STUDY ON THE BIOLOGY OF TWO SPOTTED SPIDER MITE (*Tetranychus urticae*) PEST IN BRINJAL AND BITTER GOURD: IMPACT OF ITS ECO-FRIENDLY MANAGEMENT

SONIA AKTER

DEPARTMENT OF ENTOMOLOGY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

SHER-E-BANGLA NAGAR, DHAKA-1207

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BY

SONIA AKTER

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Approved by:

………………………………….…	…………………………………………………
Prof. Dr. Md. Mizanur Rahman	**Prof. Dr. Mohammad Sakhawat Hossain**
Research Supervisor	**Research Co-supervisor**
Department of Entomology	**Department of Entomology**
SAU, Dhaka	**SAU, Dhaka**

...
Prof. Dr. Md. Mizanur Rahman
Chairman
Examination Committee

DEPARTMENT OF ENTOMOLOGY

Sher-e-Bangla Agricultural University (SAU)
Sher-e-Bangla Nagar, Dhaka-1207
Phone: 9134789

Ref. *Date:*

CERTIFICATE

This is to certify that thesis entitled **"STUDY ON THE BIOLOGY OF TWO SPOTTED SPIDER MITE (*Tetranychus urticae*) PEST IN BRINJAL AND BITTER GOURD: IMPACT OF ITS ECO-FRIENDLY MANAGEMENT,** *Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS) IN ENTOMOLOGY*** *embodies the result of a piece of bonafide research work carried out by* ***SONIA AKTER Registration no. 14-05976*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: June, 2021
Place: Dhaka, Bangladesh

Prof. Dr. Md. Mizanur Rahman
Supervisor
Department of Agricultural Botany
SAU, Dhaka

DEDICATED
TO
MY BELOVED
PARENTS

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Dated: June, 2021   ***The Author***

SAU, Dhaka

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ABSTRACT

The present study was carried out in the laboratory of Entomology Department and in the central farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh in order to conduct biological study of two spotted spider mite pests attacking brinjal and bitter gourd. Also studied the effectiveness of entomopathogenic fungi (*Trichoderma sp*), some botanicals and biopesticides (neem oil, mehagany oil, spinomax, biomax) and common insecticide (Ripcord) for the eco-friendly management of the pests. The experiment consisted of seven treatments and was laid in a single factor Randomized Complete Block Design (RCBD) with three replications. Mite pests were present in both brinjal and bitter gourd field. Adult mite was reared in laboratory, the female laid translucent eggs and the incubation period lasted for 1-3 days. The larval period ranged from 2 to 3 days and measured 183.43 ± 3.71 μ in length and 130 ± 2.70 μ in width. There were three resting stage during the life cycle of mite pests. First resting stage is called protochrysalis from which protonymph arised which was measured 243.72 ± 5.81 μ in length and 159.92 ± 4.65 μ in width. Second resting stage is deutochrysalis; the deutonymph emerged from deutochrysalis which was 382.54 ± 4.40 μ in length and 228 ± 3.6 μ width. Finally after the third resting stage which is called teleochrysalis, adult male and female emerged. Eventually different biorational control tactics, treatments showed varied response against mite pests. *Trichoderma spp.* showed the best result which was followed by Neem oil against mite pests infesting brinjal and bitter gourd field. The results showed that the total number of fruit set, % healthy fruit and infested fruit was higher with the treatment of *Trichoderma spp.* In most cases, except control treatment, ripcord showed the worst results against mite pests.

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Full meaning
%	Percent
^{o}C	Degree Celsius
AEZ	Agro-ecological Zone
AVOVA	Analysis of variance
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
cm	Centimeter
CV	Coefficient of variation
DAT	Days after transplanting
d.f.	Degrees of freedom
et al.	And others
G	Gram
Ha	Hectare
i.e.	That is
J.	Journal
K	Potassium
Kg	Kilogram
LSD	Least Significant Difference
Mg	Milligram
Ml	Milliliter
MP	Muriate of Potash
MT	Million Tons
NS	Non-significant
p	Phosphorus
RCBD	Randomized Complete Block Design
SAU	Sher-e-Bangla Agricultural University
SE	Standard Error
t	Tons
TSP	Triple Super Phosphate
Viz.,	For Example

CHAPTER I

INTRODUCTION

Bangladesh has one of the world's densest populations (1125 people per square kilometer) with a phenomenal growth rate of 1.37 percent. Despite the fact that Bangladesh is on track to become a middle-income country by 2021, agriculture remains the country's largest employer by far, employing 40.6 percent of the population (BBS 2020). Agriculture has been playing a pioneering role in Bangladesh's national economic growth and stability (Sharmin *et al*. 2018). Bangladesh grows a wide range of vegetables. It is a key part of crop agriculture in Bangladesh, contributing $718 million (3.2%) to the country's agricultural GDP in 2018 (BBS 2019). Vegetables are the most often consumed group of plants because they are a key source of micronutrients. Brinjals, tomatoes, cauliflower, bitter gourd, ridge gourd, beans, carrots, spinach, and other major vegetables are grown in Bangladesh.

The brinjal (*Solanum melongena* L.) belongs to a solanaceae family and commonly known as aubergine, eggplant, melongene, garden egg, or guinea squash in British English (Yiu 2006). It is the second most important vegetable crop in Bangladesh, next to potato, in terms of acreage, production, and consumption. It spans roughly 49,105 acres of the country's total vegetable area, producing 1.8 million tons per year (BBS 2020). Brinjal production is 55-60 t ha^{-1} (BARI 2017). The farmer is attracted to brinjal cultivation because of the better yield and longer fruiting and harvesting season (Ghimire *et al*. 2007). Yield has been seriously harmed by the attack of different insect pests, which has lowered its quality. The shoot and fruit borer, *Leucinodes orbonalis* Guenee; the jassid, *Amrasca biguttula*; the whitefly, *Bemisia* *tabaci* Gennadius; and the aphid, *Aphis gossypii*, all attack the brinjal crop. The primary bottlenecks in brinjal productivity are aphid and non-insect pests such mites, particularly the two-spotted spider mite, *Tetranychus urticae* Koch (Rizvi 1996, Chakrabarti *et al*. 2015, Jadhav 2017). Next to the shoot and fruit borer, the red spider mite causes considerable hazard to the cultivation of brinjal (Basu and Pramanik 1968). The yield was reduced by up to 12.18 percent to 32.1 percent as a result of mite infestation (Patil and Nandihali 2008). *T. urticae* was found to cause a 16.16 percent yield reduction in brinjal (Anonymous 2007).

Bitter gourd (*Momordica charantia* L.) is a popular summer vegetable in Bangladesh and throughout Asia (Khan *et al*. 2019, Beloin *et al*. 2005). It's high in ascorbic acid, iron, vitamins A, B, and C, as well as carbs (Ashrafuzzaman *et al*. 2010). It is a fast-growing cucurbitaceous vegetable in Bangladesh, with a total yield of 59,371 metric tons on 27,484 acres (BBS 2020). Bitter gourd production is 24-27t ha^{-1} (BARI 2017). It is thought to have medicinal benefits, and a chemical called 'Charantin' found in bitter gourds which can help diabetic patient to lower their blood sugar levels (Dhillon *et al*. 2005). Due to substantial damage caused by different insects, pests, and diseases, bitter gourd growers frequently fail to achieve the desired output. As a result, farmers sprayed often pesticides as pests alone resulted 25 percent annual loss of vegetable every year (FAO 2018).

Mites belong to the subphylum Chelicerata and subclass Acari, and are the most varied members of the phylum Arthropoda. Acari are the only arachnid species that attack plants. Plant feeding mites are common agricultural pests that attack fruits, vegetables, forage crops, ornamentals, and other crops. Around 7,000 phytophagous mite species have been identified worldwide, divided into five families:

Tetranychidae, Tenuipalpidae, Eriophyidae, Tarsonemidae, and Tuckerillidae (Chhillar *et al*. 2007). Tetranychidae, also known as spider mites, is a large family including about 1,200 species belonging to over 70 genera of worldwide distribution (Bolland *et al*. 1998). *Tetranychus urticae* Koch (Acari: Tetranychidae), a two-spotted spider mite, is one of the most damaging polyphagous pest species, affecting over 1000 plant species from over 140 plant families (Grbi *et al*. 2011, Migeon and Dorkeld 2014). It was first described by Koch in 1836 (Prichard and Baker 1955) and thought to originate from temperate climates (Fasulo and Denmark 2000). It feeds predominantly on the midrib and plant veins, resulting in yield losses of 50 to 100 percent (Kumar *et al*. 2010). Mites are controlled with a variety of systemic chemical pesticides, although the mite has shown rapid pesticide resistance (van Leeuwen *et al*. 2010). Due to, mites rapid growth and development, high fecundity, and haplo-diploid sex determination have all aided in the rapid evolution of pesticide resistance (van Leeuwen *et al*. 2010). Pesticide residues in vegetables are causing a decline in vegetable exports due to importing countries' major concerns (Quasem 2003). Moreover, use of synthetic chemicals have resulted in serious environmental problems and have been a threat to human life (Kim *et al*. 2005, Heil *et al*. 2008). Therefore, alternative strategies such as use of different bio-control agents, essential plant oils and bio-pesticides needs to explore for their acaricidal activity against mites in order to reduce the use of chemical acaricides that are currently being applied as well as to develop integrated management tactics.

The plant derived pesticides are environmentally safe and non-toxic to human being, fish and wild-life (Isman 2000). Many plant-derived essential oils possessed both insecticidal and acaricidal properties against different types of soft-bodied arthropod pests (Alexenizer and Dorn 2007). They usually exert multiple types of beneficial properties such as repellent, anti-feedant activity, growth regulatory activity and toxicity to many insect and mite pests (Prakash *et al*. 2008). Today's vegetable growers in Bangladesh and other countries use synthetic chemical pesticides from various groups such as organophosphate, organo-carbamate, pyrethroids, and nicotinoids (Khatun *et al*. 2016, Waseem *et al*. 2009). Bangladeshi farmers rely primarily on the application of hazardous pesticides and they spend up to 25% of the cost of cultivation on harmful pesticides application(Anon. 2004).

In Bangladesh, reports on the effectiveness of several chemical pesticides (Hossain *et al*. 2006; Uddin *et al*. 2015) and predators (Parvin and Haque 2008) to suppress mites are available. However, evidence on the effectiveness of entomopathogens, plant oils, and bio-pesticides against mites populations were scanty. As a result, the current study was designed to develop as eco-friendly management using *Trichoderma* spp., bio-pesticide, plant oils, plant extracts, insecticide against mites populations in Bangladesh.

Keeping all these information in mind present study was undertaken to accomplish the following objectives:

1. to study the biology and life cycle of two spotted spider mite pests attacking brinjal and bitter gourd and

2. to evaluate the effectiveness of entomopathogenic fungi, different botanicals and common pesticide against the mite pests.

CHAPTER II

REVIEW OF LITERATURE

Literature pertaining to the desired objectives in the introductory chapter is presented hereunder.

2.1. General overview on mites as pest

Mites are a diverse group of arthropods compared to insects, and are among the most damaging pests of vegetables worldwide (Jeppson *et al.* 1975). Spider mites (family Tetranychidae) are especially troublesome, as an outbreak of these pests can lead to serious losses and even total failure of the different crop. Within the spider mite family the most widespread and abundant pest is the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae). One reason this mite is such a ubiquitous pest is that the "species" is probably a complex of biologically variable. Much controversy exists regarding the taxonomic placement of TSSM, and there are approximately 65 synonyms included under this one species. One such problematic "species" of Tetranychus is *Tetranychus cinnabarinus* (Boisduval), the carmine spider mite, which is considered a red biotype of *T. urticae* in some studies (Auger *et al.* 2013) and a separate species in others (Kuang and Cheng 1990). Thus a comprehensive presentation and the most common descriptions of *T. urticae* will be used. Another species closely related to *T. urticae* is *Tetranychus evansi* Baker & Pritchard, the red tomato spider mite. This mite species has spread rapidly throughout the tropical and subtropical areas of the world during the last several decades, and has become a major pest on vegetables (Navajas *et al.* 2013). In the family Eriophyidae (superfamily Eriophyoidea) there are two major pest species of tomato, the tomato russet mite (TRM) *Aculops lycopersici* (Massee) and the tomato erineum mite *Aceria lycopersici* (Wolffenstein). *Ace. lycopersici* is closely related to the TRM and will be mentioned only when it differs substantially from *Acu. lycopersici*. The broad mite, *Polyphagotarsonemus latus* (Banks) (family: Tarsonemidae) is known as citrus silver mite or yellow tea mite. This species is found throughout the tropics and subtropics, and is mostly a problem in tomato greenhouse production.

2.2. Two-spotted spider mite, *Tetranychus urticae* Koch

2.2.1. Morphological identification of Two-spotted spider mite, *Tetranychus urticae* Koch

Female *T. urticae* are 0.4 mm long and broadly oval with 12 pairs of dorsal setae, whereas the male is slightly wedge-shaped with a narrow caudal end (Bolland *et al.* 1998). Female mites are approximately 50% larger than males. The color of the adult mite varies; usually they are greenish-yellow or almost translucent green, although they can also be brown or orange-red (English-Loeb 1990). Overwintering females are consistently orange to orange-red. Two large dark spots (consisting of food or bodily waste) on either sides of the idiosoma can usually be seen through the body wall (from which the species gets its common name). Mites that have recently molted may not have these spots (English-Loeb 1990).

Tetranychus urticae eggs are about 0.15 mm in diameter, round, and translucent when first laid but become white as hatching approaches. Most often the eggs are laid on the underside of leaves. Immature mites have the same general color and shape as adults, although the larvae have only 6 legs.

2.2.2. Biology of Two-spotted spider mite, *Tetranychus urticae* Koch

The life cycle for *T. urticae* consists of egg, larva, protonymph, deutonymph, and adult stages. Because spider mites are arrhenotokous (unmated females produce haploid eggs that develop into males while mated females produce diploid eggs that develop into females), this can lead to circumstances where there are very few males in the population. When this circumstance occurs the female may mate with her sons leading to inbreeding. Inbreeding can further occur by mating of brothers and sisters. Despite this potential for inbreeding, spider mites have considerable genetic diversity which allows them to adapt to new conditions and environments (Tommaso *et al.* 2007). Females oviposit fertilized and unfertilized eggs with the sex ratio of mated females being 3:1 female to male. Mated females can lay 20–30 eggs/day for a total of more than 200 over their 7–18 day life span depending on abiotic factors. Eggs, usually attached to fine silk webbing, hatch in approximately 3 days. After hatching, the first immature stage (larva) emerges with three pairs of legs, while all the nymphal and adult stages have four pairs. After each larval and nymphal stage there is a brief quiescent period, the chrysalis, during which the mite appears to be attached to the plant surface. Male mites generally mature more quickly than females and the adult males can be often seen guarding a deutonymphs chrysalis female so that they can mate with her as soon as she molts. At times a number of males will guard the same female deutonymph chrysalis, but usually only the most aggressive male succeeds in mating. This guarding behavior is often driven by the female who releases a sex pheromone at times resulting in one female mating with several males (Krips *et al.* 1998). The female mite has a pre-ovipositional period of approximately 24 h during which she often disperses. Development is most rapid during hot, dry weather (Tommaso *et al.* 2007). A single generation requires 5–20 days to reach adulthood before producing the next generation. There are many overlapping generations per year and only mated females overwinter in temperate regions.

T. urticae undergoes diapause in temperate regions when climatic conditions become too cold or hot. Diapause is indicated by a change in color to orange or reddish-orange. Diapause is induced by several factors that include food quality, temperature, and day length. Once in a hibernal (winter) diapause, females need a period of low temperature and short day lengths before diapause can be broken. How long and how deeply a population of TSSM stays in diapause is determined by their specific climatic conditions (Kawakami *et al.* 2009). This can produce site situations that will cause some mite populations to emerge from diapause earlier or later than other local populations resulting in a slow but steady release of spider mite females through out the early part of the season.

Female *T. urticae* may also stop reproduction during the cooler winter months in temperate production areas. Reproduction in greenhouses, tropical, or subtropical environments typically occurs year round. *T. urticae* often uses aerial dispersal from crop fields in the autumn to move to overwintering hosts such as chickweed, *Stellaria media* (L.) Vill. Females can also hibernate in ground litter or under the bark of trees or shrubs (Meck *et al.* 2009).

T. urticae is able to produce silk from glands located on the apex of their pedipalps. How well an individual mite survives can be greatly influenced by the mite’s ability to produce silk, as silk is used for web building, protection, and communication. *T. urticae* also uses silk as a social cue in selecting their microhabitat with group behavior being shaped by the individuals' response to social cues, such as the amount of silk already present on a leaf. When mite population begins to increase on the undersides of leaves, the combined production of silk by the adults can serve as protection from some natural enemies and increase humidity levels preventing desiccation. This silken "roof" also prevents pesticides from the leaf surface where mites are located. However, the presence of TSSM silk can be a signal for some specialist predators such as phytoseiid mites (family Phytoseiidae) and ladybird beetles to search more intensely when it is encountered (van de Vrie *et al.* 1972). *T. urticae* also use their silk for escape. Mites use the silk to spin down when they encounter a pesticide residue, especially pyrethroids, allowing them to avoid contact with the control treatment. Many Tetranychidae use silk to disperse via a process called ballooning; TSSM disperses in two different ways using their silken threads. One way is when only mated females that have not laid eggs form large silken assembles at the top of a plant. At the apex of the plant, they are picked up by the wind for dispersal. The second is when overcrowding occurs on a poor host plant. The mites collect on branch tips in masses of male and female mites, spin down on silk, and are picked up by the wind or animals (Clotuche *et al.* 2011). *T. urticae* can also use the silk as anchors and possibly as interference to other mites.

2.2.3. Distribution, host range and seasonal occurrence

T. urticae is a cosmopolitan spider mite. Although considered a temperate zone species, it is also found throughout subtropical regions. *T. urticae* is reported on over 300 host plants worldwide, including over 100 cultivated species such as cotton, corn, soybean, tomato, pepper, and numerous fruit and ornamental species (Bolland *et al.* 1998). A number of native plant species, including cutleaf evening primrose, violets, chickweed, clovers, pokeweed, wild mustard, and blackberry are common hosts from which infestations spread to nearby crops (Migeon *et al.* 2010).

T. urticae can be found on crop plants from early spring until the first killing frost in temperate areas of the world. Their populations begin to increase gradually in the early part of the growing season and rapidly at higher temperatures. Temperatures at or greater than 26.5°C with low rain fall and low to moderate humidity are prime environmental conditions for TSSM populations to rapidly increase to damaging levels.

2.2.4. Damage, losses and economic thresholds

Two-spotted spider mites have stylet-like chelicerae used for piercing host plants. This releases cellular content of the epidermal cells which the mite sucks up using its rostrum. The mite's feeding causes the mesophyll cells in the area to collapse creating very small white chlorotic spots on the leaves where they have removed the chlorophyll (Sabelis 1985 a, b).

As feeding damage progresses a stippled appearance of the foliage is evident. After several days of heavy mite feeding, necrotic spots begin to develop on leaf tissue and leaves will turn yellow or gray and collapse. Both *T. urticae* and *T. cinnabarinus* have been found to cause an unusual hyper-necrotic response in tomato that involves premature chlorosis of infested leaflets that consequently wilt and die (Szwejda 1993). Although not common, TSSM feeding damage on vegetable flowers causes a browning and withering of the petals. Mites will feed directly on the fruit, usually at the stem-end around the cap area (Meck *et al.* 2009). This feeding damage is rough to touch and has small depressed areas where the mites have removed chlorophyll and the cells have collapsed. Another fruit problem caused by TSSM is gold flecking, which appears as yellow or gold spots scattered over the surface of the fruit as it ripens. When this flecking is severe it can reduce the market value of the fruits. The flecks are only in the epidermal layer of the fruit and do not penetrate beyond this (Brust 2014). These flecks have been determined to be calcium oxalate crystals. Gold fleck is thought to be a response to certain stresses the plant encounters during the season, such as high temperatures and humidity or TSSM or thrips feeding (Brust 2014), or too high a level of calcium in the fruit as it is ripening. Of all the possible causes, TSSM seems to be the most important in causing this fruit ripening problem in temperate regions (Brust 2014). *T. urticae* is also implicated in the transmission of several viruses that include potato virus Y, tobacco mosaic virus, and tobacco ringspot virus. The mite does not actually inject the virus into the plant, instead excretes the virus onto the leaf surface and allows entry of the virus into the plant through feeding damage (Jeppson *et al.* 1975).

T. urticae, and most probably its species complex, is responsible for 10–50% yield losses in an average tomato production season. This range is so large because mite infestations can be severe in some areas of a field and almost nonexistent in others.

Environmental conditions and management programs (excessive early season insecticide applications) influence the severity of TSSM outbreaks and potential yield loss (Wilkerson *et al.* 2005). Yield loss is not only due to a reduction in tonnage of fruit, but also quality and size and therefore marketable yield (Meck 2010). Crop losses can occur when about 30% of the tomato leaf surface is damaged by spider mite feeding. In a study by Meck (2010) on tomatoes in North Carolina (United States), it was found that economic thresholds were very low at 1–2 mites/tomato leaflet. This threshold is extremely low and probably not practical for most tomato operations. Sampling for mites in a tomato field has shown that mite populations were highly aggregated and the number of samples required for just 60% precision was too large to be practical (Meck 2010).

Jayasinghe and Mallik (2010) in Thihagoda, Sri Lanka found that the middle developmental stage of tomato was the most critical period for mite damage and accounted for more than 50% of the total yield loss compared with early or late infestations. They developed an economic injury level (EIL) based on initial number of mites released on the plant and the number of days mites fed on the plant. While this EIL is a good place to start in understanding the relationship between mite numbers, feeding duration, and yield reduction, it is not practical at this time because it is impossible to know when and how many mites were initially there on a tomato plant and how long they had been feeding. Therefore, this EIL does not lend itself to commercial use.

2.3. Tomato red spider mite, *Tetranychus evansi* Baker & Pritchard

2.3.1. Morphological identification of Tomato red spider mite, *Tetranychus evansi* Baker & Pritchard

T. evansi belongs to "Group 5" of the genus *Tetranychus* (Flechtmann and Knihinicki 2002). To an untrained eye *T. evansi* looks very similar to *T. urticae* with a few exceptions. The body is from pale to dark orange in color and legs are also orange. Empodia (a lobe or spine between the two claws at the end of the tarsus) I and II of females have three pairs of proximoventral hairs and a tiny mediodorsal spur. All four proximal tactile setae on female tarsus I are nearly in line with the proximal set of duplex setae. The aedeagus (penis) is upturned distally and the dorsal margin is slightly convex (Baker and Pritchard 1960).

2.3.2. Biology of Tomato red spider mite, *Tetranychus evansi* Baker & Pritchard

The ability to predict population outbreaks of a new pest such as *T. evansi* greatly depends on its capacity to develop at different temperatures. Therefore, it is important to know the temperature requirements of a target species to understand its potential distribution and population dynamics (Ullah and Gotoh 2013). The rm-value (intrinsic rate of natural increase) of a species is used to describe the growth and adaptation of a population to certain environmental conditions (Birch 1948). Life history components, such as developmental rates, oviposition, survival rates, and the offspring proportion of females determine the rm-value (Sabelis 1985b). The rm-value can be used to forecast how much of a potential problem a mite species may pose in an agricultural system (Gotoh *et al*. 2004).

Sabelis (1991) conducted a broad review of the life history parameters of tetranychid mites and found the rm-values for these mites range from 0.219 to 0.336/day at approximately 25°C. The rm-values of *T. evansi* fall within this range. Gotoh *et al.* (2004) conducted studies on temperature-dependent developmental and reproductive traits of seven *T. evansi* strains collected from Brazil, France, Japan, Kenya, Canary Islands, Spain, and Taiwan. Temperature had a significant effect on the egg to female adult duration among the seven strains studied. The developmental times of the *T. evansi* strains ranged from 41.0 to 45.1 days at 15°C to 5.5–6.5 days at 40°C, and 9.7–10.5 days at 25°C. The strain from Brazil significantly differed from the France, Japan, Kenya, Canary Islands, and Taiwan strains in developmental duration. However, the overall life history parameters were very close among the seven *T. evansi* strains.

Sarmento *et al.* (2011a, b) showed that *T. evansi* suppresses the proteinase inhibitor (PI) activity in tomato plants by about 33% in comparison with the PI in non-infested tomato plants. This suppression resulted in higher oviposition rates (about two fold) on leaves that were attacked previously by conspecifics than on leaves that were not attacked, or on leaves that were previously attacked by heterospecifics (*T. urticae*). In *T. urticae,* oviposition rates were highest on leaves obtained from a “clean” plant followed by non-attacked leaves from an attacked plant. PIs are involved in induced plant defense and hamper the action of digestive proteinases present in the herbivore gut (Sarmento *et al.* 2011a). Oviposition rates of *T. evansi* were drastically reduced by 30% on leaves attacked previously by *T. urticae* compared with ones attacked by *T. evansi* (Sarmento *et al.* 2011b).

2.3.3. Distribution, host range and seasonal occurrence

T. evansi was first described as a new species based on specimens from tomato (*Lycopersicon esculentum* Miller) in the Mauritius Islands (Baker and Pritchard, 1960). However, it is considered to have originated from Brazil, from where it was first described as *Tetranychus marianae* McGregor (Navajas *et al.* 2013). Until the 1960s, it was known only from Mauritius Islands, Brazil, and Florida (United States). By the mid-1980s only a few other countries, such as Reunion Island, Rodrigues Island, Seychelles, Cuba, Puerto Rico, and Zimbabwe, reported it (Furtado *et al.* 2007). Since the 1990s it has spread throughout the world.

This species distribution is throughout the tropical to subtropical regions all over the world and is active year round (Navajas *et al.* 2013). In Japan, *T. evansi* was first described as *Tetranychus takafujii* Ehara and Ohashi in 2001 at Kyoto and Osaka prefectures, where it specialized on solanaceous plants (nightshades, *Solanum nigrum* L., *Solanum carolinense* L., *Solanum melongena* L.). In the next year, it was found in Tokyo and Hyogo. *T. evansi* was observed at 10 prefectures starting in 2008 from *S. nigrum*, *S. carolinense*, *Solanum photeinocarpum* Nakamura et Odashima, *S. melongena* to tomato. To date, more than 110 host species of *T. evansi* have been reported in both outdoor crops and greenhouses. Several *T. evansi* strains can attack different plant families such as Malvaceae (okra), Fabaceae, and Rosacea (Navajas *et al.* 2013).

2.3.4. Damage, losses and economic thresholds

T. evansi infests abaxial and adaxial surfaces and causes graying or browning of the leaves, which eventually wither and drop from the plant. Symptoms and losses are similar to *T. urticae*. This species is considered an important pest of all solanaceous plants, such as tomato, potato, and eggplant in Africa, and can cause up to 90% yield loss in southern Africa (Saunyama and Knapp 2003).

2.4. Broad mite, *Polyphagotarsonemus latus* (Banks)

2.4.1. Morphological identification

Female mites are about 0.2 mm long and oval in shape. Their bodies are swollen in profile and transparent, light yellow to pale brown or green, and waxy with a faint, median stripe that forks near the back end of the body (Montasser *et al.* 2011).

Males are small (0.11 mm) and have relatively long legs. They are similar in color and lack the median stripe found in the females. The fourth pair of legs on the female is reduced to a slender long hair extending from the tip. The fourth pair of legs of males ends in strong claws that are used to pick up the female nymph and place her at right angles to the male's body for transport and later mating (Ferreira *et al.* 2006).

Broad mite eggs are elliptical, gleaming, and colorless, about 0.08 mm long, and are covered with 30–40 scattered white knobs on the upper surface of each egg (Montasser *et al.* 2011). The distinctive egg is a key identifying characteristic to use when confirming that plant damage is being caused by broad mites. When eggs hatch, larvae emerge that are roughly 0.05–0.1 mm long and due to minute ridges found on their skin appear white, but later become transparent. Larvae have three pairs of legs. After 2–3 days, the larva becomes a quiescent "pupa" that appears as a clear immobile engorged body that is pointed at both ends. The "pupa" is about 0.08 mm long. Once they molt from this stage they become adults, which have four pairs of legs.

2.4.2. Biology of Broad mite, *Polyphagotarsonemus latus* (Banks)

Broad mites have somewhat modified four stage life cycle: egg, larva, quiescent pupa (some researchers call this as nymphal or even a larval stage), and adult. Non- mated females lay male eggs; mated females lay female or male eggs at a 4:1 ratio (Ferreira *et al.* 2006). Female broad mites lay 1–6 eggs/day, 35–70 eggs over a 7– 12-day period (de Coss-Romero and Peña 1998). Reproduction usually does not occur below 14°C or above 34°C. Males live 5–9 days while females live 8–13 days (Montasser *et al.* 2011). The eggs hatch in 2 or 3 days and emerge as larvae. Larvae are slow moving and do not disperse far. In 2 or 3 days, the larvae develop into a quiescent pupal stage. Quiescent female pupae become attractive to the males who pick them up and carry them to new foliage using their specialized appendages. The males then wait for the adult female to emerge and at this time they immediately mate with her (Peña and Campbell 2005). Although females are very active, males account for much of the dispersal of the broad mite population as they carry the quiescent female pupa to new areas on the plant. It has been found that adult broad mites under certain circumstances disperse by phoresy (method of dispersal in which the mites cling to the surface of another arthropod animal to be carried to a new site) using green peach aphids and several whitefly species (Ferreira *et al.* 2006).

2.4.3. Distribution, host range and seasonal occurrence

Broad mites are worldwide in distribution in both field and protected areas. *P. latus* has a wide host range in tropical and subtropical areas including 60 families of plants (Alagarmalai *et al.* 2009). In temperate climates it is a greenhouse pest throughout the year and a crop pest during the summer. Broad mites infest a great many ornamental plants such as African violet, azalea, begonia, Cannabis, chrysanthemums, cyclamen, dahlia, gerbera, gloxinia, jasmine, impatiens, lantana, marigold, snapdragon, verbena, and zinnia as well as crops such as apple, avocado, cantaloupe, castor, chili, citrus, coffee, cotton, eggplant, guava, papaya, pear, potato, sesame, string or pole beans, mango, tea, tomato, and watermelon (Grinberg *et al.* 2005, Ferreira *et al.* 2006).

Broad mite is a major pest year round in the tropical parts of the world. In subtropical areas it is a major pest during the summer and fall if weather conditions are warm and wet (Ferreira *et al.* 2006). In temperate areas it is a pest during the summer months, but under the right environmental conditions of heat and humidity it can cause severe damage.

2.4.4. Damage, losses and economic thresholds

The dramatic effects of broad mite infestations and feeding become evident by the appearance of tissue damage and changes in plant morphology and physiology (Alagarmalai *et al.* 2009). The earlier the plants are infested by broad mites the greater the damage and reduction in yields (de Coss-Romero and Peña 1998). Infested plants show growth inhibition and a decrease in leaf numbers and leaf area (Alagarmalai *et al.* 2009). Feeding by broad mites may cause leaves to bronze and thicken, become brittle, corky, or cupped downward, and narrower than normal because the mesophyll cells in the area collapse.

Young stem growth may be distorted and stunted, and heavy feeding causes tomato flowers to die and drop off. Severely damaged plants may die. Broad mites cause damage even at low densities because they secrete a plant growth regulator–like toxin when they feed. Mite damage can be confused with other plant problems such as viral diseases, micronutrient deficiencies, or herbicide injury. Even after control, damage may remain for weeks afterward. These factors make it challenging to undertake proper evaluations of control tactics, often leading to reports of control failures.

The broad mite’s minute size and ability to damage plants at very low densities generally results in plant injury serving as the first indication of an infestation. When damage is noted, terminals of symptomatic plants should be examined under magnification to verify the presence of broad mites (look for their eggs). Damage will usually start in small clumps in a field and can spread rapidly. As few as five broad mites on young plants may cause substantial plant damage leading to reduced fruit production. Brinjal, however, are less susceptible to broad mite feeding compared to sweet pepper or cucumber, and can tolerate 5–10 broad mites on a small plant.

2.5. Management of mite pests

This section will be a general discussion of mite management unless there are specific species to highlight.

2.5.1. Monitoring

Fields should be regularly inspected for mites to prevent population build up. However, the aggregated distribution of mites in the early infestation makes scouting for them challenging and a poor tool for predictive purposes (Meck 2010). Thus, scouting for mite feeding damage is a better predictive tool. It is very difficult to control mite populations once they are established. Because damage symptoms can resemble nutrient deficiencies or plant disease, the presence of mites must be confirmed. There are methods to monitor mites used by researchers, but these are time consuming and labor intensive, and are not amenable to commercial grower situations.

2.5.2. Cultural Control

Basic crop sanitation helps in the control of all the mite species by keeping the area around the crop free of mite-weed hosts, which will reduce the sources of infestation (Kay 1986). Some weeds are better at sustaining mite pests than others and these weeds, such as plantains, black nightshade, or solanaceous weeds should be targeted. Once harvest is complete, crop residues should be destroyed thus removing a breeding ground for the mites. Pruning back the affected plants and removing infested leaves will reduce pest numbers. For TSSM, dust management is particularly important. Dust on foliage makes it easier for mites to become a problem, although the mechanism of this effect has not been conclusively determined. There is evidence to show that dust interferes with mite predators and that the dust makes the foliage more hospitable for the mites. In many areas of the world there are periods of dry weather during the production of the vegetable crop and the production of dust will be difficult to stop. Growing some type of cover crop around the field or between the field and an area of dust production can greatly reduce the amount of dust that is deposited on the vegetable plant.

Vegetable plants should be kept as healthy as possible by feeding, mulching, and watering at the proper levels (Varela *et al.* 2003). Water-stressed plants increase spider mite populations compared with the same plants without water stress (English-Loeb 1990). Excessive nitrogen applications can cause succulent plant growth, which can stimulate TSSM reproduction (van de Vrie *et al.* 1972).

2.5.3. Biological Control

There has been much work done on the biocontrol of *T. urticae*, but not as much on the other mite pests. With any of the mites, conservation of natural enemies is the key management program a grower can undertake. This entails altering some agricultural practices to increase the numbers and activity of these predators, i.e., predatory beetles in the family Staphylinidae and Coccinellidae, lacewings, predatory thrips, *Orius* spp., mirid bugs, and predatory flies in the family Cecidomyiidae. This might include changing the type and rates of chemical pesticide applications, altering irrigation practices, growing cover crops and companion plants that help natural enemies, reducing dust production near the crop, etc. Much work has been done on augmentative control, which involves the mass rearing of and release of TSSM predators. The most commonly available predatory mites that have proved most efficacious for TSSM control are in the family Phytoseiidae. There are many different species commercially available. Some phytoseiid mites are specialists such as *Phytoseiulus persimilis* Athias-Henriot which feed exclusively on spider mites such as *T. urticae* and *T. cinnabarinus*. *P. persimilis* can rapidly increase in numbers in response to surging spider mite populations and is good to use if a large mite outbreak is occurring (Drukker *et al.* 1997). However, *P. persimilis* is susceptible to population crashes as its food source (spider mites) becomes scarce, and at times has problems moving on tomato plants because of the trichomes on the leaves. *P. persimilis* performs best when released on plants already infested with TSSM (Drukker *et al.* 1997). Combining *P. persimilis* with the predatory gall midge *Feltiella acarisuga* (Vallot) is particularly useful on tomato as the trichomes do not affect *F. acarisuga* and neither predator appears to interfere to any great extent with the other (Drukker *et al.* 1997).

Although *P. persimilis* is available in Europe, Africa, and Asia, other mites may be better suited for particular situations (Seif *et al.* 2001). The mite predators *Neoseiulus californicus* (McGregor) and *Neoseiulus cucumeris* (Oudemans) are more adaptable generalist feeders (TSSM and broad mites), utilizing alternate food sources including pollen, which allows them to be used in the early part of the season to suppress early mite (TSSM and broad mite) outbreaks (Weintraub *et al.* 2003). *Galendromus occidentalis* (Nesbitt) tolerates high temperatures and low humidity. *Amblyseius andersoni* (Chant) is popular in Europe where it is available in slow release sachets embedded in long ribbons easily applied to crops. How many predatory mites to release depends on many things, such as the stage of the crop, cultivar, environment, area to be covered, release rates recommended, density of the pest. The release rate can be very site-specific and therefore growers need to work closely with the commercial biocontrol producer and university personnel to determine the best timing and density of a release for the best control potential (McMurtry and Croft 1997).

Biological control agents for *T. evansi* were reviewed in detail by Navajas *et al.*

(2013). A few predators were found to be promising, such as the phytoseiid mite, *Phytoseiulus longipes* Evans (Furtado *et al.* 2006 & 2007, Ferreira *et al.* 2006). Furtado *et al*. (2006) concluded that out of the 28 phytoseiid species surveyed on solanaceous plants, *P. longipes* is the most capable predator to control *T. evansi*, because it could easily move about on brinjal leaves infested by *T. evansi* without being hampered by trichomes or the profuse webbing produced by the mites. The total fecundity of this predatory strain while feeding on T. evansi was similar to when it fed on *T. urticae* (Furtado *et al.* 2007). Another strain of *P. longipes* collected in Morocco resulted in a very low oviposition rate (0.1 eggs/day) when fed on *T. evansi*, compared with 2.7 eggs/day when fed on *T. urticae* (de Moraes and McMurtry 1987). Similar data were obtained in a Chilean strain, in which 89% of immatures did not complete their development when fed on *T. evansi*, although more than 90% of immatures reached adult- hood when fed on *T. urticae* (Ferreira *et al*. 2006). Thus, there are conspicuous differences in feeding habits among *P. longipes* strains, although all strains belong to the same species (Furtado *et al*., 2007). The spider mite predators *P. persimilis* and *N. californicus* did not survive well when fed only *T. evansi* and probably should not be used for its management (de Moraes and McMurtry 1987, Migeon *et al.* 2009).

When using augmentative release as a biocontrol strategy an important consideration is the quality of commercially available natural enemies. At times the quality of the shipment may be reduced due to poor production or shipping/handling preparations. Growers should evaluate the quantity and quality of each shipment of natural enemies as soon as the shipment arrives. Growers should calibrate their application rate by counting the number of active natural enemies and contact the supplier immediately if natural enemy quality is unsatisfactory.

While there are fewer studies on biocontrol of TRM and broad mites than the spider mites, there are predators that show potential. However, *P. persimilis*, which is a very important specialist predator of the TSSM, does not prey on TRM. *Amblyseius fallacis* (Garman) appears to survive and reproduce on and control both TSSM and TRM (Brodeur *et al.* 1997). There also may be potential for the use of *Homeopronematus anconai* (Baker) as a biological control agent as studies indicate that this predator can be effective in controlling TRM in tomato. The predatory mite

Amblyseius swirskii Athias-Henriot was found to be a good predator of TRM and broad mite under laboratory and field conditions (van Maanen *et al.* 2010). Under field conditions *A. swirskii* was able to survive on maize pollen when broad mite densities became low (Onzo *et al.* 2012). *N. cucumeris* was found to control broad mite populations, but needed to be released on every plant or on every other plant; this release method resulted in controls equal to chemical applications (Weintraub *et al.* 2003). Lower release rates resulted in poor control. Other studies have shown that *Amblyseius largoensis* (Muma) has potential as a biological control of broad mites (Rodrıguez *et al.* 2011). While there have been many studies examining other mite predators for control of mite pests on tomato under laboratory or greenhouse conditions, when moved to the field, few, if any, have been successful enough to warrant further study.

Other "biocontrols" include biopesticides such as entomopathogenic fungi. These fungi include *Neozygites floridana* (Weiser & Muma) (Duarte *et al.* 2009), *Beauveria bassiana* (Balsamo-Crivelli) Vuillemin, and *Metarhizium anisopliae* (Metchnikoff) Sorokin provided a list of commercially available species of the mycoacaricides for controlling tetranychid mites, in which 17 formulations from five fungal species were listed: *B. bassiana, H. thompsonii, Isaria fumosorosea* Wize, *Lecanicillium muscarium* (*Verticillium lecanii*) R. Zare & W. Gams, and *M. anisopliae*. *Chromobacterium subtsugae* Martin is a naturally occurring, recently discovered bacterium, which produces a number of compounds that contribute to the formation of several complex modes of action, creating a biopesticide that is highly active against mites (Palmer and Vea 2012). Control of mites using *C. subtsugae* is achieved by complex unique combinations of repellency, oral toxicity, reduced egg hatching, and reduced fecundity. This bacterium has also been shown to have only minor effects on most beneficial (Palmer and Vea 2012).

2.5.4. Chemical Control

By far the most common and effective method for controlling mite pests on vegetables is by using synthetic chemicals. However, the non-judicious use of chemical compounds against other pests such as caterpillars or thrips can cause flare-up of mites, especially TSSM. Only the common name of the chemical miticide will be provided and the chemicals presented here are not meant to be an exhaustive list of control options, but a general guide to the chemicals that are currently available and efficacious.

There are eight acaricides that consistently have shown efficacy on TSSM, TRM, and broad mites for many years: abamectin, acequinocyl, bifenazate, chlorfenapyr, etoxazole, fenpyroximate, milbemectin, and spiromesifen (Schuster 2006, Schuster *et al.* 2009, Layton *et al.* 2011, Stansly and Kostyk 2012, 2013). Abamectin serves as a good rescue miticide and offers residual control of TSSM. Bifenazate controls TSSM with less toxicity to predaceous mites and beneficial arthropods. Spiromesifen and fenpyroximate are slow acting contact controls that can take 2–5 days for results to be observed (Schuster 2006, Schuster *et al.* 2009). Etoxazol is a translaminar growth regulating (molt inhibitor) miticide that is specific to plant feeding mites. It kills the eggs and nymphs of TSSM and sterilizes the female adult, but does not adversely affect mite predators.

Experiments in Iran with six acaricides showed that bromopropylate, sulfur, and karathane were the most effective compounds for TRM while lambda-cyhalothrin or fluvalinate was found to give 98% control of TRM (Cheremushkina *et al.* 1991). Flubenzimine and abamectin were found to be the most effective treatments for TRM control followed by dicofol (dicofol is no longer used in many countries because of its toxicity to the environment) and dicofol plus tetradifon (Haji *et al.* 1988). Fourteen acaricides were tested against *Acu. lycopersici* on tomatoes in Australia (Kay and Shepherd 1988). The most effective chemicals in controlling an established infestation were flubenzimine, cyhexatin, and azocyclotin. For best control of TRM, applications were needed every 7–10 days. Also, flubenzimine and cyhexatin were the most effective preventative treatments for TRM (Kay and Shepherd 1988). Royalty and Perring (1988) found that judicious applications of avermectin B could provide good control of TRM while conserving its predator, *H. anconai.* Pesticides and spray oils were tested against broad mites with the most efficacious being: abamectin, endosulfan, fenpyroximate, pyridaben, tebufenpyrad, dicofol, petroleum-based spray oils, and canola oil.

There are three reports on chemical control of *T. evansi* by Gotoh *et al.* (2011) and Nyoni *et al.* (2011). In one study pesticides were foliar-applied and five were soil-applied to determine control efficacy for *T. evansi* in Zimbabwe with 48% of the chemicals tested being effective (Blair 1989). A few chemicals such as binapacryl, cyhexatin, and dicofol are no longer used in some countries because of their toxicity to humans and environment. Out of 23 chemicals tested, 14 and 19 were effective to adult females and eggs of the Zimbabwean *T. evansi* strain, respectively (Blair 1989).

Nine strains originating from Brazil, France, Kenya, Spain, Canary Island, Taiwan, and Japan (Kagoshima, Osaka, and Tokyo) were examined by Gotoh *et al.* (2011). All 11 chemicals tested were found to be effective for the control of *T. evansi* adults. Four strains used by Nyoni *et al.* (2011) were collected from Malawi and Fr3wance.

The LC50 values of four chemicals to adult females were variable. Only abamectin was considered to be effective to all four *T. evansi* strains tested (Nyoni *et al.* 2011). For bifenthrin, the LC50 values exceeded the recommended concentration in all four strains tested, and the LC50 values of two Malawian strains (1858–3560 mg/L) also were 20- to 39-fold greater than those of the two French strains (92.0–134.6 mg/L). For chlorpyriphos and fenpyroximate, LC50 values were similar among four strains (Nyoni *et al.* 2011).

Based on these studies, they recommend that the following chemicals should not be used to manage *T. evansi:* acephate, amitraz, bifenthrin, chlorpyriphos, cyflumetofen, dimethoate, flucythrinate, flufenoxuron, hexythiazox, and tetradifon because a marked resistance has already been documented in several studies. The present knowledge on chemical control suggests that 23 of the 35 acaricides could reduce *T. evansi* populations.

Calendar applications (spraying chemicals at regular predefined intervals rather than in response to pest populations) of chemicals increase the risk of resistance development in spider mites. This also applies to TRM and broad mites as well, but spider mites have a remarkable potential for rapid development of resistance (van Leeuwen *et al.* 2009, Ullah and Gotoh 2013). Repeated use of acaricides with the same or similar modes of action should be avoided as this may lead to increased resistance. Development of resistance can be delayed by rotating acaricides; i.e., successively using acaricides with different modes of action, or by using mixtures of several compatible acaricides (Ives *et al.* 2011, Ullah and Gotoh 2013).

Other chemical controls include various “Botanical oils” that either are refined petroleum products (mineral oils) or plant-derived oils that can effectively reduce mite populations on tomatoes as long as coverage of the plant is thorough. These horticultural oils differ in their mode of action. One of the most direct pathways is by obstructing the air passages that mites use to breathe, causing them to suffocate. In other cases, the oils may interact with the fatty acids of the pest and degrade their lipid/waxy layer that normally keeps them from drying out, or the oils may interfere with the insect's normal metabolic processes (Taverner 2002). The petroleum oils have their impurities removed that are associated with plant injury. These refined, purified oils are mixed with an emulsifier, which then allows the oil and water to mix. Botanicals oils when applied thoroughly to plants give results that are similar to the best synthetic chemical compounds. However, it is difficult to apply the oils to the underside of the foliage or in tightly folded leaves where most of the mites are located. This inability to effectively apply the oils to tomato plants can result in spotty or reduced control of the mites. Though usually not as reliable as petroleum-based oils, some of the common plant-derived oils that have shown efficacy on mites include: caraway seed, citronella java, lemon eucalyptus, pennyroyal, peppermint, rosemary, sesame, thyme and cinnamon, Neem (Makundi and Kashenge 2002) and Neem extract. Sulfur dust or wettable sulfur can be used although research shows that the efficacy of the sulfur products is especially variable.

2.6. General overview on brinjal, *Solanum melongena*

Brinjal or eggplant (*Solanum melongena* L.) is an important solanaceous crop of sub-tropics and tropics. 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. The brinjal is of much importance in the warm areas of Far East, being grown extensively in India, Bangladesh, Pakistan, China and Philippines. It is also popular in Egypt, France, Italy and United States. In India, it is one of the most common, popular and principal vegetable crops grown throughout the country except higher altitudes. It is a versatile 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. A number of cultivars are grown in India, consumer preference being dependent upon fruit color, size and shape.

Brinjal fruit (unripe) is primarily consumed as cooked vegetable in various ways and dried shoots are used as fuel in rural areas. It is low in calories and fats, contains mostly water, some protein, fibre and carbohydrates. It is a good source of minerals and vitamins and is rich in total water soluble sugars, free reducing sugars, amide proteins among other nutrients. The composition of edible portion of brinjal is given in Table 1.

Table 1 Composition per 100 g of edible portion of brinjal

Item	Conc.	Item	Conc.
Calories	24.0	Sodium (mg)	3.0
Moisture content (%)	92.7	Copper (mg)	0.12
Carbohydrates (%)	4.0	Potassium (mg)	2.0
Protein (g)	1.4	Sulphur (mg)	44.0
Fat (g)	0.3	Chlorine (mg)	52.0
Fiber (g)	1.3	Vitamin A (I.U.)	124.0
Oxalic acid (mg)	18.0	Folic Acid (µg)	34.0
Calcium (mg)	18.0	Thiamine (mg)	0.04
Magnesium (mg)	15.0	Riboflavin (mg)	0.11
Phosphorus (mg)	47.0	B-carotene (µg)	0.74
Iron (mg)	0.38	Vitamin C (mg)	12.0
Zinc (mg)	0.22	Amino Acids	0.22

Source: Gopalan *et al.* (2007)

According to Zeven and Zhukovsky (1975), it originated in India but spread eastward and by the 5th century B.C. was in China, which became a secondary center of variation. Thus, it has been known for the last 1500 years in China. Arabic traders were responsible for subsequent movement to Africa and Spain. Brinjal cultivation in the Mediterranean region is relatively recent. Portuguese colonies took it to Brazil. It is now widely cultivated for its fruits in the tropical, subtropical and warm temperate zones, especially in Southern Europe and the Southern United States. Sampson, 1936 suggested the African origin of this crop, but there is no evidence that *S. melongena* is native there though there are spiny African brinjal plants.

Insect pest infestation is one of the most limiting factors for accelerating yield potential of brinjal. The crop is prone to damage by various insects, although there is wide variability in their degree of infestation. Some of the important insects are fruit and shoot borer, jassids, mites, etc. The brinjal is also subjected to the attack of many diseases affecting roots, leaves, stems and fruits. The severity in any particular disease depends on the season and the region in which the crop is grown. Many of the diseases have caused damage only in exception years, but a few are prevalent in many areas each year and cause varying levels of damage.

2.7. General overview on bitter gourd, *Momordica charantia*

The vegetable *Momordica charantia* L., Cucurbitaceae, is known variously as bitter gourd, balsam pear, bitter melon, bitter cucumber, and African cucumber (Heiser 1979). Although it has many culinary uses, especially in south, southeast and east Asia, it is also grown as an ornamental and is used extensively in folk medicine (Heiser 1979). The fruits are cooked with other vegetables, stuffed, stir-fried, or added in small quantities to beans and soups to provide a slightly bitter flavor. However, for most food preparation, fruits are blanched, parboiled, or soaked in salt water before cooking to reduce the bitter taste. Nutrient compositions of bitter gourd fruits and presented in Table 2.

The center of bitter gourd domestication likely lies in eastern Asia, possibly eastern India or southern China (Miniraj *et al.* 1993). Uncarbonized seed coat fragments have been tentatively identified from Spirit Cave in northern Thailand. However, there have been no archaeological reports of bitter gourd remains in China (Marr *et al.* 2004). Moreover, a comprehensive compilation of plant remains from 124 Indian archaeological sites does not include bitter gourd (Kajale 1991).

Table 2 Nutrient composition of bitter gourd (*Momordica charantia* L.) fruit

Content	Concentration	Content	Concentration
Moisture (g/100 g)	83.20	Phosphorus (mg/100 g)	38.00
Carbohydrates (g/100 g)	10.60	Potassium (mg/100g)	171.0
Proteins (g/100 g)	210	Sodium (mg/100 g)	2.40
Fiber (g/100 g)	1.70	Iron (mg/100 g)	2.00
Calcium (mg/100 g)	23.00	Copper (mg/100 g)	19
Manganese (mg/100 g)	0.08	Zinc (mg/100 g)	0.46
β Carotene	126.06	Vitamin C	06.00

Source: Gopalan *et al.* (2007)

Most of the cultivated *Momordica* species are similar in their cultural needs, except for the space requirement per plant, which is based on the type and extent of vine growth. Some of the cultural practices described herein reflect empirical knowledge collected by many generations of farmers. Reports of cultural practices based on research by agricultural scientists are meager except for bitter gourd.

Momordica species grow well in hot, humid areas but also grow abundantly in subtropical climates and are day neutral. They are tolerant to a range of environments and can be grown in tropical and subtropical climates (Reyes *et al.* 1994). Bitter gourd is mainly cultivated during the spring, summer, and rainy seasons, with some winter production in subtropical climates. In contrast, it is cultivated throughout the year in tropical climates. The optimum temperature for good plant growth is 25° to 30°C. Frost can kill the plants, and cool temperatures will retard development. The bitter gourd crop can grow above 18°C with 24° to 27°C being optimum.

Bitter gourd performs well in full sun and is adaptable to a wide range of soil types but grows best in a well-drained sandy loam soil that is rich in organic matter. It grows well in soils of shallow to medium depth (50-150 cm), and like most cucurbits, bitter gourd prefers well- drained soils. For bitter gourd, the optimum soil pH is 6.0 to 6.7, but plants tolerate alkaline soils up to pH 8.0, whereas spine gourd prefers a pH of 6.0 to 7.0. Sweet gourd, in contrast, can tolerate soil salinity up to < 4 dS/m.

CHAPTER III

MATERIALS AND METHODOLOGY

The study was carried out both in laboratory of the Department of Entomology and in the central farm of Sher-e-Bangla Agricultural University, Sher-e- Bangla Nagar, Dhaka-1207 during October 2019 to February 2020. Details of the experimental methodology is given below:

3.1. Description of experimental site

3.1.1. Geographical location and climate

The present study was conducted during the period from October 2019 to February 2020. Research work was conducted in the experimental area of Sher-e- Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh (Plate 3) as well as in the laboratory of department of entomology of the same university. The location of the site is $23^0$77'N latitude and $90^0$33'E longitude with an elevation of 8.2 meter from sea level. The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by heavy scanty rainfall during the rabi season. The soil belonged to "The Modhupur Tract", AEZ-28. The experimental area was flat having available irrigation and drainage system and above flood level.

3.2. Planting materials

BARI Begun 1 and BARI Korola 1 were used as the test crop in this experiment. Seeds were collected from BARI (Bangladesh Agricultural Research Institute), Gazipur, Bangladesh.

Plate 1 Experimental field with brinjal and bitter gourd

3.3. Treatments of the experiment

Present study comprised with a single factor experiment. Six treatments were tested and evaluated for the management of mite infesting brinjal and bitter gourd along with an untreated control. So the cultivation of brinjal and bitter gourd and subsequent study on mite morphology was done separately.

Table 3. Treatments used in order to check efficacy of miticide with bio-pesticies in controlling mites

Treatments	Dose/ha
Spinomax (T_1)	0.4 ml/L of water at 15 days interval
Neem oil (T_2)	5 ml/L of water at 15 days interval
Biomax (T_3)	.2 ml/L of water at 15 days interval
Ripcord (T_4)	1 ml/L of water at 15 days interval
Trichoderma spp. (T_5)	200 mg/L of water at 15 days interval
Mehogany Leaf extract (T_6)	200 mg/L of water at 15 days interval
Untreated Control (T_7)	No treatment was applied

3.4. Experimental design

The experiment was laid out in a single factor randomized complete block design (RCBD) with three replications, where the experimental area was divided into three blocks representing the replications to reduce soil hetero-genetic effects (Plate 2). Each block was divided into seven-unit plots as treatments demarked with raised bunds. Thus, the total numbers of plots were 7X3=21. The unit plot size was 3.6 m × 1.6 m. The distance maintained between two blocks and two plots were 0.5 m and 0.5 m, respectively.

Plate 2 Layout of experimental field

3.5. Land preparation and intercultural operation

The study of brinjal and bitter gourd variety were sown in seedbed on October 2019. The plot selected for conducting the experiment was opened in the first week of November 2019 with assistance of farm dept., and left exposed to the sun for a week.

The soil was harrowed, ploughed and cross-ploughed several times after one week, followed by laddering in order to ensure good tilth (Plate 2). Organic and inorganic manures were incorporated with the soil of each unit. Seedlings were transplanted on November 15, 2019. Irrigation and drainage were provided when required. Weeding was done to keep the plots free from weeds, which ultimately ensured better growth and development (Plate 3).

3.6. Manuring and fertilizer application

As suggested by the Bangladesh Agricultural Research Institute, fertilizers N, P, K in the form of Urea, TSP, MoP respectively and S, Zn, and B in the form of gypsum, zinc sulphate and borax respectively were applied (Mondal *et al.* 2011).

Plate 3 Main field

3.7. Data recording

3.7.1. Biological study of mite

Stock culture of mite was established in the laboratory prior to the commencement of experiment. Mite infested brinjal and bitter gourd leaves (Plate 4 a, b) were collected along with mites. Then the samples were placed in petridishes after brought in the laboratory. Then some fresh brinjal leaves and bitter gourd leaves were placed in petridishes and some adult mites were transferred to those petridishes. A water soaked cotton piece was placed at the cut end of fresh brinjal and bitter gourd twig. The adult mites were removed from the petridishes soon after they laid eggs. The eggs were hatched into larvae and the larvae undergoes molting to become protonymph and deuteronymph. The days required to hatch eggs, from larvae to nymph, their biological study was recorded. The biological parameters of different stages were recorded with the help of a standardized occular micrometer fitted to a stereobinocular microscope.

a  b 

Plate 4 a. Mite infested brinjal plant; b. Mite infested bitter gourd plant

3.7.2. Data recording on efficacy of treatments against mite in brinjal and bitter gourd

3.7.2.1. Data recording on plant height affected by mite infestation and treatments

The both plant's height was measured with a meter scale 3 times in the field during the study period. Plants heights were measured at 20 DAP, 40 DAP and 60 DAP. The data were counted and mean was calculated.

3.7.2.2. Data recording on infested leaves affected by mite infestation and treatments

The number of nymphs and adults of mites were counted on six leaves (each from 2 upper, middle and lower canopy per plant). Examining each leaf was carefully done at early morning hours, when the pest was less active. To begin with, mites on upper surface (if any) of the leaves were counted and then the leaf was tilted carefully to count population on the lower surface.

3.7.2.3. Data recording on infested fruits affected by mite infestation and treatments

The pre and post treatment observations on live mite populations were assessed on 2, 7 and 15 days after spray. At each harvest, the fruit yield from individual plots was recorded separately and total yield was computed to hectare basis. The data so obtained were analyzed statistically after suitable transformation for test of significance.

3.8. Statistical analysis

Recorded data were put and compiled on MS excel spreadsheet. Later on, data were analyzed by using STATISTIX 10 software for analysis of variance. ANOVA was made by t variance test and the mean value comparisons were performed.

CHAPTER IV

RESULTS AND DISCUSSION

The results and the subsequent discussion of the present study under the following heading and sub-heading are depicted in this section:

4.1. Biological observations on life stages of *T. urticae*

4.1.1. General body shape and structure of different stages

4.1.1.1. Egg

Plate 5 Eggs of mite

The freshly laid eggs were brown or translucent white in color, which gradually turned to deep brown and then creamy pinkish as they approach hatching (Plate 5). The spherical-shaped eggs were laid singly. The incubation period ranged from 1 to 3 days.

4.1.1.2. Larvae

Plate 6 Larva of mite

The newly hatched larvae were almost spherical in shape and creamy white in color (Plate 6, Plate 7 B). Two bright and prominent red spots (simple eyes) were present on the dorsal sides of the propodosomal region. The larva possessed only three pairs of legs. The larval period ranged from 2 to 3 days. The larva measured 183.43 ± 3.71 µ in length and 130 ± 2.70 µ in width (Table 4). Initially the larva crawled around for some time and settled at a place to feed on the cell sap. The neonate larva was creamy white in color and turned green upon initiation of feeding and finally to dark green when it had fed for some time with dark specks appearing dorsolaterally. The larval period of male ranged from 1 to 2.5 days with an average of 1.69±0.49 days. In case of female a larval period of 2.09±0.5 days with a range of 1.5 to 3.0 days was observed.

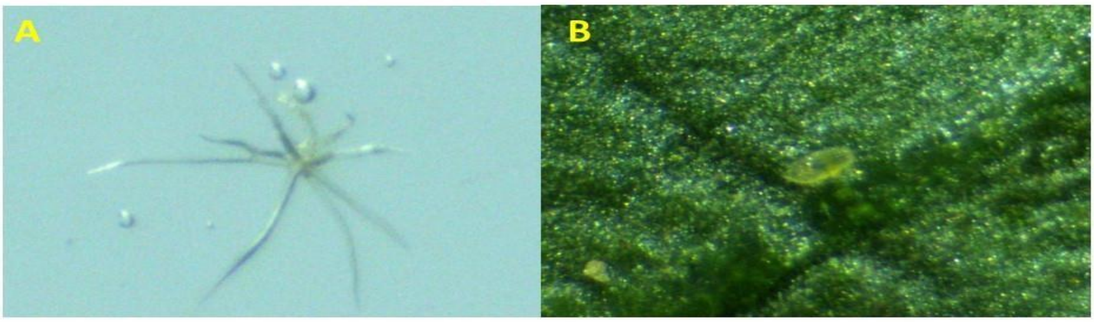

Plate 7 A. Shows slide preservation of Adult *T. urticae*; B. Shows the newly emerged nymph of mite in laboratory condition

4.1.1.3. Protochrysalis

The dark green matured larva entered into the quiescent stage by anchoring itself to the leaf surface. During this quiescent stage, the anterior 2 pairs of legs were extending straight forward and kept close to each other and posterior legs were extended backwards and held close to the sides of opisthosoma. This stage lasted for 0.25 to 1.25 (0.71±0.29) days and 0.25 to 1.50 (0.87±0.33) days for male and female, respectively.

4.1.1.4. Protonymph

The protochrysalis moulted into protonymph. The body was oval in shape with four pairs of legs and dark green in color in the beginning, which later turned into amber color. The newly emerged protonymph was oval shaped and amber colored. It was slightly bigger in size than the larva and was easily distinguished because of the presence of four pairs of legs. Feeding protonymph was greenish in the beginning and in due course it turned to dark green. It measured 243.72±5.81 µ in length and 159.92± 4.65 µ in width. The dark specks on the dorsum increased in size as the time passed. The protonymphal period of male was 2.14±0.42 (1.5 - 2.75 days) and female was 2.6±0.30 (2-3 days) winter seasons, respectively. The average protonymphal period for male and female was 1.86±0.52 and 2.24±0.45 days.

4.1.1.5. Deutochrysalis

The matured protonymph entered into quiescent, a stage which is known as deutochrysalis. The body also shrunk and decreased in size and attained a dark green color. At this stage the mite suspended all activities of feeding and remained anchored to the leaf surface. The body shrunk and decreased in size. This stage lasted for 0.81±0.16 and 1±0.25 days for male and female, respectively during winter season.

4.1.1.6. Deutonymph

Plate 8 Deutonymph

The deutonymph (Plate 8) emerged from deutochrysalis. The body was red colored, larger and broader than protonymph. Sex determination was quite noticeable during this period. The male deutonymph was smaller in size and elongated while, the female deutonymph was broader and large. The deutonymph measured 382.54 ± 4.40 µ in length and 228 ± 3.6 µ in width (Table 4). The deutonymphal period ranged from 0.5 to 2 days with an average of 1.23±0.42 days in male and from 0.75 to 2.5 days with an average of 1.67±0.65 days in female.

4.1.1.7. Teleochrysalis

The deutonymph at its maturity enters into a quiescent stage known as teleochrysalis. In this stage, the body shrinks and decreases in size. The color of this stage is light red to creamy.

4.1.1.8. Adult male and female

Plate 9 Adult male mite

Plate 10 Adult female mite

From the collected field specimen, laboratory stock culture was established. Adult and nymph specimens were thoroughly studies to distinguish between male and female species (Plate 9, 10). The body of the adult male was narrow with a distinct abdomen, greenish in color which later turned pinkish. The first pair of legs was longer than the rest of the pairs(Plate 9).

They also have numerous long hairs on their legs, and long but sparse hairs on their body. Males were smaller than females and lived for 11–12 days. The newly emerged females looked dull red which later turned to deep brick red (Plate 10). Females tend to be oval in body shape, males elongate-oval or diamond-shaped. The actively feeding female is usually greenish, with dorso-lateral dark spots (Plate 10). The simple eyes were seen as two red spots on the sides of the dorsal propodosomal region. The adult female survived for 19–24 days. The pre-oviposition period varied from 2 to 3 days with an average of 2.7 days. The oviposition period lasted for 11– 14 days with an average of 12.0 days. Each female laid about 123–160 eggs with an average of 146.6 eggs. The mean number of eggs laid was 10–12 eggs per day. The maximum number of eggs laid by a female was 11–12 eggs per day.

The length and width of different life stages are given in Table 4-

Table 4. Biological observations of life stages of *T. urticae* in Entomology lab

Stage	Mean ±SD (μ)	
	Length(μ)	Width (μ)
Egg (diameter)	129.75 ± 0.6 (129-132)	
Larva	183.43 ± 3.71 (181-190)	130 ± 2.70 (128-132)
Deutonymph	382.54 ± 4.40 (378-391)	228 ± 3.61 (225-237)
Adult-male	358.23 ± 13.87 (350-364)	185 ± 5.11 (180-188)
Adult-female	468 ± 14.33 (443-486)	283 ± 9.57 (271-297)

4.2. Position of mite species

Mite is a minute pest of vegetables which suck the plant sap from the lower part of the leaves. It causes viral disease as secondary pest. Mite causes serious damage at brinjal.

4.2.1. Population of mite observed at different canopies of brinjal field during rabi season October 2019 to February 2020

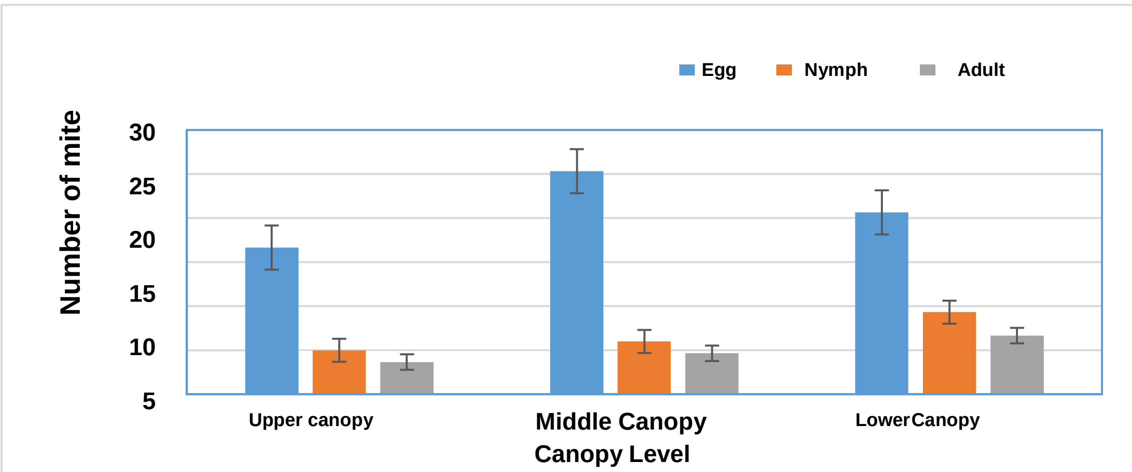

Figure 1. Population of mite species found in different canopy level of brinjal

From the Figure 1, it was revealed that on an average all stages of mite population were found in brinjal field. In order to get a clear idea about mite habitat and distribution, three levels of brinjal canopy was thoroughly observed. It was found that the highest number of eggs were present in middle canopy (25.33) followed by lower canopy (20.66) and upper canopy (16.66) (Figure 1). In case of nymph population, highest number of nymphs were obtained from lower canopy (9.33) which was followed by middle canopy (6) and upper canopy (5). Similar trend was followed by adult mite population in brinjal field. It was seen that highest number of adult mite were found from lower canopy (6.66) followed by middle (4.66) and upper canopy (3.66). Results are similar with the findings of Patil (2005). He showed that the highest number of egg, nymph and adult was found from middle canopy, bottom canopy and upper canopy respectively. The larva emerged out of the egg by making a vertical slit on one side of the cohesion. The larva widened this opening by pushing it apart with its legs and came out leaving the egg shell intact on the leaf surface. In most cases, the egg shells were not easily visible after hatching. The number of nymph and adults decreased because of natural mortality and predation.

4.2.2. Population of mite species in the bitter gourd field during rabi season October 2019 to February 2020

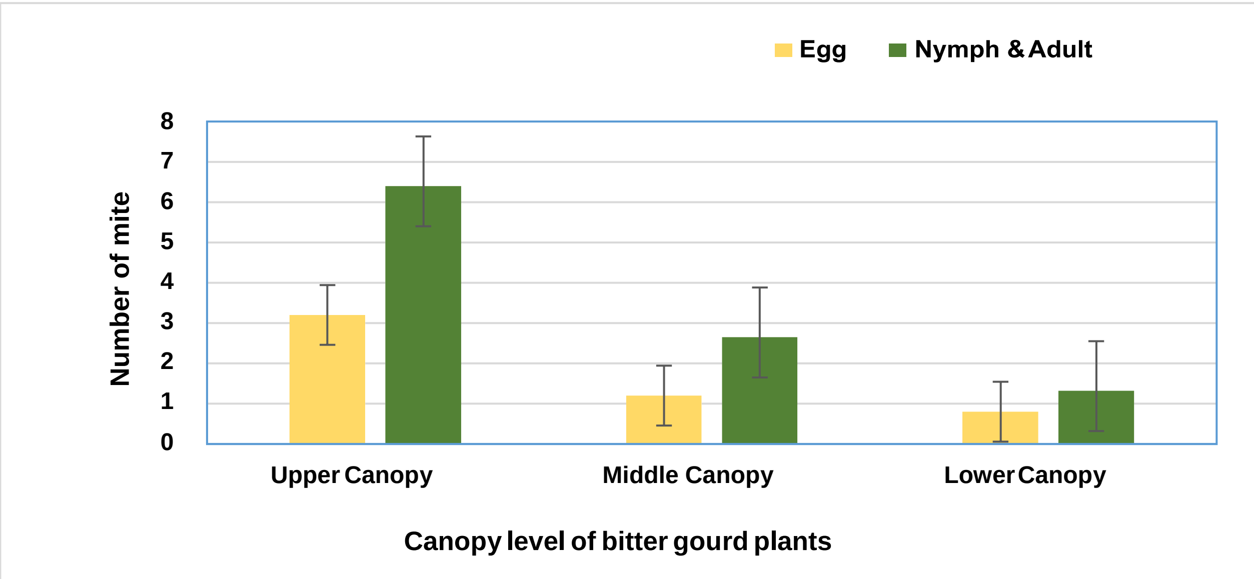

Figure 2. Population of Mite species found in different canopy level of bitter gourd

It is revealed that there was less invasion of mite pest in bitter gourd field compared to brinjal. From the Figure 2, it is found that the highest number of mites were obtained from the upper canopy (3.2 eggs and 6.4 nymphs plus adults respectively). Subsequently, from the middle canopy the number of mite population was 1.2 eggs and 2.65 adult and nymph. Furthermore, the lowest number (0.8 eggs and 1.32 nymphs and adults respectively) of mite populations were obtained from the lower canopy of sampled bitter gourd plants. It is interesting that mite pests found brinjal leaves more appetizing than bitter gourd leaves (Figue 2). Dutta *et al.* (2012) conducted an experiment on population abundance of red spider mite, *Tetranychus urticae* Koch in cucumber, ribbed gourd, bitter gourd, snake gourd, aroids and teasel gourd as well as on brinjal. They found highest number of mite pests in brinjal field and no mites was found in bitter gourd field. Thus, findings of present study shows little conformity with the study of Dutta *et al.* (2012). Along with their presence, mites affect the plants in many ways. The first sight of infestation by red spider mite was usually chlorotic, stippled appearance on the leaves.

4.3. Effect of treatment on the bitter gourd leaf infestation by mite pests during rabi season, October 2019 to February 2020

It is evident that there was varied abundance and population density of mite in the bitter gourd field during the study period after the application of treatments. The plots were sprayed thrice at 15 days interval. The counting was made after each spray. From the Table 5 it is evident that the best control was obtained after the first spray followed by second and third spray. In case of the first spray, the lowest population was found from Trichoderma (1.3 per leaf) which is significantly different from any other treatments of the experiment. After Trichoderma, the lowest mite population was found from neem oil (2.67 per leaf) followed by Spinomax (4.0 per leaf), Biomax (4.34 per leaf), mehogany leaf extract (5.34 per leaf) and Ripcord (6 per leaf). Though numerically differed, there was no significant difference between T_3 and T_6, T_1 and T_3. However, the highest mite population was found from the untreated control which was significantly different from all other treatments.

In case of second spray, the lowest population was found from Trichoderma (2.54 per leaf) treated plot which was statistically similar with neem oil treated plot (3.0 per leaf). After Trichoderma and neem oil, the lowest mite population was found from the by Biomax (5.0 per leaf), Spinomax (5.34 per leaf), mehogany leaf extract (6.14

per leaf) and Ripcord (7.33 per leaf) (Table 5). Though numerically differed, there was no significant difference between T_1, T_3 and T_6, T_4 and T_6, T_4 and T_7. However, the highest (8.67 per leaf) mite population was found from the untreated control plot.

In case of third spray, the lowest population was found from Trichoderma (4.2 per leaf) treated plot which was statistically similar to neem oil (4.31 per leaf). After Trichoderma and neem oil, the lowest mite population was found from the Biomax (6.67 per leaf), followed by Spinomax (7.0 per leaf), Mehogany leaf extract (8.33 per leaf) and Ripcord (8.62 per leaf). Though numerically differed, there was no significant difference between T_1 and T_3 and T_1 and T_6, T_4 and T_7 (Table 5) However, the highest (9.0 per leaf) mite population was found from the untreated control plot. Overall, the chronology of treatments $T_5>T_2>T_3>T_1>T_6>T_4>T_7$.

Overuse of synthetic insecticide such as Ripcord might lose its effectiveness against mite pest. Since the agrochemical industry began, insecticides and acaricides have played an increasingly important role in crop protection. However, many species of insects and mites have shown an ability to develop resistance against the pesticides used to combat them (Brent 1986). The present study the lowest effect from treatments except control was found from ripcord treated plot with the trend of resistance development by mite against synthetic pesticide. This study shows conformity with Kranthi *et al.* (2002). They also found ripcord resistance to whitefly (*Bamisia tabaci*). In their experiment, they found that all the *B. tabaci* field strains exhibited resistance to cypermethrin and susceptibility to chlorpyriphos and endosulfan.

Table 5. Effect of treatment on the bitter gourd leaf infestation of mite pests during rabi season, October 2019 to February 2020

Treatment	**No. of Mites (Nymph and adult/ Leaf)**		
	First Spray	**Second Spray**	**Third Spray**
Spinomax (T_1)	4.0 d	5.34 c	7.0 bc
Neem oil (T_2)	2.67 e	3.0 d	4.31 d
Biomax (T_3)	4.34 cd	5.0 c	6.67 c
Ripcord (T_4)	6.0 b	7.33 ab	8.62 a
Trichoderma (T_5)	1.3 f	2.54 d	4.2 d
Mehogany Leaf extract (T_6)	5.34 bc	6.10 bc	8.33 ab
Untreated Control (T_7)	7.34 a	8.67 a	9.0 a
CV (%)	**15.05**	**20.68**	**12.95**
Standard Error	**0.38**	**0.64**	**0.51**

4.4. Effect of treatments on the total number of bitter gourd fruit during rabi season October 2019 to February 2020

It has been seen that maximum number (29.33) of bitter gourd fruits was harvested from Trichoderma (T_5) treated plot (Table 6) which was significantly different from all other treatments of the study. After Trichoderma, the maximum number (27.66) of fruit was obtained from neem oil treated plot (T_2) followed by Biomax (T_3) treated plot (26 fruits per plant), Spinomax (T_1) (25.33 fruits per plant), Ripcord (T_4) (24.3 fruits per plant) and Mehogany Leaf extract (T_6) (23.67 fruits per plant.) However, the lowest number (20.67) of fruits obtained from Untreated Control (T_7) plot which was significantly different from any other treatments. Furthermore, there were no statistical variations found between T_4 and T_6, T_4 and T_1, T_1 and T_3 (Table 6). Trichoderma found to be effective against mite pests. Overall, fungal disease in insects are common and widespread. There are more than 700 species of entomopathogenic fungi currently known (Hajek and St Leger 1994, Goettel *et al.* 2000). Entomopathogenic fungi infect their hosts through the cuticle, penetrate them and spread through the body and after the fungus has killed the host, it can grow out of the host cadaver and produce more spores, increasing the chance for others to be infected. *Trichoderma* spp. has been widely used as antagonistic fungal agents against several pests as well as plant growth enhancers. Mycoparasitism, spatial and nutrient competition, antibiosis by enzymes and secondary metabolites, and induction of plant defense system are typical biocontrol actions of these fungi (Verma *et al.* 2007). According to the study of Mona and Noha (2016), the biochemical analysis of the *Trichoderma* treated adult cotton aphid revealed different quantitative changes in the total soluble protein; transaminase enzymes and the carbohydrates hydrolyzing enzymes relative activities as compared to the untreated ones. Also, the histological and ultrastructural studies showed many alterations and malformation in the treated adult *A. gossypii* body and tissue, in addition to the development and the colonization of *Trichoderma hamatum* inside the insect tissues.

Table 6. Effect of treatments on the total number of bitter gourd fruit during rabi season, October 2019 to February 2020

Treatment	Total Number of fruits per plant	Increase Over Control (%)
Spinomax (T_1)	25.33 cd	22%
Neem oil (T_2)	27.66 b	33.81%
Biomax (T_3)	26.0 c	25.78%
Ripcord (T_4)	24.3 de	17.56%
Trichoderma (T_5)	29.33 a	41.89%
Mehogany Leaf extract (T_6)	23.67 e	14.51%
Untreated Control (T_7)	20.67 f	-
CV (%)	**2.28**	-
Standard Error	**0.47**	-

4.5. Effect of treatments on the healthy and infested bitter gourd fruit during rabi season October 2019 to February 2020

From the Table 7, it is evident that there was significant variation among different treatments. The highest number of healthy fruits (27.66 fruits per plant) were obtained from Trichoderma (T_5) treated plot which was statistically different from all other treatments and Trichoderma (T_5) shows 72.87% increase in healthy fruit yield over untreated control. This was followed healthy bitter gourd fruits (25.33 fruits per plant) from Neem oil (T_2) treated plot which was also statistically different from other treatments and showed 58.31% increase in healthy fruit yield over untreated control. Though there was no statistically significant variation in healthy fruit yield between Spinomax (T_1) (22.67) and Biomax (T_3) treated plot (23.66). Later showed 47.87% higher result over untreated control where Spinomax (22.67 fruits per plant) showed 41.68% increase over control. Similarly, there was no statistical variation between Ripcord (T_4) and Mehogany Leaf extract (T_6) rather numerically differed from each other. Ripcord (21.33 fruits per plant) showed 33.31% increase over unteated control whereas Mehogany Leaf extract (20.33 fruits per plant) showed 27.06% increase over untreated control (Table 7). However, the lowest healthy fruit yield (16 fruits per plant) was obtained from the untreated control plot.

The lowest number of infested fruits (1.67 fruits per plant) were obtained from Trichoderma treated plot (T_5) which showed 71.45% decrease over control. Further, the number of infested fruit was observed in following order, Neem oil (T_2), Biomax (T_3), Spinomax (T_1), Ripcord (T_4), Mehogany Leaf extract (T_6) and untreated. No statistical variations found among the T_2, T_3 and T_5 as well as T_1, T_2, T_3 and T_4. Numerically, Neem oil and Biomax showed 50% decrease over untreated control followed by Spinomax, Ripcord, Mehogany Leaf extract which accounted 42.91%, 35.62% and 28.54% decrease in infested fruit number over untreated control. However, the highest infested bitter gourd fruits (4.66 fruits per plant) was obtained from untreated control plot which was statistically different from all other treatments. Overall, bitter gourd plots experienced lower level of infestation. This might be due to the fact that generally bitter gourd plants are less susceptible to mite pests (Dutta *et al.* 2012). Balkema- Boomstra *et al.* (2003) reported that bitter (pentanorcucurbitacin A & B, momordicine II & IV) in bitter gourd make the crop somewhat resistance against insect pests. Present findings are comparable to their results.

Table 7. Effect of treatments on the number of healthy bitter gourd fruit during rabi, season October 2019 to February 2020

Treatment	**Number of healthy fruits per plant**	**Increase over control (%)**	**Number of infested fruits per plant**	**Decrease over control (%)**
Spinomax (T_1)	22.67 c	41.68%	2.66 bc	42.91%
Neem oil (T_2)	25.33 b	58.31%	2.33 cd	50%
Biomax (T_3)	23.66 c	47.87%	2.33 cd	50%
Ripcord (T_4)	21.33 d	33.31%	3.0 bc	35.62%
Trichoderma (T_5)	27.66 a	72.87%	1.67 d	71.45%
Mehogany Leaf extract (T_6)	20.33 d	27.06%	3.33 b	28.54%
Untreated Control (T_7)	16.0 e	-	4.66 a	-
CV (%)	**3.08**		**19.47**	
Standard Error	**0.39**		**0.32**	

4.6. Effect of treatments on the yield of bitter gourd fruit during rabi season October 2019 to February 2020

The highest yield (28.833 t/ha) was obtained from T_5 (Trichoderma) treated plot which was statistically significant from any other treatments of the present study and obtained 31.04% more yield over the untreated control (Table 8). The yield was then followed by Neem oil (T_2) and Biomax (T_3) treated plot which observed 27.333 and 26.333 t/ha respectively and get no significant variation was observed between them. The lowest yield (22 t/ha) obtained from the untreated control plot which was statistically similar with the result obtained from Mehogany Leaf extract (T_6) treated plot. Mehogany Leaf extract showed only 4.5% yield increase over control (Table 8). Overall, the Trichoderma (T_5) showed the best performance in every cases. This may be attributed to holistic approach as eco-friendly management tactics.

Table 8. Effect of treatments on the yield of bitter gourd fruit during rabi season October 2019 to February 2020

Treatment	Yield (t/ha)	Increase Over Control (%)
Spinomax (T_1)	25.000 c	13.63%
Neem oil (T_2)	27.333 b	24.22%
Biomax (T_3)	26.333 b	19.68%
Ripcord (T_4)	23.557 d	7.04%
Trichoderma (T_5)	28.833 a	31.04%
Mehogany Leaf extract (T_6)	22.993 de	4.5%
Untreated Control (T_7)	22.000 e	-
CV (%)	**2.81**	-
Standard Error	**0.41**	-

4.7. Effect of treatments on the brinjal leaf infestation of mite pests during rabi season October 2019 to February 2020

It is evident that there was varied abundance and population density of mite in the brinjal field during the study period after the application of treatments. The plots were sprayed thrice at 15 days interval. The counting was made after each spray. From the Table 9 it was evident that the best control was obtained after the first spray followed by second and third spray. In case of the first spray, the lowest population was found from Trichoderma (11.33 per leaf) which is significantly different from any other treatments of the experiment. After Trichoderma, the lowest mite population was found from neem oil (12.66 per leaf) treated plot followed by Spinomax (14.0 per leaf) treated plot (Table 9), Biomax (14.33 per leaf), mehogany leaf extract (15.33 per leaf) and Ripcord (16 per leaf). Though numerically differed, there was no significant difference between T_3 and T_6, T_1 and T_3. However, the highest mite population (17.33 per leaf) was found from the untreated control plot which was significantly different from all other treatments.

After the second spray, the lowest population was found from Trichoderma (12.33 per leaf) treated plot which was statistically similar to that of neem oil (13.0 per leaf) treated plot. After Trichoderma and neem oil, which was followed by the Biomax (15.0 per leaf), Spinomax (15.33 per leaf), mehogany leaf extract (16.0 per leaf) and Ripcord (17.33 per leaf) treated plot. No significant difference between T_1, T_3 and T_6, T_4 and T_6, T_4 and T_7 treated plots. However, the highest (18.0 per leaf) mite population was found from the untreated plot.

After third spray, the lowest population was found from Trichoderma (14.0 per leaf) treated plot which was statistically similar with neem oil (14.0 per leaf). After Trichoderma and neem oil, the lowest mite population was found from followed by Biomax (16.67 per leaf) treated plot followed Spinomax (17.0 per leaf), Mehogany leaf extract (18.33 per leaf) and Ripcord (18.62 per leaf). Though numerically differed but they were not statistically different T_1 and T_3 and T_1 and T_6, T_4 and T_7. However, the highest (19.67 per leaf) mite population was found from the untreated control. Overall, the chronology of treatments was $T_5>T_2>T_3>T_1>T_6>T_4>T_7$.

Table 9. Effect of treatments on the brinjal leaf infestation of mite pests during rabi, season October 2019 to February 2020

Treatment	No. of Mites (Nymph and adult/ Leaf)		
	First Spray	**Second Spray**	**Third Spray**
Spinomax (T_1)	14.00 d	15.33 ab	17.00 ab
Neem oil (T_2)	12.66 e	13.00 b	14.00 b
Biomax (T_3)	14.33 cd	15.00 ab	16.67 ab
Ripcord (T_4)	16.00 b	17.33 a	18.67 a
Trichoderma (T_5)	11.33 f	12.33 b	14.00 b
Mehogany Leaf extract (T_6)	15.33 bc	16.00 ab	18.33 a
Untreated Control (T_7)	17.33 a	18.00 ab	19.67 ab
CV (%)	**4.62**	**15.26**	**14.20**
Standard Error	**0.38**	**1.32**	**1.33**

4.8. Effect of treatments on the total number of brinjal fruit during rabi season October 2019 to February 2020

There was statistical variation among the treatments used in the study. It has been seen that maximum number (17.33) of brinjal fruits was harvested from Trichoderma (T_5) treated plot (Table 10) which was statistically significant from any other treatments of the study. After Trichoderma, the maximum number (15.667) of fruit was obtained from neem oil (T_2) treated plot followed by Biomax (T_3) treated plot (14 fruits per plant), Spinomax (T_1) treated plot produced 13.33 fruits per plant, Ripcord (T_4) treated plot produced 12.33 fruits per plant and Mehogany Leaf extract (T_6) treated plot produced 11.67 fruits per plant. However, the lowest number (10.33) of brinjal fruits obtained from Untreated Control (T_7) which was significantly different from any other treatments. Furthermore, there were no statistical variations amongT_4 and T_6, T_4 and T_1, T_1 and T_3 (Table 10). Trichoderma found to be effective against mite pests.

Table 10. Effect of treatments on the total number of brinjal fruit during rabi season October 2019 to February 2020

Treatment	Total Number of fruits per plant	Increase Over Control (%)
Spinomax (T_1)	13.333 cd	30%
Neem oil (T_2)	15.667 b	51.69%
Biomax (T_3)	14.00 c	35.52%
Ripcord (T_4)	12.33 de	19.36%
Trichoderma (T_5)	17.33 a	67.76%
Mehogany Leaf extract (T_6)	11.67 e	12.97%
Untreated Control (T_7)	10.33 f	-
CV (%)	**4.22**	-
Standard Error	**0.32**	-

4.9. Effect of treatments on the number of healthy and infested brinjal fruit during rabi season October 2019 to February 2020

From the Table 11, it is evident that there were significant variations among the different treatments. The highest number of healthy fruits (14.67 fruits per plant) were obtained from Trichoderma (T_5) treated plot which was statistically different from any other treatments and Trichoderma (T_5) showed 193.4% increase in healthy fruit yield over untreated control. The number of healthy brinjal fruits (12.33 fruits per plant) was followed by Neem oil (T_2) treated plot which was also statistically different from other treatments and showed 146.6% increase in healthy fruit yield over untreated control. Though there was no statistical variation between Spinomax (T_1) and Biomax (T_3) but numerically better yield was obtained from Biomax (9.67 fruits per plant) which showed 113.4% higher than untreated control where Spinomax (10.67 fruits per plant) showed 93.4% increase over control. Similarly, there was no statistical variation between Ripcord (T_4) treated plot and Mehogany Leaf extract (T_6) treated plot rather numerically differed from each other. Ripcord treated plot (8.33 fruits per plant) showed 66.6% increase over untreated control whereas Mehogany Leaf extract (7.33 fruits per plant) showed 46.06% increase over untreated control. However, the lowest healthy fruit yield (5.0 fruits per plant) was obtained from the untreated control plant.

On the other hand, there was also significant variation between the obtained infested brinjal fruits from different treatments. The lowest number of infested fruits (2.67 fruits per plant) were obtained from Trichoderma (T_5) which showed 49.91% decrease over untreated control. Further, the number of infested brinjal fruit was observed in following order, Neem oil (T_2), Biomax (T_3), Spinomax (T_1), Ripcord (T_4), Mehogany Leaf extract (T_6) and untreated control plots. No statistical variations found among the T_2, T_3 and T_5 as well as T_1, T_2, T_3 and T_4. Numerically, Neem oil and Biomax showed 37.52% decrease over untreated control plot followed by Spinomax, Ripcord, Mehogany Leaf extract which experienced 31.14%, 24.95% and 18.67% decrease in infested fruit number over controlrespectively. However, the highest infested bitter gourd fruits (5.33 fruits per plant) was obtained from untreated control plot which was statistically different from all other treatments of the current study.

Table 11. Effect of treatments on the number of healthy and infested brinjal fruit during rabi season October 2019 to February 2020

Treatment	Number of healthy fruits per plant	Increase Over Control (%)	Number of infested fruits per plant	Decrease Over Control (%)
Spinomax (T_1)	9.67 c	93.4%	3.67 bc	31.14%
Neem oil (T_2)	12.33 b	146.6%	3.33 cd	37.52%
Biomax (T_3)	10.67 c	113.4%	3.33 cd	37.52%
Ripcord (T_4)	8.33 d	66.6%	4.00 bc	24.95%
Trichoderma (T_5)	14.67 a	193.4%	2.67 d	49.91%
Mehogany Leaf extract (T_6)	7.33 d	46.6%	4.33 b	18.67%
Untreated Control (T_7)	5.00 e	-	5.33 a	-
CV (%)	**7.10**	-	**14.42**	-
Standard Error	**0.39**	-	**0.31**	-

4.10. Effect of treatments on the yield of brinjal during rabi season, October 2019 to February 2020

The highest yield (37.833 t/ha) was obtained from T_5 (Trichoderma) which was significantly higher than other treatments of the present study and obtained 22.03% more yield over untreated control. This yield was then followed by Neem oil (T_2) and Biomax (T_3) treated plot which were 36.33 and 35.33 t/ha respectively and no significant variation was observed between these two treatments. The lowest yield (31.0 t/ha) comes from the untreated control plot which was statistically similar to those obtained from Mehogany Leaf extract (T_6) treated plot. Mehogany Leaf extract showed only 3% increase in yield over control. Overall, the Trichoderma (T_5) showed the best results in every cases (Table 12). This may be attributed to holistic approach as an eco-friendly management tactics

Table 12. Effect of treatments on the yield of brinjal during rabi season, October 2019 to February 2020

Treatment	Yield (t/ha)	Increase Over Control (%)
Spinomax (T_1)	34.00 c	9.67%
Neem oil (T_2)	36.33 b	17.19%
Biomax (T_3)	35.33 b	13.96%
Ripcord (T_4)	32.57 d	5.06%
Trichoderma (T_5)	37.83 a	22.03%
Mehogany Leaf extract (T_6)	31.93 de	3%
Untreated Control (T_7)	31.00 e	-
CV (%)	**2.07**	-
Standard Error	**0.41**	-

Trichoderma based products have been particularly successful because of their capacity to control phytopathogenic fungi. Some Trichoderma strains have a predominant biostimulant action that makes them unique for their extended use in horticulture. They are safe for humans, livestock and crop plants and in the natural environment colonize plant roots without apparent adverse reactions. Both solid and liquid formulations containing conidia can be used to produce suitable quantities effective and viable inocula during product formulation and field use. The mechanism of phytostimulation by Trichoderma involves multilevel communication with root and shoot systems, as it releases into the rhizosphere auxins, small peptides, volatiles and other active metabolites this promote root branching and nutrient uptake capacity, thereby boosting plant growth and yield. Recent proteomic and genetic data suggest that Trichoderma activates the mitogen activated protein kinase 6, transcription factors and DNA processing proteins, which represent promising targets toward formulation of more efficient products.

CHAPTER V

SUMMARY AND CONCLUSION

Summary

The swork was undertaken to study the morphology of mites species attacking brinjal and bitter gourd field as well as to develop as eco-friendly i.e., bio rational control measures against mite pests in those fields. The study was conducted in the central farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. Randomized complete block design (RCBD) was used for evaluating the treatment. Spinomax, neem oil, biomax, ripcord, Trichoderma, mahogany leaf extract and an untreated control treatment were used as different treatments in the study.

For the morphological study of mites found in brinjal and bitter gourd field, they were identified as *T. urticae*. The eggs were spherical-shaped and laid singly. The incubation period ranged from 1 to 3 days. The larval period ranged from 2 to 3 days. The larva measured 183.43 ± 3.71 μ in length and 130 ± 2.70 μ in width. The dark green matured larva entered into the quiescent stage called Protochrysalis lasted for 0.25 to 1.25 (0.71±0.29) days and 0.25 to 1.50 (0.87±0.33) days for male and female, respectively. The protochrysalis moulted into protonymph. It measured 243.72±5.81 μ in length and 159.92± 4.65 μ in width. The matured protonymph entered into quiescent, a stage which is known as deutochrysalis. The deutonymph measured 382.54 ± 4.40 μ in length and 228 ± 3.6 μ in width. The deutonymph at its maturity enters into a quiescent stage known as teleochrysalis.

Adult males were smaller than females and lived for 11-12 days. The newly emerged females looked dull red which later turned to deep brick red. The adult female survived for 19-24 days. The pre-oviposition period varied from 2 to 3 days with an average of 2.7 days. The oviposition period lasted for 11-14 days with an average of 12.0 days. Each female laid about 123-160 eggs with an average of 146.6 eggs.

In the present study the mite pests were present observed in both brinjal and bitter gourd field. In case of brinjal, mite pests were present in all three canopies such as upper, middle and lower part of plant. Number of egg found in brinjal plant were higher those that of nymph and adult. On the other hand, mite pests was present mostly in the middle canopy of brinjal plant followed by lower canopy and upper canopy. In most cases, the egg shells were not easily visible after hatching. The number of nymph and adults decreased because of natural mortality and predation. It is revealed that there was less invasion of mite pest in bitter gourd field compared to brinjal. The highest number of mites were obtained from the upper canopy followed by the middle canopy and lower canopy of bitter gourd plant.

At the second part of the study, several botanicals and commercial pesticides were tested against mite pests infesting brinjal and bitter gourd. It is evident that there was varied abundance and population density of mite in the bitter gourd field during the study period after the application of treatments. The best control was obtained after the first spray of Trichoderma (T_5) treatment followed by second and third spray. In case of the first spray, the lowest population was found from Trichoderma (1.3 per leaf) treated plot which is significantly different from any other treatments. The highest mite population was counted from the untreated control plots which was also significantly different from other treatments. In case of second spray, the lowest population was found from Trichoderma (2.54 per leaf) treated plot and the highest (8.67 per leaf) mite population was found from the untreated control plot. In case of third spray, the lowest population was found again from Trichoderma (4.2 per leaf) treated plot and the highest (9.0 per leaf) mite population was found from the untreated control plots.

It has been seen that maximum number (29.33) of bitter gourd fruits were harvested from Trichoderma (T_5) treated plot and the lowest number (20.67) of fruits obtained from untreated Control (T_7) which was significantly lower from any other treatments. The highest number of healthy fruits (27.66 fruits per plant) were obtained from Trichoderma (T_5) applied plots whereas, the lowest healthy fruit yield (16 fruits per plant) was obtained from the untreated control plots. On the other hand, the lowest number of infested fruits (1.67 fruits per plant) were obtained from Trichoderma (T_5) treated plot which showed 71.45% decrease over control. The highest infested bitter gourd fruits (4.66 fruits per plant) was obtained from untreated plot control which was statistically higher from all other treatments of the current experiment.

However, the highest yield of bitter gourd (28.833 t/ha) was obtained from T_5

(Trichoderma) treated plot which was statistically significant from all other treatments of the present study and obtained 31.04% more yield over untreated control.

It is evident that there was varied abundance and population density of mite in the brinjal field during the study period after the application of treatments and the best control was obtained after the first spray followed by second and third spray. In case of the first spray, the lowest population was found from Trichoderma (11.33 per leaf) treated plot which was significantly different from any other treatments of the experiment whereas, the highest mite population (17.33 per leaf) was found from the untreated control plot. After the second spray, the lowest population was found from Trichoderma (12.33 per leaf) treated plot and the highest (18.0 per leaf) mite population was found from the untreated control plant. After the third spray, the lowest population was found from Trichoderma (14.0 per leaf) treated plot and the highest (19.67 per leaf) mite population was found from the untreated control plot.

It has been seen that maximum number (17.33) of brinjal fruits was found from Trichoderma (T_5) treated plot and the lowest number (10.33) of brinjal fruits obtained from the untreated control(T_7). The highest number of healthy fruits (14.67 fruits per plant) were obtained from Trichoderma (T_5) treated plot which was statistically different from all other treatments and Trichoderma (T_5) treated plot showed 193.4% increase in healthy fruit yield over control. However, the lowest healthy fruit yield (5.0 fruits per plant) was obtained from the untreated control plots.

The lowest number of infested fruits (2.67 fruits per plant) were obtained from Trichoderma (T_5) treated plot and the highest infested bitter gourd fruits (5.33 fruits per plant) was obtained from untreated control plots which was statistically higher than all other treatments of the study. Accordingly to, the highest yield (37.833 t/ha) was obtained from T_5 (Trichoderma) treated plots which was statistically significant from all other treatments of the present study and 22.03% more yield than over control.

Conclusion

The present study showed several evidence of decline in the insect population as a result of using some entomopathogenic fungi proving their worth and potential as mycopesticide. However, a major hurdle of using Entomopathogenic fungi as plant protection agent might cause toxicity of secretory metabolites, especially secondary metabolites. For future prospects, strategies to standardize the risk assessment of these fungal species as biopesticides are needed. Proper selection of strains with specific host target without having negative influence on non-target organisms is another major point of concern.

CHAPTER VI

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