinotarsa decemlineata.* The deterrent mechanism by the glandular hairs was attributed to the mechanical effect of spine-like projections on the foliage and chemical effect associated with a volatile substance released from the tips of glandular trichomes on tomato (Kennedy *et al.*, 1985). The oviposition site is a critical factor for the young larvae seeking out hosts because the slow moving larvae find it difficult to reach the appropriate host plant (David & Gardiner 1962). The neonate larvae usually suffer very high mortality if forced to leave their original host (Wittstock, 2004). Consequently, oviposition is based on cues that correlate with the prospects of larval survival.

The high value of net reproductive rate (R_0) on brinjal is a reflection of high intrinsic rate of natural increase (r_m) values (Table-21). Since r_m is the most important parameter for describing the growth potential of a population under given climatic and food conditions, r_m reflects an overall effect on development, reproduction and survival (Southwood and Handerson, 2000). In this study there was a significant difference observed in the intrinsic rate of increase (r_m) with respect to host plants. Abbas *et al.*, (1985) studied the survivorship and fertility schedules *H. sparsa* on *Solanum torvum* under laboratory conditions and found the r_m value 0.125. The development period was faster on brinjal, hence, the r_m value was highest on brinjal than other host plants. In addition, the finite rate of increase (λ) was comparatively more on brinjal and population of *H. vigintioctopunctata* doubles in the minimum duration on brinjal.

2. B. Effect of solanaceous and cucurbitaceous hosts on development of *H. vigintioctopunctata*

Development of immature stages

In the present studies, host plants significantly affected the development of immature stages of *H. vigintioctopunctata*. The longest and shortest development times of individuals from neonate to the end of the pupal stage was recorded on tomato and brinjal respectively (Table-22). This difference was probably a result of different food sources used by the parent during the larval stages. Similar inference was drawn in the past for *H. vigintioctopunctata* reared on different solanaceous crops including brinjal (Srivastava *et al.*, 1969). Vasantha *et al.*, (1984) also reported that *H. vigintioctopunctata* completed larval development in the shortest time on brinjal as compared to makoi and tomato. It was further confirmed by Parjhar *et al.*, (1997) recording shortest larval development time on brinjal and potato as compared to makoi, ashwagandha and tomato. A faster development time on particular host may allow a shorter life cycle, high reproductive productivity and more rapid population growth (Singh and Parihar, 1988). This reinforces the suggestion that brinjal is most suitable host for *H. vigintioctopunctata* than other host plants tested.

Development of adult stage

Host plants affected the life history parameters of *H. vigintioctopunctata.* Thus, adult longevity, ovipositional period and fecundity were significantly affected by different host plants. In the present study, adults lived longer on brinjal as compared to the different hosts tested. The increased longevity on brinjal could be probably due to the feeding preference of *H. vigintioctopunctata* on particular host plant having high quality dietary protein. The ovipositional period and fecundity was also noticed highest on brinjal and lowest on tomato when compared with black night shade, winter cherry and bittergourd (Table-23). These differences could be due to variation in nutritional and phagostimulant factors such as carbon and nitrogen as well as defensive metabolites that directly affect potential and achieved herbivore development and fecundity (Awmack and Leather, 2002). Females that have developed under different regimes of nutrition will have different potential fecundities (Blais, 1953). Reports of Siquiera *et al.*, (2004) showed that the fecundity of the females was 59.78 eggs when fed on the leaves of tomato which further confirm the findings of present studies. Higher rates of reproduction with low mortality rate of insects on a host indicate greater suitability of a host plant (Awmack and Leather 2002).

3. Differential responses of brinjal cultivars/accessions against *H. vigintioctopunctata* in field conditions.

The assessment of damage index and grading is an improved modification over the previous method employed by Sambandam *et al.*, (1972) and was worked out as per the modified scoring procedure (Rajendran & Gopalan, 1997 (b); Nayak & Rath, 2001). Results on varietal rankings of brinjal cultivars evaluated indicated that all the genotypes showed variable responses to this susceptibility trait. Susceptible reaction was exhibited by the cultivar, Pusa purple long which is in conformity with Gosh & Senapati (2001, b), Reddy & Srinivasa (2001) and Bhagat & Munshi (2004), they categorized this cultivar as susceptible variety of brinjal among the cultivars screened. In the present study, Pusa purple round and Lalat were graded as moderately resistant cultivars (Table-24). The high trichome density and longer size of trichomes might be responsible for non-preference mechanism of resistance in moderately resistant brinjal varieties as also inferred by Rath *et al.*, (2002). Similar results were obtained by Sambandam *et al.*, (1972) who reported Pusa Purple round moderately resistant to *H. vigintioctopunctata*.

Among the brinjal cultivars screened, none was resistant to the *H. vigintioctopunctata*. Similar inferences were drawn by Elanchezhyan *et al.*, (2008), Mandal *et al.*, (2000), Rajendran & Gopalan (1998) and Raju *et al.*, (1987) as a result of varietal evaluation of brinjal cultivars against this beetle.

4. Evaluation of certain organic amendments against *H. vigintioctopunctata* on brinjal in field conditions.

In the present study, all the plants grown in organic amended soils were proved effective in reducing the beetle incidence up to certain level over NPK as inorganic form. The reduced susceptibility to the pest may be due to the presence of the organic matter and microbial activity associated with organically managed soils affords a buffering capability to maintain nutrient balance in plants. An optimal nutrient balance results in both good plant growth and resistance to herbivory (Phelan *et al.,* 1996).

However, the combination of FYM (12.5 t/ha) + Azophos (2Kg/ha) + Neem cake (800Kg/ha) + neem oil (3%) was found most effective in reducing the beetle incidence up to 82.22 per cent over NPK (Table-25). This is in close agreement with the earlier findings of Suresh *et al.*, (2008) and Ravikumar *et al.*, (2008) who reported that application of FYM along with neem cake and biofertilizers was effective in reducing the incidence of *H. vigintioctopunctata* in brinjal and ashwagandha, respectively.

Among all the organic amended soils, the plants grown in the soil treated with the combination of FYM + Biofertilizer + Oil cake were proved better in reducing the beetle incidence when compared with plots treated with the FYM/ Poultry Manure alone. It may be due to the action of free living Nitrogen fixing bacteria and phosphate-solubilizing bacteria contained in bio-fertilizer and performance of neem cake added to FYM. When neem cake is added to the FYM, it increases the conversion of nitrogenous compounds into nitrogen gas (Senthivelu *et al.*, 2006), Nitrogen fixing bacteria changes the free nitrogen into the soluble form (Franche *et al.*, 2008) and phosphate solubilizing bacteria increases P uptake by the plant (Rodríguez and Fraga, 1999), thus making nitrogen and phosphorous available easily to the plants for longer duration and increases productivity and soil fertility and inducing vigor and vitality in plants making them less susceptible to insect attack.

In the present study, the plants grown in soil treated with FYM (12.5 t/ha) and Poutry Manure (3 t/ha) alone were found capable of reducing the incidence of beetle with per cent reduction of 32.04 and 25.96 respectively, over NPK. This might be due to the fact that organic manures, apparently promote an increase of soil organic matter and microbial activity and a gradual release of plant nutrients which does not lead to enhanced

N levels in plant tissues, thus allowing plants to derive a more balanced nutrition. Thus, while the amount of N immediately available to the crop may be lower when organic manures are applied, the overall nutritional status of the crop appears to be improved. FYM has been reported to be capable of releasing sufficient K in soil (Rao *et al.*, 1996) and that may be the reason for continuous supply of K in high amounts. The application of FYM/PM also provide supplies of secondary and trace elements, occasionally lacking in conventional farming systems that rely primarily on artificial sources of N, P, and K. Besides nutrient concentrations, optimum fertilization, which provides a proper balance of elements, can stimulate resistance to insect attack (Luna, 1988). The low 'N' content in the plants due to organic manures leads to increased phenols, tannins and lignin that contribute to leaf toughness and production of more cell wall related structural compounds which are not desirable for herbivores (Scriber and Slansky, 1981). Therefore, insects are unable to ingest sufficient quantities of nutrients. According to Zadda *et al.*, (2007) brinjal plants, which received organics, registered less quantity of reducing sugars, proteins, and leaf chlorophyll when compared to NPK as straight fertilizer applied plots, thus making less prone to insect attack.

The plants treated with NPK alone as inorganic form was recorded with highest incidence of 11.62 per cent by *H. vigintioctopunctata* because chemical fertilizers can dramatically influence the balance of nutritional elements in plants, which in turn, leads to concentrations of foliar N which make plants more vulnerable to pest attack.

In contrast to beetle incidence, fruit yields were largely comparable between the plots receiving manures and synthetic fertilizers. The highest fruit yield (169.8 q/ha) coupled with 58.1 per cent yield increase over NPK was recorded with maximum cost benefit ratio (CBR) of 1: 5.7 in the plots treated with FYM (12.5 t/ha) + Azophos (2Kg/ha) + Neem cake (800Kg/ha) + neem oil (3%). Similarly, all other treatments with the combination of FYM, biofertilizer, neem cake and neem oil showed the maximum tolerance to attack by *H. vigintioctopunctata* and highest edible fruit yield (Table- 26 & 27). The increased yield may be attributed to the repellence, feeding and oviposition deterrence, growth inhibition, ovicidal and larvicidal activity caused by neem oil as well as the induced resistance generated in the plants by using the required quantities of organic manures and biofertilizers.

It can be summarized by stating that higher uptake of N, P and K due to their continuous and balanced availability and, ample supply of minor elements resulted not only in better resistance but also higher tolerance to pests in brinjal following application of FYM + biofertilizer + neem cake and neem oil. Further, slow release of nutrient from FYM has not been able to swing the nutrient balance in favor of N in brinjal and thereby beetle attack remained considerably suppressed, besides the action of neen oil against *H. vigintioctopunctata.*

5. Bio-efficacy of some botanicals against *H. vigintioctopunctata* on brinjal in semi-field conditions

The studies on plant products revealed that some of the plant products viz., *Annona squamosa* seed extract and *Calotropis* leaf extract were moderately effective in causing mortality of *H. vigintioctopunctata*, though not as effective as that of neem oil (Neem excel) (Table-28). Several earlier workers have also demonstrated the effectiveness of neem oil against *H. vigintioctopunctata* (Mishra *et. al.*, 1990; Udaiyan and Ramarathinam, 1994; Shanmugaraj, 1995).

Higher mortality due to neem oil when compared to other products of plants could be attributed to the presence of limonoides and other bitter compounds of neem, responsible for antifeeding activity that resulted into the starvation and death of insects. These findings are in conformity with the results of Ascher (1981), Tewari and Moorthy

(1985) which showed reduction in the feeding by this pest when host plant was treated with neem oil.

In the present studies, typical symptoms observed in the insects fed with neem oil treated leaves could be attributed to the presence of active ingredient of Neem, Azadirachtin which might be responsible for inhibition of release of morpohogenetic peptide hormones, resulting in disruption of ecdysteroid or Juveline hormone concentration in the haemolymph which in turn affected moulting, metamorphosis and reproduction (Dong and Zhoa, 1996). Similarly, antifeedant and growth disrupting effects of Azadarachtin and related compounds were also recorded and reported against *H. vigintioctopunctata* by Schmutterer (2002).

Among the botanical, *Annona squamosa* seed extract and *Calotropis* leaf extract at concentration of 5.0 per cent registered highest mortality of 86 per cent and 80 per cent, respectively on 7th day. Earlier, similar performances of *Annona squamosa* and *Calotropis* were also reported against *H. vigintioctopunctata* on brinjal (Venkataramareddy *et. al.*, 1993; Ghatak and Mondal, 2008 and Murugesan and Murugesh, 2008).

CHAPTER-6
SUMMARY

1. Studies pertaining to the population fluctuation of hadda beetle and incidence of it's parasitoids in brinjal in relation to weather parameters revealed that the population of both the species was significantly correlated with weather parameters. The initial infestation of *H. vigintioctopunctata* and *H. dodecastigma* occurred in mid-February (2011) and mid-March (2010), thereafter population of both the species gradually increased. Two population peaks were observed; first in mid-May and second in early August, in both the years. Results of studies on seasonal abundance of *Henosepilachna* spp. led to know peak period of activity and duration of their occurrence in nature, which will be helpful in devising timely management strategies for this pest in Aligarh agro-climatic conditions.

   Two chief parasitoids i.e. *Pediobius foveolatus* and *Tetrastichus* sp. were recorded in both the years. Results also indicate that the parasitism of immature stages occurred from mid April to early June and reoccurred from late June to early October. Per cent parasitism ranged from 27.60 to 43.30 in eggs, 29.50 to 49.50 in grubs and 14.10 to 24.10 in pupae during 2010 and 2011.

2. Studies pertaining to the seasonal incidence of hadda beetle on six cultivars of brinjal revealed that the population was non-significantly affected by temperature, relative humidity and rainfall. The increase in population of all stages of *H. vigintioctopunctata* was found gradual in summers (March to May). None of the weather parameters alone was responsible for the multiplication and growth of *H. vigintioctopunctata* on different cultivars. It is assumed that for a major part of the season, the meteorological parameters remained conducive for the rapid

multiplication of this pest. Moreover, the degree of infestation and rates of population change of the beetle on different varieties seemed to be governed by varietal characteristics.

3. Studies pertaining to the effect of host plants on life-table and development of *H. vigintioctopunctata* revealed that the longest and shortest development times of individuals from neonate to the end of the pupal stage were recorded on tomato and brinjal respectively. Tomato had the highest antibiosis resistance against *H. vigintioctopunctata* and was the least favourable of the hosts evaluated for this pest as indicated by the long developmental time, low survival of immature stages and reduced fecundity as reflected in lower values of r_m as compared to brinjal with altogether contrary figures with respect to these factors making it the most susceptible host followed by winter cherry, black nightshade and bitter gourd. Information so gathered indicates towards differential susceptibility of different host plants to this pest as assessed on the basis of life stage parameters of this beetle.

4. Results on screening of brinjal cultivars indicated that all the genotypes showed variable responses to this susceptibility trait. The order of susceptibility was observed as Pragati > Nageena > Pusa purple long > Navkiran > PPL-74 > Suchitra > Sweekar > BR-112 > Lalat < Pusa purple round. Pusa purple round and Lalat were graded as moderately resistant cultivars however; none was resistant to the *H. vigintioctopunctata*. Consequently, there is vital entail to screen other brinjal varieties which are being used by the farmers in and around Aligarh region and to find out the resistant/tolerant cultivars.

5. Studies pertaining to the effect of certain organic amendments against *H. vigintioctopuncta* revealed that the combination of FYM (12.5 t/ha) + Azophos (2Kg/ha) + Neem cake (800Kg/ha) + neem oil (3%) was found most effective in reducing the beetle incidence up to 82.22 per cent over NPK recording the highest fruit yield (169.8 q/ha) and this proved most economic with respect to cost benefit ratio (CBR) of 1: 5.7. Application of this combination of organic amendments proved most satisfactory in suppressing the beetle incidence as compared to other treatments and untreated plants. Plants treated with NPK alone as inorganic form was recorded with highest per cent incidence (11.62 per cent) by *H. vigintioctopunctata.*

6. Studies pertaining to effect of some botanicals against *H. vigintioctopunctata* revealed that treatments of Neem excel at concentration of 3.0 per cent and *Annona squamosa* seed extract and *Calotropis* leaf extract at concentration of 5.0 per cent consistently gave good kill and proved significantly superior over other treatments at different duration.

The present studies have generated knowledge on various bio-ecological aspects of hadda beetles, *Henosepilachna* spp. with particular reference to *H. vigintioctopunctata* a noxious insect pest, infesting the commercial variety of brinjal grown in the region along with other potential cultivars and alternate host plants. The information so generated, besides being an addition to the basic knowledge, will be helpful in determination of pest status, it's monitoring, fore-casting and taking timely control decisions. The information on screening of different cultivars and alternate host plants for resistance/susceptibility of *H. vigintioctopunctata*, and development of non-chemical means of its management may be helpful in a long way in developing the agro-technology and package of practices for growing insect-free crop and increasing the crop yield. Above mentioned management options may further be evaluated in experimental fields/large scale field trials and after their validation in farmer's fields, if found successful, they may be included in IPM programme of this pest for recommendation to the farmers.

CHAPTER-7
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