PREVALENCE AND MANAGEMENT OF INSECT PESTS OF RED AMARANTH (LALSHAK), *AMARANTHUS GANGETICUS* AND IT'S NATURAL ENEMIES

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CERTIFICATE

This is to certify that the thesis entitled **"Prevalence And Management of Insect Pests of Red Amaranth (Lalshak), *Amaranthus gangeticus* and Its Natural Enemies"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of Master of Science in Entomology, embodies the result of a piece of *bona fide* research work carried out by **MD. TAREQ HASAN**, Registration Number **10-03884** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: June, 2016
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Dedicated To My Beloved Father

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PREVALENCE AND MANAGEMENT OF INSECT PESTS OF RED AMARANTH (LALSHAK), *AMARANTHUS GANGETICUS* AND ITS NATURAL ENEMIES

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ABSTRACT

An experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period of rabi season November 2016 to February 2017 to investigate the prevalence and management of sucking and chewing insect pest of red amaranth (Lalshak), *Amaranthus gangeticus*. Lalshak variety BARI I was used as test crop for the experiment. The experiments consists of 7 treatments as T1: Mechanical method + Cultural method at 7 days interval, T2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval, T3: application wood ash @ 10 g/m2 at 7 days interval, T4: Spraying of neem leaves extract @ 20 g/L of water at 7 days interval, T5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval, T6: Spraying malathion 57EC @ 1.5 ml/L of water at 7 days interval and T7: Untreated control. The experiment was laid out following Randomized Complete Block Design (RCBD) with three replications. Data was recorded on pest incidence, abundance of beneficial insects and leaf infestation due to different insect pests. As insect pests grasshopper, red pumpkin beetle, green leaf eating caterpillar, green stink bug, leaf miner, white fly and jute hairy caterpillar was observed. As beneficial insect population, lady bird beetle, specid wasp, bee wolf and braconid parasite was observed for different management practices. The infested leaves/plant by grasshopper, red pumpkin beetle, green leaf eating caterpillar, green stink bug, leaf miner, white fly and jute hairy caterpillar were 2.16, 2.37, 3.49, 1.11, 2.22, 3.33 and 4.44 percent respectively found into treatment which are the lowest among the treatment, while the highest infestation for same insect pests (12.04%, 15.85%, 15.56%, 15.56%, 17.78%, 21.11% and 18.89%) was observed in T7 treatment. Among the different insect pests management practices, spraying of malathion 57EC @ 1.5 /L of water at 7 days interval was better for controlling insect pests of red amaranth with lowest infestation level.

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CHAPTER I

INTRODUCTION

Amaranthus species are important leafy vegetable crop cultivated and consumed daily in Bangladesh and many countries of the world. Unfortunately, insect pests are major setback for commercial production and for the purpose of food security in the country. Amaranthus, collectively known as amaranth under the family Amaranthaceae, is a cosmopolitan genus of annual or short-lived perennial plants. Some amaranth species are cultivated as leaf vegetables, pseudocereals and ornamental plants. Most of the species from *Amaranthus* are summer annual weeds and are commonly referred to as pigweed. Catkin-like cymes of densely packed flowers grow in summer or autumn.

Approximately 60 species are recognized, with inflorescences and foliage ranging from purple and red to green or gold. Growing amaranth is possible all year round in the tropics. Amaranth consists of 60-70 species, 40 of which are considered native to the America. Over 400 varieties within these species are found throughout the world in both temperate and tropical climates, and fall roughly into one of four categories: grain, vegetable, ornamental or weed (Mohan *et al.*, 2007). Vegetable amaranth has been used in China for over 400 years. Amaranth is much closer genetically to its wild ancestors than our developed and nutritionally depleted typical vegetables. Amaranth leaves are an excellent source of carotene, iron, calcium, protein, vitamin C and trace elements. Amaranth leaves are nutritionally similar to beets, Swiss chard and spinach, but are much superior. For example amaranth leaves contain three times more calcium and three times more niacin (vitamin B_3) than spinach leaves. Amaranth seeds are also high in potassium, zinc, Vitamin B and E and can contain over 20% protein (depending on the variety). Several insects however can inflict substantial damage. Amaranth can succumb to caterpillars, webworms, blister beetles, lygus bugs and stem borers.

The lygus bug, coffee bug or tarnished plant bug (*Lygus*spp.) is a brown, lady-bird sized sucking insect that attacks flowers and seeds. It can cause substantial damage both by preventing flowers from producing seeds and by reducing seed weight. Solutions made from pyrethrum or synthetic pyrethrins will help to control lygus. Other insects that can injure the developing amaranth include fall armyworm (*Spodopter afrugiperda*), cabbage looper (*Trichoplusia ni*), corn earworm (*Heliothis zea*) and the cowpea aphid (*Aphis craccavora*). The amaranth weevil (*Conotrachelus seniculus*) can damage roots, resulting in lodging or other root diseases. The potato flea beetle (*Epitrix cucumeris*) can damage seedlings and the beet leafhopper (*Circulifer temellus*) can transmit curly top virus, but this has been seen only in areas near large areas of sugar beet production.

The management of these insect pests has been practiced through the use of insecticides. Dales (1996) noted that the use of synthetic insecticides pose health risk and result in environmental pollution. Also, Schmutterer (2002) reported that the World Health Organization (WHO) had reported the poisoning of at least 3 million agricultural workers from which 20,000 deaths are recorded annually due to pesticide usage. Awasthi (2001) also noted that consumers of vegetables may be at risk from pesticide residues. Thus, research has been geared towards identifying non-chemical methods of pest control, which are safe, cheap, easy toapply and accessible to farmers (Jilani and Su, 1983). In this regard botanicals from neem have shown considerable potential (Okunlola *et al.*, 2008) and National Research Council, 1992.

The leaf and seed extracts of the neem tree, *Azadirachta indica*. Juss have been shown to affect over 200 insect species including some species of aphids, beetles, caterpillars, leafminers, mealybugs, scales, thrips, true bugs and whiteflies; it is also the most popular botanical pesticide against foliage feeding pests. The aqueous extract of *Azadirachta indica* bark has been shown to be as effective as a synthetic insecticide (Cymbush) in controlling foliage feeders of vegetables Okunlola (2008). Meanwhile, Copping (2001) has earlier reported that no known incompatibilities of neem extracts with other crops protection agents. There is evidence available for the synergistic action ofneem with microbial pesticides such as NPVs of tomato fruit worm Senthikumar (2008) and common armyworm Nathanand Kalaivani (2006) and entomopathogenic fungi (*Beauveria bassiana*) against common army worm Mohan *et al* (2007). Asian Vegetable Research and Development Centre (AVRDC) has developed IPM strategies for tomato and vegetable soybean involving neem as an integral component with microbial pesticides such as *Bacillus thuringiensis* and NPVs in managing phytophagous insects Srinivasan*et al* (2009). Such IPM strategy would only be possible through a thorough knowledge of the pest under consideration.

Under the above perspective the present study has been undertaken with fulfilling the following objectives-

- To study the prevalence and determine infestation level of insect pest of red amaranth (Lalshak), *Amaranthus gangeticus* during the growing season in Bangladesh.

- To find out efficacy of the management practices against insect pests of red amaranth (Lalshak), *Amaranthus gangeticus* and its natural enemies

CHAPTER II

REVIEW OF LITERATURE

Red Amaranth (Lal Shak) is an important leafy vegetable in Bangladesh. Like many other vegetables, the growth and yield of Red amaranth are influenced by different factors like sowing time, temperature, soil moisture, plant spacing, organic and inorganic fertilizer etc. The crop has received less attention of the researchers on its various aspects because normally it grows with less care or management practices. For that a very few studies on insect attack and its control of Red amaranth have been carried out in our country as well as in many other countries of the world. Hence, the research work so far done in Bangladesh is not adequate and conclusive. Very few research work have been done relating Prevalence and management of sucking and chewing insect pest of Red amaranth in different parts of the world as well as in Bangladesh. An attempt has been made in this chapter to review literature available at home and abroad pertaining to the present research work under the following headings.

2.1 Insect Pest of Amaranth

Amaranths are susceptible to damage by foliar insect pests and diseases such as aphids (*Aphis spp*.), leaf worms (*Spodoptera spp*.), leaf rollers (*Sylepta derogota*), leaf miners (*Liriomyza spp*.), spider mites (*Tetranychus spp*.), stem boring weevils (*Hypolixus haereus*), bugs (*Asparia armigera*) and flea beetles (*Podagrica spp.*) (Richard, 1989; Okunlola *et al*., 2008). List are given below:

Common Name	Scientific Name	Order
Grasshopper	*Sphenarium purpurascens*	Orthoptera
Aphid	*Macrosiphum sp.*	Hemiptera
Stink bug	*Euschistus biformis*	Hemiptera
Leafhopper	*Empoasca sp.*	Hemiptera
Wasp	*Bracon sp.*	Hymenoptera

Lady bird beetle	*Coccinella septempunctata*	Coleoptera
white grubs	*Phyllophaga errans*	Coleoptera
Red Pumpkin beetle	*Aulacophora foveicollis*	Coleoptera
Flea beetle	*Diphaulaca bicolor*	Coleoptera
Dragonfly Nymph	*Erythrodiplax berenice*	Odonata
Beet armyworm	*Spodoptera exigua*	Lepidoptera

Aphid

Aphids are major pest of Amaranths causing leaves to curl and become unattractive to consumers and customers. They feed by sucking plant sap. Small aphid population may be relatively harmless, but heavily infested Amaranth plants usually have wrinkled leaves, stunted growth and deformed seeds. Amaranth plants, particularly young plants, may dry out and die. Heavy attack on older Amaranth plants may cause crop loss by decreasing flower and seed viability (Okunlola *et al.*, 2008; Youdeowei, 2004).

Aphids are a major pest of vegetables including Amaranth (Picker *et al.*, 2004). Amaranth is majorly attacked by *Myzus persicae*. Aphids feed by sucking sap from plant tissues especially leaves causing the leaves to curl, wrinkle and discolour. They also result to overall slow and stunted growth of plant and under heavy infestation it may cause the plant to dry out. Seed production is also hampered by aphid infestation where it may lead to deformed seeds, decreased flower and seed formation or reduced seed viability (Picker *et al.*, 2004).

Bugs

Bugs can cause severe damage to flowering head and seeds and particularly damaging to grain Amaranth when present in large numbers during critical seed fill stage. They are usually of minor importance in vegetable Amaranth (Youdeowei, 2004).

Leaf worms

Leaf worms or cutworms attack young seedlings. The caterpillar emerges from the soil at night, encircle the plant with its body and cut through the stem of young plants just above ground level or below ground level causing plant wilt and death (Richard, 1989; Kirby and Dill, 2004).

Leaf rollers larvae feed on the lower surface of the leaves folded and covered with webs or rolled and spun together (Booth, 1983; Imam *et al.*, 2010).

Makwali (2002) in his research on grain amaranth reported that the most prevalent bugs infesting grain Amaranth are *Cletus* sp. and *Cletomorpha* sp. whose population often reaches peak during the seed head: the critical milky seeds stage. This was supported by the research done by Oke and Ofuya (2011) which showed that this bugs feed on the seeds causing discoloration, shriveling and premature dying of seeds thereby reducing seed yield and viability.

Amaranthus weevil

Hypolixus spp is a major pest of cultivated amaranth (Tara, J.S. 2009). The eggs overwinter in the soil or inside the debris of harvested plants. Adults defoliate the plants while the larvae feed on the internal tissues of the stem and branches to form irregular zigzag tunnels resulting in galls. Females lay eggs 40 minutes after copulation singly in excavated holes in stems, branches, petiole or midrib of the leaves. Agarwal (1985) also reported, in his research the presence of adults in the field is noticed by the scratched stem, branches and eaten up tender margins of leaves. The weevil has a slow steady development with overlapping generations. Adults are dark brown, variegated with white hairs and several dark patches of dense pubescence. The body is medium sized 9 measuring 11.7 mm with females being slightly larger than males. They have chewing mouth parts with prominent mandibles that are used to borrow through the stem (Tara, J.S. 2009).

Adults of amaranth weevils are all leaf and stem feeders. There were three significant species that included *Hypolixus nubilosus, Nematoceru s*sp. and *Barismassaica*. They chew semi-circles out of the leaf edges and windows in the leaf lamina. They target mostly the soft stems and leaves. Adult defecation was visible all over the plants as small brown blotches. Their larvae on the other hand utilizes a number of feeding niches with *Nematoceru s*sp. and *Barismassaica* boring endophytically in the above ground parts such as meristems and larger side stems and plant crowns, while *Hypolixus nubilosus* bore endophytically in stems and roots.

Leaf miner

Leaf miner larvae make long, slender, white mines (tunnels) in leaves. Severe mined leaves many turn yellow and drop. Severely attacked seedlings are stunted and may eventually die (Sorensen, 1995; Rodriquez, 1997; Sparle and Liu, 2001; Degri *et al.,* 2007; Degri *et al.,* 2012).

Spider mite

Spider mite feeding on Amaranth plants may cause reduction in plant growth, flowering and number of seeds. Damage is most severe when mites attack young plants particularly during the dry season (Richard, 1989; Okunlola *et al.*, 2008), stem boring weevils feed on the leaves but the larvae (grubs) bore into roots and stems, causing rotting, wilting, lodging and disposition to diseases thus increasing crop loss (Sorensen, 1995).

Aderolu *et al*. (2013) reported *H. recurvalis* as the most abundant Lepidopteran pest of Amaranth in Nigeria while Akinlosotu (1977) reported that *Gasteroclisus rhomboidalis* as the major pest of *Amaranthus cruentus* in Nigeria.

Kagali *et al*. (2013), in Kenya who reported that *Cletus sp* in the order Hemiptera was the insect with greatest number occurring surveyed with 100% infestation. Other pests with high infestations are *Zonocerus variegatus, Hymenia recurvalis, Gasteroclisus rhomboidalis* and *Liriomyza spp.*

2.2 Control Methods

In view of the fact that amaranth is consumed directly from the farm as a leafy vegetable or grain and sometimes consumed as a raw salad it is important then to develop pest control options that are safe, as well as cheap and simple to adopt (Sithanantham *et al.*, 2004). Some of the strategies used to control pests in other ALVs can also be employed in control of pests in Amaranth. These methods include:

2.2.1 Botanical pesticides

This are mainly extracts from plants or plant parts such as seeds, barks, leaves, roots. Seeds and leaves of neem (*Azadirachta indica*) and its relative Persian lilac (*Melia azedarach*) have been used widely in organic farming in Kenya to control insects (Sithanantham *et al*., 2004). Another plant that has been used extensively is pyrethrum.

2.2.2 Microbial Bio-pesticides

The use of microbes to control insect pest and diseases is an area that has attracted a lot of attention from researchers throughout the world including Kenya in recent times. Several microbes including fungi, bacteria, viruses and entomopathogenic nematodes (EPN) have been employed to control insect pests. These include: Bacteria such as *Bacillus thuringensis* (Bt), *Agrobacterium sp*.; Fungi: *Trichoderma sp*., *Metarhizium sp., Beuveria sp.;* Nematodes: *Steinernerma sp*. and *Heterorhabditalis sp*. (Neuenschwender *et al*., 2003).

2.2.3 Cultural practices

Cultural controls employ practices that make the environment less attractive to pests and less favorable for their survival, dispersal, growth and reproduction, and that promote the pest's natural controls. The objective for this control strategy is to reduce pest numbers, either below economic injury levels, or sufficiently to allow natural or biological controls to take effect (Sithanantham *et al*., 2004).

Cultural control employs environmentally supportive and knowledge/skill-intensive techniques, such as the optimal design and management of agro-ecosystems in time and space which include; management of adjacent environments, use of companion crops, rotations, timing of seeding, harvesting and field operations as well as more heavy-handed interventions like burning of crop residues, flooding and destruction of uncultivated areas containing alternative hosts of pests (Losenge, 2005).

2.2.4 Integrated Pest Management (IPM)

According to Agrios (2005) integrated pest management can be described as a pest management system that utilizes all suitable techniques in as compatible manner as possible and maintains the pest population levels below those causing economic injury. Integrated Pest Management relies on a combination of common-sense practices such as, the associated environment and the population dynamics of the pest species which are effective and environmentally sensitive (Mullen *et al*., 1997).

The concept of IPM was first introduced in the mid-1970s to reduce the over-dependence on pesticides that were used for reducing losses due to pests (Metcalf & Luckman, 1975).

Integrated pest management programs utilize current comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with least possible hazard to people and the environment. This strategy is knowledge-intensive and farmer-based decision making process and it encourages natural control of pests. It also prevents pest outbreaks and the development of pest resistance. The pesticide-free agricultural commodities from the IPM-practiced fields have a great scope to increase the income of farmers (Mullen *et al*., 1997).

2.3 Factors on insect pest infestation

The highest insect pest populations recorded under Amaranths spaced at 20cm × 10cm and 20cm × 15cm could be due to the close canopy these spacing had, which encouraged the feeding activity of the insect pests (Makus, 1990).
AVRDC (2003) reported that closely spaced vegetables and horticultural crops suffer more from insect pests attack due to the conductive environment which they provide for the insect and consequently a favorable and productive shelter for the insect pests and thus make it easier for the pest to find its food near on the host plant (Sorensen, 1995; Hein, 2003). There was no significant difference between insect pest population infestations on variety and spacing.

2.4 Methods of collecting insects

Slow moving and sedentary arthropods were collected by hand (Nderitu *et al*., 2008). The plant was searched visually for possible insect pests which were then collected into vials, labeled and taken to the laboratory at NMK for identification, curation and archival. Healthy plants were also uprooted and stems and roots dissected to examine the presence of phytophagous insects that do not cause visible damage. A mild pesticide was sprayed on the plants to prevent the insect pests from escaping (Millar *et al*., 2000).

Beating sheets were used to collect well camouflaged or hidden insect pests on plants that were missed during sampling by hand picking (Millar *et al*., 2000). A small sheet was placed beneath the plants preferably a white sheet and the insect pests were knocked down from the plant onto the sheet by beating with a stick. The insects were then picked up from the sheet with aid of a hand lens and forceps and placed into vials. This method was employed to collect sessile and wingless insect pests (Millar *et al*., 2000).

Flying insects were collected using aerial nets (Nderitu *et al.*, 2008). Aerial net consist of a light weight frame made of soft durable material such as, aluminum with a net attached to it. Once the insect has been caught, the end of the net was flipped over to prevent it from escaping. Harmless insects were removed by hand, while harmful once were directed into a killing bottle (Millar *et al*., 2000).

Other insect pests that are ground dwelling such as, termites and weevils that attacked roots and stems of amaranth or those that moved to the ground to ovipositor spend one stage of their development cycle in the soil were collected using pitfall traps (Millar *et al*., 2000). Cylindrical containers were placed in holes dug at random within the amaranth plot with the upper rim of the container being flush with the ground surface. A killing agent, ethylene glycol was added to the trap to kill the insect after entering the trap. The traps was inspected weekly for possible insect pests and if available collected using forceps and placed in vials. The holes were distributed evenly within the plots (Millar *et al*., 2000).

2.5 Determining the yield loss due to insect pest damage

Naturally occurring infestations are often used to give a range of infestations or damage in a single plant, plot or field. The yield was determined per unit area in different plots with different degrees of pest infestation and correlation between the crop yield and degree of infestation was worked out to estimate crop yield loss (Odendo *et al*., 2003). This was used to identify the pests of economic importance to amaranth and require control interventions.

2.6 Effects of various control strategies on insect pest population

The area to be used as a plot for planting amaranth was manured using farm yard manure before primary cultivation was done. The area was thoroughly ploughed ensuring that manure mixed evenly with the soil and was well distributed on the entire plot. Thirty plots were prepared each measuring 3 meters in length and 1.5 meters wide. The depth of preparation was 30cm during primary plough. This was followed by harrowing which encompasses breaking up of large particles of soil as well as raising the beds to 30cms above the ground surface. The beds were raked flat on the top maintaining the dimensions.

Planting method was by direct seeding where seeds were mixed with sand, that is, 1g of seed mixed with 100 g of sand to ensure uniform stand. Seeds were sawn in rows by making furrows 0.5 to 1.0 cm deep using a stick or finger. Inter-row spacing was 20 cm and thinning followed immediately after germination to achieve the desired within row spacing (Palada & Chang, 2003).

2.7 Diversity of insect pests

The results from this study show diversity in the number of insect species associated with cultivated amaranth in Meru County. These results concur with the findings from similar survey carried out in Puebla, Mexico (Lopez *et al*., 2011). From the results Heteroptera is the order with greatest number of species, that is, 13 species, which causes significant damage to grains. The most significant genus in this Order was Cletus with four species. This genus was the most occurring with infestations of 100% in all plots. This may be as a result of amaranth being a suitable host for heteropterans. Other studies by Lopez *et al*., (2011) in Mexico and Aderolu *et al*., (2013) in Nigeria also recorded high number of heteroptera species attacking amaranth.

The most abundant species were *Cletus sp*. (Heteroptera), *Eurystulus spp*. (Heteroptera), *Hypolixus nubilosus* (Coleoptera), *Microcentrum rhombifolium* (Orthoptera) and *Herpetogramma spp*. (Lepidoptera). Aderolu *et al*. (2013) reported *Hymenia recurvalis* and *Hypolixus truncatulus* as the most abundant pests in Nigeria. This shift in the species in the two studies may be due to geographical difference in the two study areas. From the results there was high diversity of amaranth pest species with a Shannon-Weaver index of 4.256 during the first growing season and 4.148 during the second growing season. This trend of insect species confirms the insect species previously reported on amaranth by López *et al*. (2011) and Torres *et al*. (2011).

2.8 Significance of pest species collected

Adults of amaranth weevils are all leaf and stem feeders. There were three significant species that included *Hypolixus nubilosus, Nematocerus sp.* and *Baris massaica*. They chew semi-circles out of the leaf edges and windows in the leaf lamina. They target mostly the soft stems and leaves. Adult defaecation was visible all over the plants as small brown blotches. Their larvae on the other hand utilizes a number of feeding niches with *Nematocerus sp*. and *Baris massaica* boring endophytically in the above ground parts such as meristems and larger side stems and plant crowns, while *Hypolixus nubilosus* bore endophytically in stems and roots.

The results of this study revealed that the infestation by the weevils took place throughout the growing period of the crop, with the number increasing gradually as the crop grew but began to drop as it matured. The females oviposited in the stems where eggs hatched into larvae which fed while tunneling through the stem. This pest resulted to significant crop loss especially through foliage damage. Other studies have also reported that this pest was found to cause considerable damage on amaranth leaves and stems (Torres et al., 2011 & López *et al*., 2011).

All plants examined in the laboratory presented galleries throughout the main stem. The galleries had occasional interruptions, dark coloration and the presence of chewed plant material mixed with feces of *Herpetogramma spp*. larvae. This is consistent with reports from amaranth crop fields in Mexico where the pupae were observed in the soil nearby host plants (Torres *et al*., 2011). *Herpetogramma bipunctalis* larvae have been observed feeding on several plant species (Solis, 2006; Oliveira *et al*., 2012). In Mexico this species was observed feeding on leaves and grains of *Amaranthus spp*. plant (Torres *et al*., 2011) as well as boring and building galleries inside the plant stems as observed in this study.

The galleries and exit holes make the stem weak and if the weather is windy it causes lodging of the crop resulting to yield loss if the crop is not yet mature (Plate 15). If the weather is not windy the crop continues to grow without significant loss on yield. Oliveira *et al*. (2012) observed that 100% of the crop examined presented galleries of up to 5mm in diameter throughout the main stems which was an indication of the presence of *H. bipunctalis* larvae. This larvae was also observed feeding and building galleries in stems of amaranth in Puebla, Mexico (López *et al*., 2011).

In the present study *Cletus sp*. was observed and collected in all plots and farms visited. It was found to be a major grain pest of amaranth and in high infestation, caused total loss of yield. These insects are observed mostly at the beginning of milking stage and the population increases as the grain matures. This was also observed by Oke and Ofuya (2011) in their study on amaranth in Ibadan, Nigeria. They observed that the population of Cletus sp. increases gradually from the start of milking stage to maturity, with the highest population being recorded slightly before harvesting.

Among the insects that damage the foliage we found grasshoppers which were observed in all the plots. The order Orthoptera was a significant order with four families and four species. This order consists of grasshoppers which is the only group of insects in this order collected during the research period. The most significant species was *Microcentrum rhombifolium* which infested the leaves of the crop especially during the early stages of crop development cutting the leaves and causing windowing. The number of species recorded in this study is higher compared to one species recorded by Gracia *et al*., (2012) in their study in Brazil and López *et al*. (2011) in their study in Mexico which recorded two species. Grasshoppers were using grass close to the amaranth plots as an alternative host and therefore were difficult to control. This has also been reported by Capinera *et al*. (2007) in USA.

2.9 Diversity of potential natural enemies

Most hymenopterans and some coleopterans observed in this study were classified as natural enemies or parasitoids of amaranth pests. *Dentichamias busseolae* which was sampled during the second season of planting has been reported as a pupal parasitoid of lepidopterans. The female parasitoid oviposits only in a borer pupa without a cocoon in a stem (Mailu *et al*., 1984).

Braconid parasite (*Bracon sp*.) was also observed occurring on amaranth during both the first and second season. Similarly, this insect was recorded in the survey conducted by López *et al*. (2011) in Mexico. *Bracon sp*. is a gregarious ectoparasitoid of weevils (Coleoptera) pest larvae (Dillon *et al*., 2008 and Evarard *et al*., 2009). Female braconid respond to the stimuli associated with the grab of the weevil actively feeding on or inside the stem of the crop (Faccoli and Henry, 2003).

The female then inserts its ovipositor through the back of the stamp, to inject the larva with paralyzing venom prior to depositing a cluster of eggs on or near the body of the host (Evarard *et al*., 2009). This is the first study in Kenya which has reported the naturally occurring enemies and parasitoids of amaranth insect pest.

2.10 Botanical verses chemical control

An effective control strategy is the one that reduces the population of the insect pests such that the overall yield loss is not economically significant and causes little or no damage to other beneficial insects or organisms. There was significant difference in the leaf yield loss between chemical control and neem extract treatments with plots treated with neem extract having a higher loss.

The neem leaf extracts were effective in causing significant reduction in leaf damage (70.79±1.5%) and grain damage (77.27±1.6%) compared to the untreated controls but comparatively less effective to chemical control by 6%. This implies the suitability of employing this method as an environmentally safe control measure. This assertion has been corroborated by Aderolu, Omooloye and Okelana (2013) who found that modified aqueous neem leaf extracts was effective in reduction of leaf damage by 72% and overall field infestation by 78%. Plots treated with neem extracts and pesticides recorded the lowest bug population therefore we can conclude that neem extracts can be employed in designing an integrated pest management plan for this pest. Other plant extracts (botanical extracts) have also been employed to manage amaranth insect pests. Arivudainambi *et al*. (2010) in their study found out that application of *Cleistanthus collinus* extracts on amaranth crop reduce population of beat web leaf caterpillar (*Hymenia recurvalis*).

CHAPTER III

MATERIALS AND METHODS

The present study was conducted to investigate the prevalence and management of insect pests of red amaranth (Lalshak), *Amaranthus gangeticus* and it's natural enemies. Lalshak variety-BARI I was collected From BARI, Gazipur. This chapter deals with the information regarding materials and methods that were used in conducting the experiment. It consists of a short description of locations of the experimental site, characteristics of soil, climate, materials of the investigation, layout and design of the experiment, land preparation, manuring and fertilizing, seed sowing, intercultural operations, harvesting, data collection procedure and statistical analysis etc. The materials and methods that were used in conducting the present experiment are described in this chapter.

3.1 Location of the experimental site

The present study was carried out at the main field, Sher-e-Bangla Agricultural University, Dhaka and it was located in 24.09^0N latitude and 90.26^0E longitudes. As per the Bangladesh Meteorological Department, Agargaon, Dhaka-1207 the altitude of the location was 8 m from the sea level. This experiment conducted during the period of rabi season November 2016 to February 2017.

3.2 Characteristics of soil

The general soil type of the experimental field is Shallow Red Brown Terrace soil and the soil belongs to the Tejgaon series under the Agroecological Zone, Madhupur Tract (AEZ-28). A composite sample of the experimental field was made by collecting soil from several spots of the field at a depth of 0-15 cm before initiation of the experiment. The collected soil was air-dried, grind and passed through 2 mm sieve and analyzed at soil Resources Development Institute (SRDI), Farmgate, Dhaka for some important physical and chemical properties. The soil was having a texture of silty clay loam with pH and organic

Plate no. 01: Experimental field of amaranth in the central farm of SAU

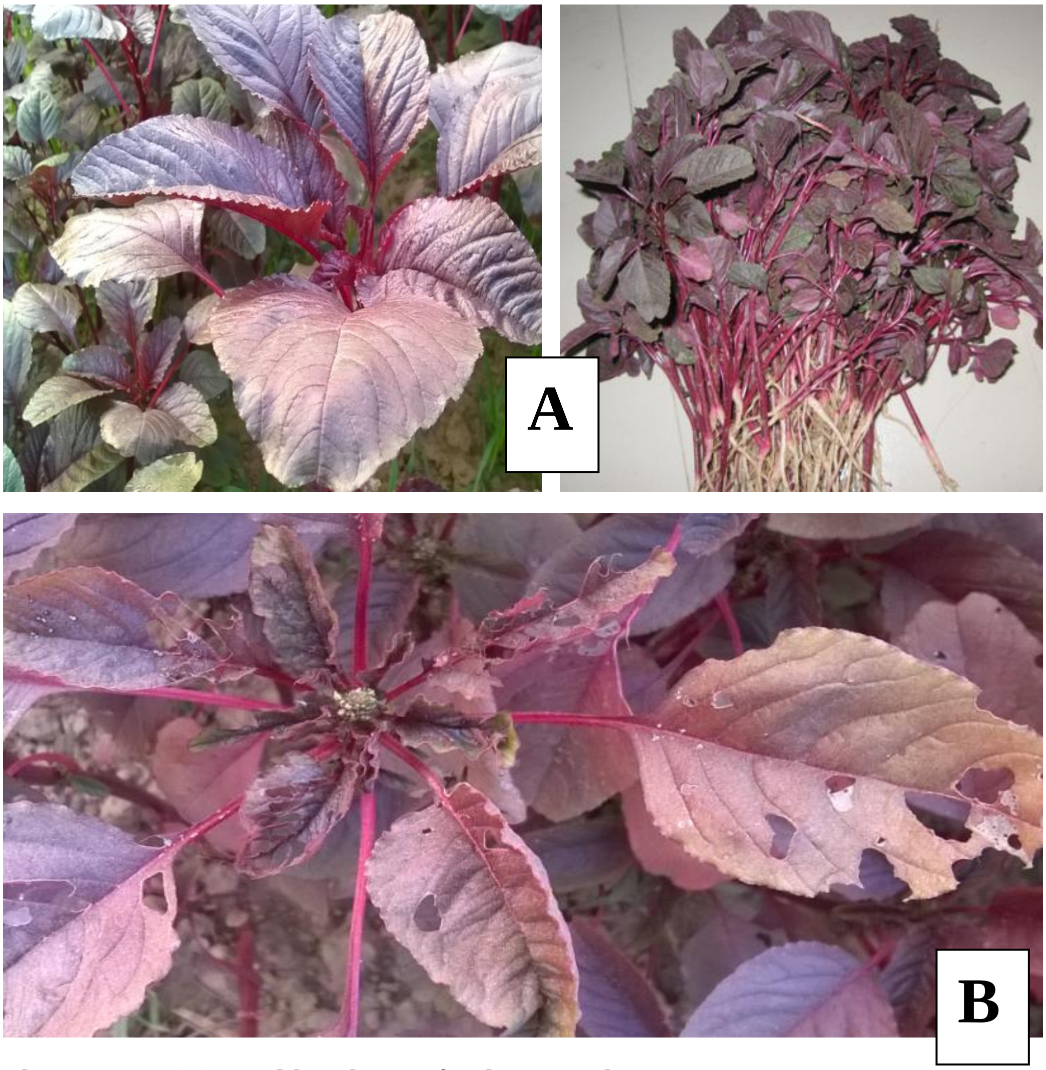

Plate no. 02: (**A)** Healthy plants of red amaranth
(**B**) Infested plants of red amaranth

matter 6.2 and 1.12%, respectively. The results showed that the soil composed of 27% sand, 43% silt and 30% clay, details have been presented in Appendix I.

3.3 Climatic condition

The climatic condition of experimental site is subtropical and characterized by three distinct seasons, the Robi from November to February and the Kharif-1, pre-monsoon period or hot season from March to April and the Kharif-2 monsoon period from May to October. The monthly average temperature, relative humidity and rainfall during the crop growing period were collected from weather yard, Bangladesh Meteorological Department and presented in Appendix II. During the experimental period the maximum temperature (27.1^{0}C) and highest rainfall (30 mm) was recorded in the month of February 2017, whereas the minimum temperature (12.4^{0}C) and no rainfall was recorded in the month of January 2017.

3.4 Treatments of the experiment

The present study was conducted to prevalence and management of insect pest of red amaranth (Lalshak), *Amaranthus gangeticus* and its natural enemies. The treatments of the experiment are furnished below:

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion 57EC @ 1.5ml /L of water at 7 days interval

T_7: Untreated control

3.5 Design and layout of the experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The treatment combinations were randomly assigned to each unit plot so as to allot one treatment combination once in each replication. There were three blocks and each block containing 7 plots. Thus the total number of plots was 21. The size of unit plot was 2.5 m × 2 m = 5 m^2. The distance between the plots and the blocks were 0.5 m.

3.6 Land preparation

The experimental plot was thoroughly prepared by ploughing and cross ploughing with the help of power tiller followed by laddering to have a good tilth. During land preparation weeds and stubbles were collected and removed from the plot and clods were broken. The surface of the land was leveled, and finally irrigation and drainage channels were prepared around the plot.

3.7 Fertilization application

Urea, Triple super phosphate (TSP), Muriate of potash (MoP) and gypsum were used as a source of nitrogen, phosphorous, potassium and sulphur respectively. Urea, TSP, MoP and gypsum were applied at the rate of 50, 85, 35 and 5 kg per hectare, respectively following the Bangladesh Agricultural Research Institute (BARI) recommendation. All of the fertilizers except urea were applied during final land preparation and urea was applied into two equal installments at 20 and 30 days after sowing (DAS).

3.8 Seed sowing

Seeds were sown in well-prepared land on 21 November, 2016. The Amaranth seeds were sown by broadcasting method and covered uniformly with light soil for proper germination. The seeds sow uniformly at the rate of 0.8g/m^2. The seeds were mixed with sand at a ratio of 1 g seed to 100 g sand in order to obtain a uniform stand. The seedlings emerged after five days and they were properly watered every day in the late afternoon (5.00 pm - 6.00 pm) to maintain vigorous plant growth.

Plate no. 03: Egg mass of jute hairy caterpillar on amaranth leaf

Plate no. 04 : Grasshopper on Amaranth leaf

3.9 Intercultural operations

After emergence of seedling, various intercultural operations were accomplished for better growth and development of the plant, which were as follows:

3.9.1 Thinning

When the seedlings were well established, excess seedlings were thinned out to maintain proper plant spacing (25cm x 10cm).

3.9.2 Weeding

Weeding was accomplished as and when necessary to keep the crop free from weeds, for better soil aeration and to break the crust. It also helped in soil moisture conservation.

3.9.3 Irrigation

Regular irrigations were given with the help of watering can throughout the growing period. Irrigation was given at every alternate day after sowing.

3.10 Harvesting

Harvesting was done on 28 December, 2016 when plants reached to edible maturity.

3.11 Collection of data

Ten plants from each unit plot were randomly selected and collected as insect samples by sweeping net and infested leaves and shoots for collection of data. The following parameters were considered for data collection.

3.11.1 Number of insects per plot

Number of insect per plot by two sweeping was collected for data collection.

3.11.2 Visual count of insect

Visual sowing of insect count from selected 10 plants per plot.

3.11.3 Beneficial insect count

Beneficial insect counts form every plot for data collection.

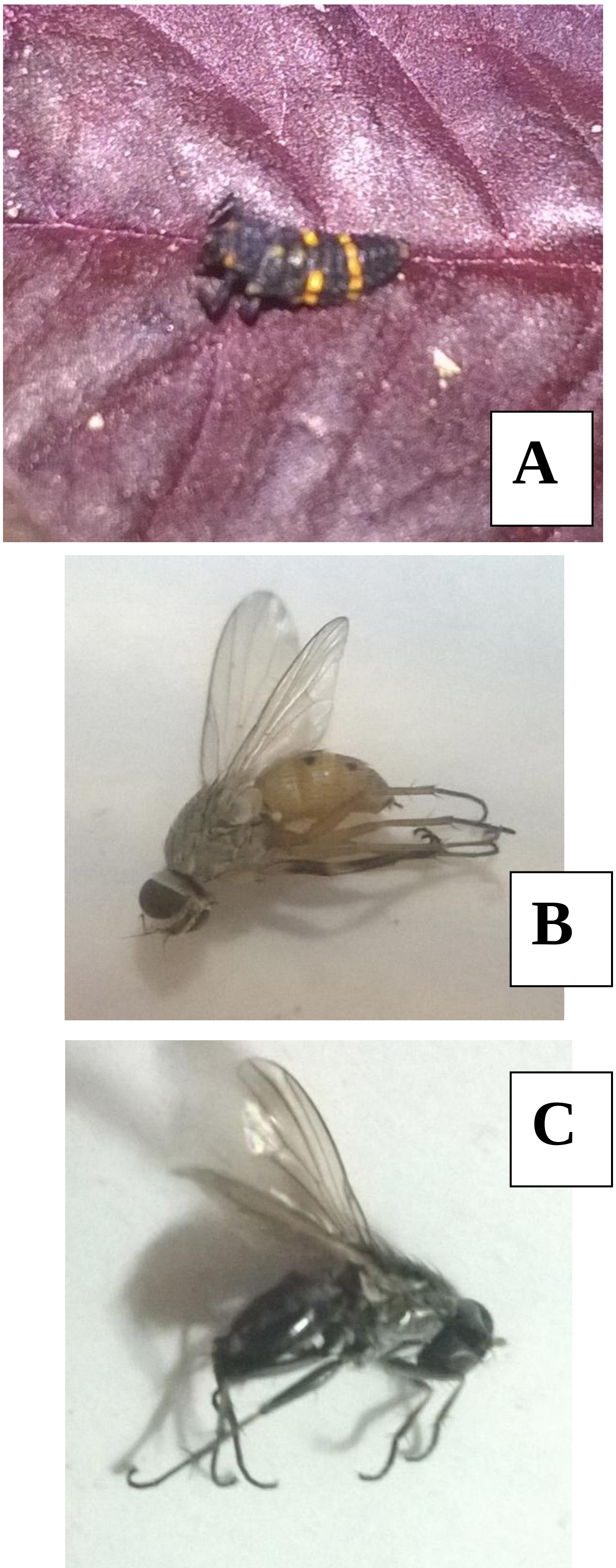

Plate No. 05: Beneficial insects, (A) Grub of lady bird beetle, (B) Bee wolf and (C) Braconid wasp

3.11.4 Determination of leaf infestation by number and infestation reduction over control

All the healthy and infested leaf were counted from 10 plants from middle rows of each plot and examined carefully. The healthy and infested leaves were counted at for different insect pests and converted into per plant and then the percent leaf infestation was calculated using the following formula:

$$\text{Leaf infestation (\%)} = \frac{\text{Number of infested leaves}}{\text{Total number of leaves}} \times 100$$

3.12 Statistical analysis

The collected data on various parameters were statistically analyzed using MSTAT-C package programmers. The mean for all the treatments were calculated and analyzed and analyses of variance of all the characters were performed by F-variance test. The significance of differences between the pairs of treatment means was calculated by the least significant difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the prevalence and management of insect pests of red amaranth (Lalshak), *Amaranthus gangeticus* and it's natural enemies. Data was recorded on pest incidence, abundance of beneficial insects and leaf infestation due to different insect pests. The results have been discussed and presented under the following headings and sub-headings:

4.1 Incidence of insect pests

Insect population for 10 selected plants/plot were observed at 7 days interval with clean observation and grasshopper, red pumpkin beetle, green leaf eating caterpillar, green stink bug, leaf miner, white fly and jute hairy caterpillar was counted and converted in per plant and recorded. In was observed that for different management practices number of recorded different insect pests showed statistically significant variation under the present trial.

4.1.1 Grasshopper

In case of grasshopper, the highest number (4.13) of grasshopper was observed in T_7 (untreated control) treatment which was closely followed (3.47 and 3.00) by T_3 (Spreading wood ash @ 10 g/m^2 at 7 days interval) and T_1 (Mechanical method + Cultural method at 7 days interval), while the lowest number of grasshopper (1.47) was observed from T_6 (Spraying malathion 57EC @ 1.5 ml/L of water at 7 days interval) which was statistically similar (1.87) to T_4 (Spraying neem leaves extract @ 20 g/L of water at 7 days interval) and closely followed (2.27 and 2.67) by T_2 (Spraying soap water @ 1.5 g detergent/L of water at 7 days interval) and T_5 (Spraying neem seed kernel @ 20 g/L of water at 7 days interval), respectively (Table 1). Data revealed that Spraying malathion 57EC @ 1.5 ml/L of water at 7 days interval was more effective in controlling grasshopper in red amaranths followed by Spraying neem leaves extract @ 20 g/L of water at 7 days interval under the present trial.

Table 1. Effect of different management practices on the incidence of insect pests of red amaranth during study

Treatment	Number of insects						
	Grasshopper	Red pumpkin beetle	Green leaf eating caterpillar	Green stink bug	Leaf miner	White fly	Jute hairy caterpillar
T_1	3.00 bc	3.13 bc	2.87 b	2.07 bc	3.07 b	3.80 bc	3.60 bc
T_2	2.27 de	2.40 d	2.27 cd	1.20 d	1.53 d	3.00 d	3.07 d
T_3	3.47 b	3.60 b	3.07 ab	2.40 b	3.20 b	4.20 b	4.07 b
T_4	1.87 ef	1.87 e	2.20 d	1.00 d	1.33 d	2.40 e	2.80 de
T_5	2.67 cd	3.00 c	2.67 bc	1.80 c	2.13 c	3.40 cd	3. 20 cd
T_6	1.47 f	1.07 f	1.60 e	1.00 d	0.00 e	1.80 f	2.27 f
T_7	4.13 a	4.87 a	3.40 a	3.27 a	3.80 a	5.40 a	5.20 a
$LSD_{(0.05)}$	0.167	0.531	0.429	0.531	0.425	0.522	0.480
Level of significance	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CV(%)	6.77	7.02	5.120	8.22	9.14	5.78	6.38

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion 57EC @ 1.5ml /L of water at 7 days interval

T_7: Untreated control

4.1.2 Red pumpkin beetle

For red pumpkin beetle under the present trial in red amaranths, the highest number (4.87) was recorded in T_7 treatment which was closely followed (3.60 and 3.13) by T_3 and T_1 treatment, whereas the lowest number of red pumpkin beetle (1.07) was found from T_6 which was followed (1.87) by T_4 treatment (Table 1).

4.1.3 Green leaf eating caterpillar

For green leaf eating caterpillar, the highest number of green leaf eating caterpillar (3.40) was obtained in T_7 treatment which was statistically similar (3.07) to T_3 and closely followed (2.87 and 2.67) by T_1 and T_5, while the lowest number (1.60) was recorded in T_6 which was followed (2.20 and 2.27) by T_4 and T_2 treatment, respectively (Table 1).

4.1.4 Green stink bug

In case of green stink bug, the highest number of green stink bug (3.27) was found in T_7 treatment which was closely followed (2.40 and 2.07) by T_3 treatment and T_1, whereas the lowest number (1.00) was observed in T_6 and T_4 treatment which was statistically similar (1.20) to T_2 and followed (1.80) by T_5 treatment (Table 1).

4.1.5 Leaf miner

In case of leaf miner, the highest number of leaf miner (3.80) was observed in T_7 treatment which was closely followed (3.20 and 3.07) by T_3 and T_1, while no leaf miner was found in T_6 treatment (Table 1).

4.1.6 White fly

In case of white fly under the present trial in red amaranths, the highest number of white fly (5.40) was found in T_7 treatment which was closely followed (4.20 and 3.80) by T_3 and T_1 treatment, whereas the lowest number of white fly (1.80) was recorded in T_6 treatment which was closely followed (2.40) by T_4 treatment (Table 1).

4.1.7 Jute hairy caterpillar

For jute hairy caterpillar, the highest number of jute hairy caterpillar (5.20) was recxorded in T_7 treatment which was closely followed (4.07 and 3.60) by T_3 and T_1, whereas the lowest number (2.27) was observed in T_6 which was followed (2.80) by T_4 treatment (Table 1).

Okunlola *et al.* (2008) reported that Amaranths are susceptible to damage by foliar insect pests and diseases such as aphids, leaf worms, leaf rollers, leaf miners, spider mites, stem boring weevils, bugs and flea beetles. Youdeowei (2004) reported that aphids are major pest of Amaranths causing leaves to curl and become unattractive to consumers and customers. Leaf miner larvae make long, slender, white mines (tunnels) in leaves. Severe mined leaves many turn yellow and drop (Degri *et al.*, 2012).

4.2 Abundance of beneficial insect

During the study period beneficial insect population of 10 selected plants/plot were observed at 7 days interval with clean observation and lady bird beetle, specid wasp, bee wolf and braconid parasite was counted then converted into per plant and recorded in per plant basis. Data revealed that for different management practices abundance of beneficial insects varied significantly under the present trial.

4.2.1 Lady bird beetle

In case of lady bird beetle, the highest number (3.20) was recorded in T_7 (untreated control) treatment which was statistically similar (2.80) to T_1 (Mechanical method + Cultural method at 7 days interval) and closely followed (2.40) by T_3 (Spraying wood ash @ 10 g/m^2 at 7 days interval), while the lowest number of lady bird beetle (1.00) was foundd from T_6 (Spraying malathion @ 20 ml/L of water at 7 days interval) which was closely followed (1.60) by T_4 (Spraying neem leaves extract @ 20 g/L of water at 7 days interval) treatment (Table 2).

Table 2. Effect of different management practices on the abundance of beneficial insects of red amaranth during study period

Treatment	Number of beneficial insects			
	Lady bird beetle	Sphecid wasp	Bee wolf	Braconid parasite
T_1	2.80 ab	1.13 a	1.13 abc	2.80 bc
T_2	2.07 c	1.13 a	1.07 bc	2.80 bc
T_3	2.40 bc	1.13 a	1.07 bc	2.73 bc
T_4	1.60 d	1.07 a	1.07 bc	2.60 c
T_5	2.20 c	1.13 a	1.27 ab	2.93 b
T_6	1.00 e	0.67 b	0.73 d	1.80 d
T_7	3.20 a	1.27 a	1.33 a	3.27 a
$LSD_{(0.05)}$	0.422	0.192	0.215	0.293
Level of significance	0.01	0.01	0.01	0.01
CV(%)	8.44	7.05	9.22	5.45

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 plants per treatment
In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

4.2.2 Sphecid wasp

In case of sphecid wasp, the highest number (1.27) was found in T_7 treatment which was statistically similar with other treatment except T_6, while the lowest number of sphecid wasp (0.67) was recorded from T_6 treatment (Table 2).

4.2.3 Bee wolf

In case of bee wolf, the highest number (1.33) was observed in T_7 treatment which was statistically similar (1.27 and 1.13) with T_5 and T_1 treatment, respectively and closely followed (1.07) by T_2, T_3 and T_4, whereas the lowest number of bee wolf (0.73) was found from T_6 treatment (Table 2).

4.2.4 Braconid parasite

In case of braconid parasite, the highest number (3.27) was recorded in T_7 treatment which was closely followed (2.93, 2.80 and 2.73) by T_5, T_1, T_2 and T_3, respectively, while the lowest number (01.80) was observed in T_6 treatment which was followed (2.93) by T_5 treatment (Table 2).

Mailu *et al*. (1984) reported that most hymenopterans and some coleopterans were classified as natural enemies or parasitoids of amaranth pests (). *Dentichamias busseolae* which was sampled during the second season of planting has been reported as a pupal parasitoid of lepidopterans. Braconid observed occurring on amaranth both the first and second season (Lopez *et al*. 2011). Female braconid respond to the stimuli associated with the grab of the weevil actively feeding on or inside the stem of the crop (Faccoli and Henry, 2003). The female then inserts its ovipositor through the back of the stamp, to inject the larva with paralyzing venom prior to depositing a cluster of eggs on or near the body of the host (Evarard *et al*., 2009).

4.3 Infestation status

During the study period healthy and infested leaves for different insect pests of 10 selected plants/plot were observed at 7 days interval then converted into per plant as healthy and infested leaves and % of infestation and infestation reduction over control was estimated. Data revealed that healthy and infested leaves and infestation over control by different insect pest showed statistical significant variation due to different management practices.

4.3.1 Infestation by grasshopper

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by grasshopper showed statistically significant differences due to different management practices (Table 3). The highest number of healthy leaves/plant (28.90) was observed in T_6 (Spraying malathion 57EC @ 1.5ml /L of water at 7 days interval) treatment which was statistically similar (27.30 and 26.10) to T_4 (Spraying neem leaves extract @ 20 g/L of water at 7 days interval) and T_5 (Spraying neem seed kernel @ 20 g/L of water at 7 days interval), respectively, whereas the lowest number (20.50) was recorded in T_7 (untreated control) treatment which was statistically similar (20.70, 22.10 and 23.70) to T_3 (Spraying wood ash @ 10 g/m^2 at 7 days interval), T_2 (Spraying soap water @ 1.5 g detergent/L of water at 7 days interval) and T_1 (Mechanical method + Cultural method at 7 days interval). The lowest number of infested leaves/plant (0.63) was found in T_6 treatment which was statistically similar (0.83) to T_4, whereas the highest number of infested leaves/plant (2.80) was observed in T_7 which was followed (1.17, 1.33 and 1.40) by T_5, T_2, and T_3, respectively. The lowest infestation of leaves/plant (2.16%) was recorded in T_6 treatment which was statistically similar (3.02%) to T_4 and followed (4.28%) by T_5 treatment, while the highest infestation (12.04%) was recorded in T_7 treatment which was followed (5.58%, 5.69% and 6.33%) by T_1, T_2 and T_3 treatment, respectively. Red amaranth leaf infestation percentage reduction over control by grasshopper was estimated for different management practices and the highest value (82.06%) was recorded in T_6 and the lowest value (47.43%) from T_3 treatment.

Table 3. Efficiency of different management practices against leaf infestation by grasshopper throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	23.70 bc	1.40 b	5.58 b	53.65
T_2	22.10 c	1.33 b	5.69 b	52.74
T_3	20.70 c	1.40 b	6.33 b	47.43
T_4	27.30 a	0.83 c	3.02 d	74.92
T_5	26.10 ab	1.17 b	4.28 c	64.45
T_6	28.90 a	0.63 c	2.16 d	82.06
T_7	20.50 c	2.80 a	12.04 a	--
$LSD_{(0.05)}$	3.431	0.239	1.179	--
Level of significance	0.05	0.01	0.01	
CV(%)	4.35	9.71	11.87	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

Gracia *et al*. (2012) reported that damage the foliage of red amaranths was found grasshoppers which were observed in all the plots. The most significant species was *Microcentrum rhombifolium* which infested the leaves of the crop especially during the early stages of crop development cutting the leaves and causing windowing.

4.3.2 Infestation by red pumpkin beetle

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by red pumpkin beetle showed statistically significant differences due to different management practices (Table 4). The highest number of healthy leaves/plant (25.27) was recorded in T_6 treatment which was statistically similar (23.13) to T_4 treatment and closely followed (22.13) by T_5, whereas the lowest number (16.33) was recorded in T_7 treatment which was statistically similar (17.40) to T_1 and followed (19.27 and 20.80) by T_2 and T_3 treatment. The lowest number of infested leaves/plant (0.67) was observed in T_6 treatment which was statistically similar (0.80) to T_4, whereas the highest number of infested leaves/plant (3.07) was observed in T_7 which was followed (1.33 and 1.27) by T_2 and T_3, respectively. The lowest infestation of leaves/plant (2.57%) was recorded in T_6 treatment which was statistically similar (3.36%) to T_4 and followed (4.59% and 5.76) by T_5 and T_3 treatment, respectively whereas the highest infestation (15.85%) was found in T_7 treatment which was followed (7.78% and 6.47%) by T_1 and T_2, respectively. Red amaranth leaf infestation percentage reduction over control by red pumpkin beetle was estimated for different management practices and the highest value (83.79%) was attained in T_6 and the lowest value (50.91%) from T_1 treatment. Application of neem extracts and pesticides recorded the lowest insect pests population therefore we can conclude that neem extracts can be employed in designing an integrated pest management plan. Aderolu and Okelana (2013) who found that modified aqueous neem leaf extracts was effective in reduction of leaf damage by 72% and overall field infestation by 78%.

Table 4. Efficiency of different management practices against leaf infestation by red pumpkin beetle throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	17.40 ef	1.47 b	7.78 b	50.91
T_2	19.27 de	1.33 bc	6.47 bc	59.18
T_3	20.80 cd	1.27 bc	5.76 cd	63.66
T_4	23.13 ab	0.80 de	3.36 ef	78.80
T_5	22.13 bc	1.07 cd	4.59 de	71.04
T_6	25.27 a	0.67 e	2.57 f	83.79
T_7	16.33 f	3.07 a	15.85 a	--
$LSD_{(0.05)}$	2.161	0.287	1.619	--
Level of significance	0.01	0.01	0.01	
CV(%)	11.75	13.74	4.54	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

4.3.3 Infestation by green leaf eating caterpillar

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by green leaf eating caterpillar showed statistically significant differences due to different management practices (Table 5). The highest number of healthy leaves/plant (29.47) was recorded in T_6 treatment which was statistically similar (28.53 and 26.60) to T_4 and T_5 treatment and closely followed (25.47) by T_2 treatment, whereas the lowest number (21.00) was recorded in T_7 treatment which was statistically similar (22.53 and 23.67) to T_3 and T_1 treatment, respectively. The lowest number of infested leaves/plant (1.07) was found in T_6 treatment which was statistically similar (1.33) to T_4 and closely followed (1.53) by T_5, whereas the highest number of infested leaves/plant (3.87) was observed in T_7 which was followed (2.00, 1.67 and 1.60) by T_3, T_1 and T_2, respectively. The lowest infestation of leaves/plant (3.49%) was observed in T_6 treatment which was statistically similar (4.46%) to T_4 and followed (5.47% and 5.91) by T_5 and T_3 treatment, respectively, whereas the highest infestation (15.56%) was found in T_7 treatment which was followed (8.16%) by T_3. Red amaranth leaf infestation percentage reduction over control by green leaf eating caterpillar was estimated for different management practices and the highest value (77.57%) was recorded in T_6 and the lowest value (47.56%) from T_3 treatment. Arivudainambi *et al*. (2010) found that application of *Cleistanthus collinus* extracts on amaranth crop reduce population of leaf caterpillar.

4.3.4 Infestation by green stink bug

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by green stink bug showed statistically significant differences due to different management practices (Table 6). The highest number of healthy leaves/plant (29.67) was attained in T_6 treatment which was statistically similar (29.33 and 28.67) to T_4, T_5 and T_3 treatment and closely followed (28.33) by T_2 treatment, whereas the lowest number (25.33) was recorded in T_7 treatment which was followed (28.00) by T_1 treatment. The lowest number of infested

Table 5. Efficiency of different management practices against leaf infestation by green leaf eating caterpillar throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	23.67 cd	1.67 bc	6.61 c	57.52
T_2	25.47 bc	1.60 bc	5.91 cd	62.02
T_3	22.53 d	2.00 b	8.16 b	47.56
T_4	28.53 a	1.33 cd	4.46 de	71.34
T_5	26.60 ab	1.53 c	5.47 cd	64.85
T_6	29.47 a	1.07 d	3.49 e	77.57
T_7	21.00 d	3.87 a	15.56 a	--
$LSD_{(0.05)}$	2.746	0.394	1.493	--
Level of significance	0.01	0.01	0.01	--
CV(%)	6.09	7.88	6.55	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

Table 6. Efficiency of different management practices against leaf infestation by green stink bug throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	28.00 c	2.00 b	6.67 b	57.13
T_2	28.33 bc	1.67 bc	5.56 bc	64.27
T_3	28.67 abc	1.33 bcd	4.44 bcd	71.47
T_4	29.33 ab	0.67 cd	2.22 cd	85.73
T_5	29.33 ab	0.67 cd	2.22 cd	85.73
T_6	29.67 a	0.33 d	1.11 d	92.87
T_7	25.33 d	4.67 a	15.56 a	--
$LSD_{(0.05)}$	0.927	0.927	3.087	--
Level of significance	0.01	0.01	0.01	--
CV(%)	5.98	7.66	8.12	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 10 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

leaves/plant (0.33) was found in T_6 treatment which was statistically similar (0.67 and 1.33) to T_5, T_4 and T_3, while the highest number of infested leaves/plant (4.67) was recorded in T_7 treatment which was followed (2.00 and 1.67) by T_1 and T_2, respectively. The lowest infestation of leaves/plant (1.11%) was found in T_6 treatment which was statistically similar (2.22 and 4.44%) to T_5, T_4 and T_3 treatment, respectively, whereas the highest infestation (15.56%) was observed in T_7 treatment which was followed (6.67% and 5.56%) by T_1 and T_2 treatment, respectively. Red amaranth leaf infestation percentage reduction over control by green stink bug was estimated for different management practices and the highest value (92.87%) was recorded in T_6 and the lowest value (57.13%) from T_1 treatment. Youdeowei (2004) observed that bugs can cause severe damage to flowering head and seeds and particularly damaging to grain amaranth when present in large numbers during critical seed fill stage.

4.3.5 Infestation by leaf miner

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by leaf miner showed statistically significant differences due to different management practices (Table 7). The highest number of healthy leaves/plant (29.33) was observed in T_6 treatment which was statistically similar (29.00 and 28.67) to T_4 and T_5 treatment, whereas the lowest number (24.67) was recorded in T_7 treatment which was followed (27.33, 27.67 and 28.00) by T_1, T_2 and T_3 treatment. The lowest number of infested leaves/plant (0.67) was observed in T_6 treatment which was statistically similar (1.00 and 1.33) to T_4 and T_5 treatment and closely followed (2.00) by T_3, while the highest number (5.33) was found in T_7 treatment which was followed (2.67 and 2.33) by T_1 and T_2, respectively. The lowest infestation of leaves/plant (2.22%) was observed in T_6 which was statistically similar (3.33 and 4.44%) to T_4 and T_5 treatment, respectively, whereas the highest infestation (17.78%) in T_7 treatment which was followed (8.89% and 7.78%) by T_1 and T_2 treatment, respectively. Red amaranth leaf infestation percentage reduction over control the highest value (87.51%) was attained in T_6 and the lowest value (50.00%) from T_1 treatment.

Table 7. Efficiency of different management practices against leaf infestation by leaf miner throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	27.33 e	2.67 b	8.89 b	50.00
T_2	27.67 de	2.33 bc	7.78 bc	56.24
T_3	28.00 cde	2.00 bcd	6.67 bcd	62.49
T_4	29.00 ab	1.00 ef	3.33 ef	81.27
T_5	28.67 abc	1.33 def	4.44 def	75.03
T_6	29.33 a	0.67 f	2.22 f	87.51
T_7	24.67 f	5.33 a	17.78 a	--
$LSD_{(0.05)}$	0.844	0.844	2.812	--
Level of significance	0.01	0.01	0.01	--
CV(%)	7.01	11.33	12.89	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 10 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

4.3.6 Infestation by white fly

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by white fly showed statistically significant differences due to different management practices (Table 8). The highest number of healthy leaves/plant (29.00) was observed in T_6 treatment which was statistically similar (28.67 and 28.33) to T_4 and T_5 treatment, whereas the lowest number (23.67) was recorded in T_7 treatment which was followed (27.00 and 27.67) by T_1, T_2 and T_3 treatment. The lowest number of infested leaves/plant (1.00) was found in T_6 treatment which was statistically similar (1.33 and 1.67) to T_4 and T_5 treatment, while the highest number of infested leaves/plant (6.33) was observed in T_7 treatment which was followed (3.00 and 2.33) by T_1, T_2 and T_3, respectively. The lowest infestation of leaves/plant (3.33%) was recorded in T_6 treatment which was statistically similar (4.44 and 5.56%) to T_4 and T_5 treatment, respectively, whereas the highest infestation (21.11%) was recorded in T_7 treatment which was followed (10.00% and 7.78%) by T_1, T_2 and T_3 treatment, respectively. Red amaranth leaf infestation percentage reduction over control by white fly was estimated for different management practices and the highest value (84.23%) was recorded in T_6 and the lowest value (52.63%) from T_1 and T_2 treatment. Okunlola *et al*. (2008) also reported the lowest level of infestation in red amaranth by using different chemicals and botanicals than the control.

4.3.7 Infestation by jute hairy caterpillar

Number of healthy leaves, infested leaves and percent leaf infestation of red amaranth by jute hairy caterpillar showed statistically significant differences due to different management practices (Table 9). The highest number of healthy leaves/plant (28.67) was found in T_6 treatment which was statistically similar (28.33 and 28.00) to T_4, T_5 and T_3 treatment, respectively, whereas the lowest number (24.33) was recorded in T_7 treatment which was followed (27.00 and 27.67) by T_1 and T_2 treatment. The lowest number of infested leaves/plant (1.33) was found in T_6 treatment which was statistically similar (1.67 and 2.00) to T_4, T_5 and T_3 treatment, while the highest number of infested leaves/plant (5.67) was

Table 8. Efficiency of different management practices against leaf infestation by white fly throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	27.00 d	3.00 b	10.00 b	52.63
T_2	27.00 d	3.00 b	10.00 b	52.63
T_3	27.67 cd	2.33 bc	7.78 bc	63.15
T_4	28.67 ab	1.33 de	4.44 de	78.97
T_5	28.33 abc	1.67 cde	5.56 cde	73.66
T_6	29.00 a	1.00 e	3.33 e	84.23
T_7	23.67 e	6.33 a	21.11 a	--
$LSD_{(0.05)}$	0.753	0.753	2.507	--
Level of significance	0.01	0.01	0.01	--
CV(%)	8.22	10.04	12.16	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 10 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

Table 9. Efficiency of different management practices against leaf infestation by jute hairy caterpillar throughout the study period

Treatment	Leaf in number/plant			
	Healthy	Infested	% infestation	Infestation decrease over control (%)
T_1	27.00 c	3.00 b	10.00 b	47.06
T_2	27.67 bc	2.33 bc	7.78 bc	58.81
T_3	28.00 ab	2.00 c	6.67 c	64.69
T_4	28.33 ab	1.67 c	5.56 c	70.57
T_5	28.33 ab	1.67 c	5.56 c	70.57
T_6	28.67 a	1.33 c	4.44 c	76.50
T_7	24.33 d	5.67 a	18.89 a	--
$LSD_{(0.05)}$	0.907	0.907	3.021	--
Level of significance	0.01	0.01	0.01	--
CV(%)	4.09	13.56	15.22	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 10 plants per treatment

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

T_1: Mechanical method + Cultural method at 7 days interval

T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval

T_3: Spreading wood ash @ 10 g/m^2 at 7 days interval

T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval

T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval

T_6: Spraying malathion @ 1.5 ml/L of water at 7 days interval

T_7: Untreated control

observed in T_7 treatment which was followed (3.00) by T_1 treatment. The lowest infestation of leaves/plant (4.44%) was recorded in T_6 treatment which was statistically similar (5.56 and 6.67%) to T_4, T_5 and T_3 treatment, respectively, whereas the highest infestation (18.89%) was recorded in T_7 treatment which was followed (10.00%) by T_1 treatment. Red amaranth leaf infestation percentage reduction over control by jute hairy caterpillar was estimated for different management practices and the highest value (76.50%) was recorded in T_6 treatment and the lowest value (47.06%) was observed from T_1 treatment. Kirby and Dill (2004) reported that the caterpillar emerges from the soil at night, encircle the plant with its body and cut through the stem of young plants just above ground level or below ground level causing plant wilt and death and make a significant yield loss in red amaranth.

CHAPTER V

SUMMARY AND CONCLUSION

The study was conducted at the main field, Sher-e-Bangla Agricultural University, Dhaka during the period of rabi season November 2016 to February 2017 to investigate the prevalence and management of insect pests of red amaranth (Lalshak), *Amaranthus gangeticus* and its natural enemies. Lalshak variety BARI I were used as test crop in this experiment. The experiments consists of 7 treatments as T_1: Mechanical method + Cultural method at 7 days interval, T_2: Spraying soap water @ 1.5 g detergent/L of water at 7 days interval, T_3: Spraying wood ash @ 10 g/m^2 at 7 days interval, T_4: Spraying neem leaves extract @ 20 g/L of water at 7 days interval, T_5: Spraying neem seed kernel @ 20 g/L of water at 7 days interval, T_6: Spraying malathion 57EC @ 1.5 ml/L of water at 7 days interval and T_7: Untreated control. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Data was recorded on pest incidence, abundance of beneficial insects and leaf infestation due to different insect pests and significant variation was observed for different studied characters due to different treatments.

Insect population for 2 sweeps/plot were observed at 7 days interval and observed grasshopper, red pumpkin beetle, green leaf eating caterpillar, green stink bug, leaf miner, white fly and jute hairy caterpillar for different management practices. In case of grasshopper, the highest number (4.13) of grasshopper was recorded in T_7, while the lowest number of grasshopper (1.47) was observed from T_6. For red pumpkin beetle under the present trial in red amaranths, the highest number (4.87) was found in T_7 treatment, whereas the lowest number of red pumpkin beetle (1.07) was observed from T_6. For green leaf eating caterpillar, the highest number of green leaf eating caterpillar (3.40) was found in T_7 treatment, whereas the lowest number (1.60) in T_6. In case of green stink bug, the highest number of green stink bug (3.27) was recorded in T_7 treatment, whereas the lowest number (1.00) was recorded in T_6 and T_4

treatment. In case of leaf miner, the highest number of leaf miner (3.80) was found in T_7 treatment, while no leaf miner was found in T_6 treatment. In case of white, the highest number of white fly (5.40) was observed in T_7 treatment, whereas the lowest number (1.80) was observed in T_6 treatment. For jute hairy caterpillar, the highest number of jute hairy caterpillar (5.20) was recorded in T_7 treatment, whereas the lowest number (2.27) was found in T_6.

During the study period beneficial insect population of 2sweeps/plot were observed at 7 days interval and recorded lady bird beetle, sphecid wasp, bee wolf and braconid parasite for different management practices. In case of lady bird beetle, the highest number (3.20) was found in T_7, while the lowest number of lady bird beetle (1.00) was found from T_6. In case of sphecid wasp, the highest number (1.27) was observed in T_7, whereas the lowest number of specid wasp (0.67) was observed from T_6 treatment. In case of bee wolf, the highest number (1.33) was found in T_7, whereas the lowest number of bee wolf (0.73) in T_6 treatment. In case of braconid parasite, the highest number (3.27) was found in T_7 treatment, while the lowest number (01.80) was observed in T_6 treatment.

In case of grasshopper, the highest number of healthy leaves/plant (28.90) was observed in T_6, whereas the lowest number (20.50) was recorded in. The lowest number of infested leaves/plant (0.63) was found in T_6 treatment, whereas the highest number of infested leaves/plant (2.80) was found in T_7. The lowest infestation of leaves/plant (2.16%) was recorded in T_6 treatment, while the highest infestation (12.04%) was observed in T_7. In leaf infestation percentage reduction over control the highest value (82.06%) was recorded in T_6 and the lowest value (47.43%) from T_3 treatment. For red pumpkin beetle, the highest number of healthy leaves/plant (25.27) was observed in T_6 treatment, whereas the lowest number (16.33) was recorded in T_7 treatment. The lowest number of infested leaves/plant (0.67) was found in T_6 treatment, whereas the highest number of infested leaves/plant (3.07) was attained in T_7. The lowest infestation of leaves/plant (2.57%) was recorded in T_6, whereas the highest infestation

(15.85%) was found in T_7 treatment. In leaf infestation percentage reduction over control by red pumpkin beetle for different management practices and the highest value (83.79%) was observed in T_6 and the lowest value (50.91%) from T_1 treatment. In green leaf eating caterpillar, the highest number of healthy leaves/plant (29.47) was observed in T_6, whereas the lowest number (21.00) was recorded in T_7 treatment. The lowest number of infested leaves/plant (1.07) was found in T_6, whereas the highest number (3.87) was found in T_7. The lowest infestation of leaves/plant (3.49%) was recorded in T_6, whereas the highest infestation (15.56%) was recorded in T_7 treatment. In leaf infestation percentage reduction over control by green leaf eating caterpillar the highest value (77.57%) was found in T_6 and the lowest value (47.56%) from T_3 treatment.

For green stink bug, the highest number of healthy leaves/plant (29.67) was observed in T_6, whereas the lowest number (25.33) was recorded in T_7 treatment. The lowest number of infested leaves/plant (0.33) was found in T_6, while the highest number of infested leaves/plant (4.67) was recorded in T_7 treatment. The lowest infestation of leaves/plant (1.11%) was found in T_6, whereas the highest infestation (15.56%) in T_7 treatment. Red amaranth leaf infestation percentage reduction over control by green stink bug the highest value (92.87%) was recorded in T_6 and the lowest value (57.13%) from T_1 treatment. In case of leaf miner, the highest number of healthy leaves/plant (29.33) was observed in T_6, whereas the lowest number (24.67) was observed in T_7 treatment. The lowest number of infested leaves/plant (0.67) was attained in T_6, while the highest number (5.33) was observed in T_7 treatment. The lowest infestation of leaves/plant (2.22%) was recorded in T_6, whereas the highest infestation (17.78%) in T_7 treatment. In leaf infestation percentage reduction over control the highest value (87.51%) was observed in T_6 and the lowest value (50.00%) from T_1 treatment. For white fly, the highest number of healthy leaves/plant (29.00) was found in T_6, whereas the lowest number (23.67) was recorded in T_7 treatment. The lowest number of infested leaves/plant (1.00) was recorded in T_6, while the highest number of infested leaves/plant (6.33) was observed in T_7

treatment. The lowest infestation of leaves/plant (3.33%) was recorded in T_6, whereas the highest infestation (21.11%) was recorded in T_7 treatment. Red amaranth leaf infestation percentage reduction over control by white fly the highest value (84.23%) was found in T_6 and the lowest value (52.63%) from T_1 and T_2 treatment. In case of jute hairy caterpillar, the highest number of healthy leaves/plant (28.67) was obtained in T_6, whereas the lowest number (24.33) was recorded in T_7 treatment. The lowest number of infested leaves/plant (1.33) was found in T_6, while the highest number of infested leaves/plant (5.67) was observed in T_7 treatment. The lowest infestation of leaves/plant (4.44%) was observed in T_6, whereas the highest infestation (18.89%) in T_7 treatment. Red amaranth leaf infestation percentage reduction over control by jute hairy caterpillar the highest value (76.50%) was recorded in T_6 treatment and the lowest value (47.06%) from T_1 treatment.

Among the different insect pests management practices, spraying of malathion @ 1.5 ml/L of water at 7 days interval followed by spraying of neem leaves extract @ 20 g/L of water at 7 days interval was better for controlling insect pests of red amaranth with lowest infestation level.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Other pest management and also crop management practices may be include in future study for a definite conclusion.

2. This experiment should be carried out in different agro-ecological zones (AEZ) of Bangladesh for confirmation of the results.

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APPENDICES

Appendix I. Characteristics of the soil of experimental field

A. Morphological characteristics of the soil of experimental field

Morphological features	Characteristics
Location	Expeimental Field , SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% Clay	30
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

Appendix II. Monthly record of air temperature, relative humidity and rainfall of the experimental site during the period from November, 2016 to February 2017

Month	Air temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
November, 2016	25.8	16.0	78	00
December, 2016	22.4	13.5	74	00
January, 2017	24.5	12.4	68	00
February, 2017	27.1	16.7	67	30

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka-1207