SURVEILLANCE AND MANAGEMENT OF WHITE RUST (*Albugo candida*) DISEASE OF RED AMARANTH FOR SEED PRODUCTION

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*This is to certify that, the thesis entitled, "**Surveillance and management of white rust (Albugo candida) disease of red amaranth for seed production**" submitted to the Department of Plant Pathology, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE (M.S.) IN PLANT PATHOLOGY embodies the result of a piece of bona fide research work carried out by **Md. Zahidul Islam**, Registration No.**: 18-09015** 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 been duly been acknowledged by him.

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Dedicated to

My

Beloved Parents

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SURVEILLANCE AND MANAGEMENT OF WHITE RUST (*Albugo candida*) DISEASE OF RED AMARANTH FOR SEED PRODUCTION

ABSTRACT

Experiments were conducted in Sher-e-Bangla Agricultural University, Dhaka-1207, to identify the causal organism of white rust disease of red amaranth (*Amaranthus tricolor* L.) and for its suitable management for seed production during *rabi* and *kharif* seasons of 2018-19. Eight treatments including chemicals, botanicals, bio-pesticides viz. Ridomil gold 68WG (Mencozeb + Metalaxyl @ 0.2%), Autostin 50 WP (Carbendazim @ 0.2%), Dithane M 45 (Mancozeb @ 0.2%), Goldton 50WP (Copper oxychloride @ 0.2%), Bordeaus mixture (CaO + $CuSO_4$ @ 1%), G-Derma (*Trichoderma sp.*) @ 0.3%, Garlic bulb extract 1:1 (w/v) (*Allium sativum* @ 2%), and Allamanda leaf extract 1:1 (w/v) (*Alamanda cathertica* @ 2%) were considered for the management of white rust disease of Red amaranth (*Amaranthus tricolor* L.). Four foliar sprays were done at seven days interval, started from 7 days after disease appeared. The field experiments were conducted by following RCBD design with three replications. Obligate fungi *Albugo candida* was successfully identified by microscopic study as the causal organism of white rust disease of red amaranth. Among the treatments, Ridomil gold 68WG gave best result against white rust disease of red amaranth. Moreover, Allamanda leaf extract showed better effect and Autostin 50WP had moderate effect against the disease compare to other treatments. Growth and seed yield of red amaranth varied significantly among the treatments. In *Rabi* season of 2018, After 4^{th} spray, the lowest plant incidence was recorded in Ridomil gold (24%) followed by Allamanda leaf extract (31%). Similarly, the lowest disease severity was found in Ridomil gold (1.83%) followed by Allamanda leaf extract (2.43%). Ridomil Gold reduced 63.07% plant incidence, 62.78% leaf incidence and 84.31% disease severity at 61 DAS over control. However, Allamanda leaf extract reduced 52.30% plant incidence, 52.78% leaf incidence and 79.17% disease severity over control. Similar results also found in *kharif* season of 2019 where after 4^{th} spray, the lowest plant incidence was recorded in Ridomil Gold (18.66%) which was statistically identical with Allamanda leaf extract (22%) and the lowest disease severity was found in Ridomil gold (1.93%) followed by Allamanda leaf extract (2.23%). At 57 DAS, Ridomil Gold reduced plant incidence (69.73%), leaf incidence (65.71%) and disease severity (88.41%) over control. However, Allamanda leaf extract reduced plant incidence (64.32%), leaf incidence (60.48%) and disease severity (86.61%) over control. Considering the overall performance of the treatments, Ridomil Gold 68WG showed the best effect in controlling white rust disease. Thus, Ridomil Gold 68WG could be used for seed production of red amaranth. Moreover, Allamnada leaf extract could be used as an eco-friendly approach for white rust disease management to ensure safe crop production.

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ACRONYMS AND ABBREVIATIONS

ABBREVIATIONS	Full Name
AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
cm	Centimeter
CV	Coefficient of Variation
DAS	Days After Sowing
et al.,	And others
e.g.	exempli gratia (L), for example
etc.	Etcetera
FAO	Food and Agricultural Organization
g	Gram (s)
i.e.	id est (L), that is
Kg	Kilogram (s)
LSD	Least Significant Difference
M^2	Meter squares
mL	Milliliter
M. S.	Master of Science
No.	Number
SAU	Sher-e-Bangla Agricultural University
Var.	Variety
^oC	Degree Celceous
%	Percentage

CHAPTER I

INTRODUCTION

Amaranth is one of the important vegetables of Amaranthaceae family. Amaranth has been naturalized in central parts of Asia and possibly Iran (Kawazu *et al*., 2003) and has cultivation history of more than 2000 years (Daneshvar, 2000). Amaranth is a widely grown leafy vegetable crop in Africa and Asia. The leafy amaranth is said to be the native of India (Shanmugavelu, 1989; Nath, 1976). *Amaranthus* are promising leafy vegetable crops considering their increasing availability in retail and supermarkets and have been ranked among the most preferred indigenous vegetables in Kenya (Agong and Masinde, 2006). In Bangladesh more than 60 different vegetables are grown of which winter vegetables amount for more than 62% of both area and production (Hossain, 1992). The major vegetable grown in winter including cabbage, cauliflower, radish, red amaranth, mustard, bottle gourd etc. Amaranth species classified into three categories, which represent more or less use groups: vegetable amaranths, grain amaranths and weed amaranths (Das, 2012). It is reported that vegetable crops need more intensive care and they give more profit compare to other like cereal, pulse and oil seed (Hossain, 1992).

Increasing population of the world has doubled the food demands and inundated the available land resources. Alongside other food alternatives, vegetables are considered cheap source of energy (Hussain *et al*., 2009). Vegetables are rich sources of essential bio-chemicals and nutrients such as carbohydrates, carotene, protein, vitamins, calcium, iron, ascorbic acid and palpable concentration of trace minerals (Salunkhe and Kadam, 1998). *Amaranthus* is a host of numerous minerals such as, calcium, magnesium, iron, zinc, manganese and others. it offers a combined source of cheap and healthy food as well as medicinal value and health benefits for people (Habwe *et al*., 2009). Studies have shown that nutritional value of vegetable amaranth is comparable to some exotic vegetables such as spinach and/or superior to others such as *Brassicca* species (Odhav *et al*., 2007). It contains high levels of essential amino acids and minerals elements like calcium, iron, and zinc (Andini *et al*., 2013; Kwenin *et al*., 2011). The content of tannins reported in various Amaranthus cultivars was in a very wide range, from 0.4 to 5.2 mg/g; however, these fluctuations might be due to the differences between plant species and cultivars and due to the differences in measurement method. Amaranth plants also contain compounds which can potentially compromise health. Adequate consumption of vegetables can contribute to wellness and sense of wellbeing of people living with diabetes, high blood pressure and may even prolong life (Oguntibeju *et al*., 2013). All parts of the plant are used as medicine to heal many diseases in African communities (Achigan-Dako *et al.*, 2014).

Amaranth is a popular, cheap and easily cultivable vegetable throughout the year round. It can be grown at homestead area, kitchen garden, small fellow land and in the field. The succulent leaf and stem of amaranth are used as vegetable. In Bangladesh about 29403 acres' land is brought under red amaranth cultivation which yield about 59150 m. ton. annually (BBS, 2018). Among the leafy vegetables, red amaranth (*Amaranthus tricolor* L.) is the most commonly cultivated species in Bangladesh. Red amaranth is a good source of minerals and vitamins (A, B and C). Moreover, the crop is adapted to a wide range of soil conditions. Sandy soil with slight acidity is best suited (Palada and Chang, 2003). In our country, its cultivation is increasing day by day (BBS, 2010). During winter, its growth and development is slower than summer and rainy season (Bose *et al*., 1993). Average yield of red amaranth varies from 5 to 8 ton/ha. in conventional farming in Bangladesh (BARI, 1991).

Red amaranth cultivation technology is easy but some diseases cause great loss under favorable condition. Red amaranth is subject to attack by many diseases caused by fungi, bacteria viruses, mycoplasma and nematode. These diseases cause reduction of yield of red amaranth. Red amaranth is attacked by about a dozens of diseases in Bangladesh (Talukder, 1974; BARI, 1984). Fungi are the great threat for vegetable as well as amaranth production. Different fungi are responsible for disease developments which attack the amaranth plants during seedling to maturity stages. Common diseases are white rust, *Alternaria* blight, damping off, stem rot, root knot, wilting and so on.

Among diseases of red amaranth, white rust caused by *Albugo candida* is noted as the major one considering its higher incidence, wider distribution and adverse effect on yield and quality of the crop. White rust disease caused by *Albugo candida* is one of the most important constraint to production of good quality seed of red amaranth (Rahman, 2010). The Oomycetes fungus, *A. candida* is known to be present wherever red amaranth is grown (Nyvall, 1989). white rust disease mainly appeared on the leaves. Disease symptom firstly appeared on the lower side of leaves. When the infection is confined to leaves it may not result in any appreciable yield loss (Kolte, 1985). Wet rot or stem rot caused by *Choanephora curcubitarum* is a major fungal disease on *A. cruentus*, while *A. tricolor* and *A. dubius* are much less susceptible to this disease (Ebert *et al*., 2011).

White rust is one of the major diseases of vegetables and oilseed crops. White rusts, caused by several species of the fungus *Albugo* sp., occur worldwide on beet (garden and sugar), Brussels sprouts, cabbage, cauliflower, Chinese cabbage, collards, garden cress, horseradish, kale, lettuce, mustards, parsnip, radish, rape, salsify (black and white), spinach, sweet potato, turnip, watercress, amaranth, red amaranth and possibly water-spinach. In addition, numerous common weeds and herbaceous ornamentals are also attacked by this fungus. *A. candida* causes economically significant yield and quality losses in seed and vegetable produce of crucifers in several different ways. White rust disease on the foliage reduces the photosynthetic capacity of plants and affects yield and normal plant development. Disease on the foliage affects and downgrades the leaves for sale and its human consumption as a vegetable.

The presence of conspicuous white pustules at the vegetative stage can be of serious concern to farmers. Infected leaves show blister like appearance. The stem and leaves become twisted and deformed. It commonly occurs when nights are cool and damp and days are warm. epidemic development of white rust is dependent upon many factors, viz. aggressiveness of races, amount of initial inoculum, time of first appearance of the disease and prevailing weather conditions. These factors determine the final intensity of disease and associated yield loss (Singh *et al*., 2003).

Disease incidence and severity of white rust of red amaranth varied among the locations and seasons. White rust (*Albugo candida*) is a highly destructive disease of oilseed Brassicas such as *Brassica juncea* and *B. rapa*. Most commercial *B. juncea* or *B. rapa* varieties are highly susceptible and yield losses from combined infection of leaves and inflorescences can be up to 20% or 60% in Australia and India, respectively (Shivsitaram *et al*., 2006). Moreover, white rust (*Albugo candida*) disease was sporadically present in many amaranthus production fields. The disease incidence on affected crops ranged from 21 to 45% across all the areas surveyed. Initial symptoms were small chlorotic spots on the upper leaf surface. As the disease developed, white pustules (sori) or blisters were frequently produced as irregularly oval, elongated concentric rings, 3 to 4 mm in diameter, mostly on the lower leaf surface but also often on the upper surface. In the advanced stages of the disease, the white pustules often coalesced, and lesions appeared grainy due to the production of numerous oospores, rendering infected leaves unmarketable (Soylu *et al.*, 2017).

Resistant cultivars, if available, are the most effective, practical, eco-friendly and economical choice. However, at present, no such resistant varieties are available in Bangladesh. A number of chemicals have been evaluated to control the disease in India (Verma and Petrie, 1979). In Bangladesh, recommendation for management of white rust is also limited. A very few research works were conducted to manage this disease.

Using different chemical fungicides viz. Ridomil Gold 68 WP (Chlorothalonil + Mefenoxam) @ 0.2%, Contaf 25 EC (Triazole) @ 0.1%, and X-tra Care 300 EC (Myclobutanil) 0.05% to control white rust (*Albugo occidentalis*) of red amaranth (*Amaranthus* spp.). Among these, Ridomil Gold was found most effective one to control white rust disease (Talkuder *et al*., 2012).

Efficiency of different cultural practices and chemicals namely Sunvit (0.2%), sanitation, Contaf 25 EC (0.1%), Orazim 50WP (0.05%), Zoom 50WP (0.1%), Ridomil Gold 68WG (0.2%), X-Tra Care 300 EC (0.05%) were evaluated against white rust disease in the Experimental Farm of Regional Agricultural Research Station in Jamalpur during 2009-2010 under natural condition. The lowest disease incidence and best yield were found in the plot which was sprayed with Ridomil Gold 68WG (Rahman, 2010).

Using chemical fungicides to control the white rust disease as foliar application of Ridomil MZ-72 WP containing active ingredient of 8% Metalaxyl and 64%

Mancozeb @ 2g/L can reduce the incidence and severity of white rust disease effectively (Rathi and Singh, 2009).

Antifungal action of garlic extracts, Allamanda extracts, neem extracts have been reported by many researchers. Garlic bulb extract and Allamanda leaf extract were found promising inhibiting mycelial growth of fungus in *in vitro* condition and also reduced the disease incidence and severity of vegetables in field condition (Islam, 2005).

Trichoderma is a genus of asexually reproducing fungi that is present in all types of soils. *Trichoderma* species have been recognized as antagonists of soil-borne and foliage pathogens and as efficient decomposers of cellulosic waste materials. Moreover, they have the ability to increase plant growth and induce plant resistance. Along with mycoparasitism, antibiotics and competition, induced resistance is one of the most important mechanisms of *Trichoderma* action against fungal plant pathogens (Cumagun, 2012).

White rust (*Albugo candida*) is a highly destructive disease of cruciferous vegetable and oilseed crops. The low productivity or red amaranth in Bangladesh is chiefly attributed due to the prevalence of white rust disease. Moreover, white rust infestation drastically reduces market price of red amaranth. This disease is considered major problem of seed production of red amaranth in Bangladesh. In field level, farmers used chemical fungicides to manage this disease. However, indiscriminate use of fungicides, frequent spry with high dose and using two or more fungicides together are common practices for disease management in Bangladesh. In view of economic importance of the crop, the present study was undertaken to determine *in vivo* efficacy of fungicides, botanicals and bio-agent against white rust disease of red amaranth to ensure quality seed production.

Considering the above scenario, the following objectives were considered for this research experiment:

1. To identify the causal organism of white rust disease of red amaranth;
2. To measure disease incidence and severity of white rust disease of red amaranth in different areas of Bangladesh; and
3. To evaluate chemical fungicides, botanicals and bio-fungicide against white rust disease of red amaranth.

CHAPTER II

REVIEW OF LITERATURE

Red amaranth is a popular leafy vegetable crop of Bangladesh, which is widely grown throughout the country. It is a cheap source of vitamins (A, B and C) and minerals. Most of the people consume it due its nutritive value and availability. Many diseases attack this vegetable during production, which reduces the production and quality of this vegetable. There is very limited significant research on white rust of red amaranth in Bangladesh. This chapter is to review the previous studies that are related to the present study. The review of some related studies are described below:

2.1 Amaranth (*Amaranthus tricolor*)

Muruiki (2015) stated *Amaranthus* is a host of numerous minerals such as, calcium, magnesium, iron, zinc, manganese and copper among others. it offers a combined source of cheap and healthy food as well as medicinal value and health benefits for people (Habwe *et al*., 2009).

Achigan-Dako *et al.* (2014) reported that all parts of the plant are used as medicine to heal many diseases in African communities.

Qiang *et al*. (2014) recommended amaranths vegetables as a food with medicinal properties for young children, lactating mothers and for patients with constipation, fever hemorrhage, anemia or kidney complaints Nitrogen is one of the major elements for plants growth and metabolism.

Mwaura *et al*. (2014) stated that leafy vegetable is appropriate to resource-poor farmers as it offers cheap means of income generation and employment opportunities along the production chain, thus economic security, especially in the peri-urban proximities.

Oyediji *et al*. (2014) reported that NPK and poultry manure improve the growth and yield of three different species of amaranth (*Amaranthus hybridus, Amaranthus deflexus and Amaranthus tricolor*) but influenced proximate composition differently where NPK had the highest crude fiber, protein and fat while poultry manure showed the highest fat content.

Oguntibeju *et al*. (2013) reported that adequate consumption of vegetables can contribute to wellness and sense of wellbeing of people living with diabetes, high blood pressure and may even prolong life.

Das (2012) classified amaranth species into three categories, which represent more or less use groups: vegetable amaranths, grain amaranths and weed amaranths.

Onyango *et al.* (2012) observed that amaranth species have a rapid growth habit and can be harvested relatively soon (3 to 4 weeks) after sowing and possesses short harvesting interval.

Olfati *et al*. (2012) stated amaranth is a basic constituent of cell components, including nucleic acids, protein, chlorophyll and growth hormones. It is available to plants in either cation form (NH_4^+), or the anion form (NO_3^-).

Andreas *et al.* (2011) referred amaranths as drought tolerant vegetable, possibly due to the ability of the species to grow under wide range of adverse environmental conditions.

Kunyanga *et al*. (2011) reported that the content of tannins in various Amaranthus cultivars was in a very wide range, from 0.4 to 5.2 mg/g; however, these fluctuations might be due to the differences between plant species and cultivars and due to the differences in measurement method. The condensed tannin extracts of raw, cooked, and roasted grains, as well as raw, cooked, and blanched vegetables, showed antidiabetic effects by inhibiting α-amylase and α-glucosidase activity up to 50% and 78%, respectively. Roasting of grains and cooking of vegetables better preserved the tannins and their functional properties than soaking plus cooking and blanching.

Wambugu and Muthamia (2009) reported that amaranth plant is a very versatile crop, economical to produce and readily adapts to different environmental conditions in which it grows. Rapid growth habit of amaranth makes it appropriate to be used for nutrition intervention purposes.

O'Brien and Price (2008) conducted an experiment on some under aged children and reported that incidence of blindness in children due to poor nutrition had reduced with the consumption of 50-100g of amaranth leaves per day.

Priya *et al.* (2007) said that amaranths have been reported to be of excellent nutritional value because of their rich content of essential vitamins such as vitamin A, B6, C and K.

Gupta *et al*. (2005) examined amaranths in addition to their high nutritional value also accumulate high levels of antinutritional factors such as oxalates. He reported that oxalate plays various functional roles in plants, including calcium regulation, plant protection and detoxification of certain metals. He also said it is well established from the studies carried out by many workers on animals that oxalates present in foods interfere with the assimilation of calcium.

Grubben and Denton (2004) said it is photoperiod sensitive and most species flower when the day length is shorter than twelve hours, the mineral uptake is very high.

Chinthapalli *et al.* (2003) reported that *Amaranthus* are C_4 plants which enable efficient photosynthetic activity and water use efficiency under high temperature and radiation intensity.

Mujica and Jacobsen (2003) stated that *Amaranthus* species is a broad group of species from the family Amaranthaceae. It is often difficult to characterize taxonomically, due to the overall similarity of many of them, small and difficult-to-see diagnostic parts, intermediate forms and the broad 10 geographical distributions.

Palada and Chang (2003) conducted an experiment in Taiwan in 2000-2002, and reported that a temperature range of 20-30°C is required for better vegetative growth and the crop is adapted to a wide range of soil conditions where sandy soil with slight acidity is best suited.

Abukutsa-Onyango (2003) reported that the nutrient content of red amaranth can provide 100% of the recommended daily allowance for an adult for calcium, iron, B-carotene, ascorbic acid and 40% of protein if 100g of the fresh vegetable is consumed.

2.2 The pathogen *Albugo candida*

Barhate *et al.* (2015) stated that maximum incidence and intensity of chrysanthemum white rust disease was observed at 25-27°C temperature and high relative humidity of 85-90 per cent in protected condition while in case of non-protected condition less infection occurred due to high temperature and low humidity.

Verma (2012) said that *Albugo candida* the causal fungus of the white rust disease of many cruciferous crops, causes both local and general infection. Local infections produce white to cream coloured pustules on the undersides of leaves.

Mishra *et al*. (2009) reported that epidemic development of white rust caused by *A. candida* is dependent upon many factors, viz. aggressiveness of race, amount of available initial inoculum, time of first appearance of the disease and prevailing weather conditions. *A. candida* isolates from different crop species/cultivar or from different geographical regions may be different in their incubation period, latent period and production of sporangia and zoospores, pustule size, shape and texture and aggressiveness.

Sullivan *et al.* (2002) reported that symptoms of white rust begin as chlorotic lesions on the upper leaf surface. As the lesions develop, small white pustules (sori) containing sporangia are produced on the underside of the leaf and occasionally on the upper leaf surface. The pustules often are so abundant that nearly the entire leaf surface is covered. Primary infection is thought to occur from soil borne oospores that are splashed on plants by rainfall or overhead irrigation, or by airborne sporangia.

2.3 Diseases of Crops Caused by *Albugo candida*

Yadava *et al.* (2011) reported that *Albugo candida* the causal organism of the white rust of the rapeseed- mustard, occurs in all parts of the world where cruciferous crops are grown. It is one of the important diseases of rapeseed-mustard in India causing a yield loss of 17-34 percent.

Minchinton *et al.* (2005) reported that at least seventeen physiological races of *A. candida* have been described based on the ability to cause disease in different crucifer species.

Sullivan *et al.* (2002) said that *Albugo candida,* is an obligate oomycete pathogen that causes white rust, an economically important foliar disease of spinach (*Spinacia oleracea* L.) in production areas of the United States east of the Rocky Mountains. White rust is a serious problem for spinach production in the Arkansas River Valley of Oklahoma, where it was first reported in 1943. The disease causes substantial yield losses through a reduction in the quality and marketability of fresh and processed spinach.

2.4 Diseases of Red Amaranth (*Amaranthus tricolor*)

Ebert *et al*. (2011) observed that wet rot or stem rot caused by *Choanephora curcubitarum* is a major fungal disease on *A. cruentus,* while *A. tricolor* and *A. dubius* are much less susceptible.

Rahman (2010) reported white rust disease caused by *Albugo candida* is one of the most important constraints to production of good quality seed of red amaranth.

Yadav (2004) had reported minimum disease severity of white rust and maximum seed yield in 20th October sown mustard crop in Bhatinda from the adjoining state of Punjab in India.

Grubben (2004) conducted an experiment on Alternaria leaf spot and reported that *A. cruentus* in Tanzania while it is hardy or not susceptible to nematode damage. some amaranth lines are susceptible to soil-borne organisms associated with damping-off and stalk-rot caused by *Pythium, Fusarium* and *Bacterium*. Damping-off caused by *Pythium* and *Rhizoctonia* may be serious in seedbeds. Good drainage and light dense-sowing will help to reduce this problem.

Singh *et al*. (2003) were conducted an experiment on white rust disease of red amaranth and reported that the epidemic development of white rust is dependent upon many factors, viz. aggressiveness of races, amount of initial inoculum, time of first appearance of the disease and prevailing weather conditions. These factors determine the final intensity of disease and associated yield loss.

2.4.1 White Rust (*Albugo candida*) Disease of Red Amaranth

Hina *et al.* (2014) stated that *Albugo candida* is an obligate parasite and can be survived by means of producing oospores in infected plants parts and in soil for more than 20 years. Optimum temperature for effective infection is 12-22°C and relative humidity (RH) 60-90% (Sullivan *et al*., 2002).

Rathi and Singh (2009) stated that when disease suddenly appear, it is very difficult for a farmer either to apply different organic formulations or totally uproot plants. Chemicals will protect by forming layer on leaves surface while some have ability to penetrate the system and help the plant to reverse the biochemical changes induced by the pathogen. These are rapid and quick remedy and easy to apply in case of sudden outburst of disease. Many field trials of different concentrations of fungicides were resulted in 30-65% disease control in India. Seed treatment and foliar spraying of different fungicides concentrations were tested on multiple varieties to validate them as cost effective.

Mishra *et al.* (2009) reported that *Albugo candida* produces two types of infection: local and systemic. Local infection is characterized by the formation of raised creamy white sporangial pustules on the undersurface of leaves, on tender shoots. The affected tissue turns necrotic and dies. Systemic infection is usually seen in young inflorescences and terminal leaves. It stimulates hypertrophy and hyperplasia resulting in abnormal swelling and malformation of the affected organs. Floral organs turn green, become greatly enlarged and distorted, and seed formation is prevented.

Mishra *et al.* (2009) reported that white rust is the most destructive disease of Brassica in hot and humid areas of Pakistan caused by *Albugo candida* (Abbas *et al*., 2008). It causes 20-90% yield losses throughout the world.

Oram *et al.* (2006) reported that white rust or white blister, caused by the oomycete *Albugo candida* (Pers.) Kuntze, is a disease of many *Brassicaceae* species, including the condiment mustard and oilseed crop *Brassica juncea*. The pathogen produces localised lesions on the leaves and systemic infection which results in distorted leaves.

2.5 Management of White Rust Disease of Red amaranth

2.5.1. Management of White Rust Disease by Cultural Practices

Talukder and Riazuddin (2011) conducted an experiment at Regional Agricultural Research Station (BARI), Rahmatpur in Barisal, Bangladesh during 2010-2011 and found that among different sowing dates of red amaranth as 12 November, 22 November, 02 December, 12 December and 22 December best performance in mitigating white rust disease with maximum yield in the plot which was sown in 12 November.

Rahman (2010) conducted an experiment in Jamalpur, Bangladesh during 2009-2010 and stated that, white rust caused by *Albugo candida* is one of the most important constraints to production of good quality seed of red amaranth in Bangladesh.

Rahman and Goswami (2008) conducted an experiment at Regional agricultural research Station of BARI in Jamalpur, Bangladesh during 2006-2007 and reported that sowing date has an effect on disease development, among various sowing dates like 01 November, 07 November, 14 November, 21 November, 28 November, 05 December and 12 December of BARI Lalshak-1. The lowest disease severity and highest yield was recorded at 01 November sowing followed by 07 November.

Yasmin *et al*. (2008) conducted an experiment on different sowing date of red amaranth in the period of 2005-2007 in BARI, Gazipur, Bangladesh and reported that among the six sowing dates, the first week November gave the highest seed yield and low disease severity of white rust on red amaranth when the plots were sprayed with 0.025% Tilt 250EC (Propiconazole).

Goswami (2006) conducted an experiment on different variety of red amaranth collected from local market of Bangladesh and stated that white rust caused by *Albugo* spp. is a damaging disease of red amaranth. He recorded the lowest disease severity in Raktolal variety followed by RM and BARI Lalshak-1.

Singh and Singh (2006) reported that yields were higher in October sown crops in comparison to late sown crops during all the years of experimentation. Observations of less severity of white rust and more yield in the mustard crop sown during October have been made earlier from North Western parts of India.

Rahman and Goswami (2008) reported that red amaranth is an important leafy vegetable in Bangladesh. White rust caused by *Albugo* spp. is a serious and damaging disease of the crop. Among four cultivars of red amaranth namely BARI Lalshak-1, Red King, Roktolal and Mosharrof, none of them was free from this disease but lowest disease severity was found in the cultivar Red King followed by BARI Lalshak-1. The experiment was conducted in the research field of BARI, Jamalpur, Bangladesh during 2006-2007.

2.5.2 Management of White Rust Disease by Chemical Fungicides

Talkuder *et al*. (2012) conducted an experiment at Regional Horticultural Research Station of BARI in Rahmatpur, Barisal, Bangladesh during 2009-2011 by using Ridomil Gold 68 WP (Chlorothalonil + Mefenoxam) @ 0.2%, Contaf 25 EC (Triazole) @ 0.1%, and X-tra Care 300 EC (Myclobutanil) 0.05% to control white rust (*Albugo occidentalis*) of red amaranth (*Amaranthus* spp.). Among these, Ridomil Gold was found most effective one to control white rust disease.

Meena *et al.* (2011) showed that chemical fungicides in combination with ecofriendly products such as *T. harzianum* and *Pseudomonas fluorescence* will give better results against white rust diseases.

Rahman (2010) evaluated the efficacy of different cultural practices and chemicals namely Sunvit (0.2%), sanitation, Contaf 25 EC (0.1%), Orazim 50WP (0.05%), Zoom 50WP (0.1%), Ridomil Gold 68WG (0.2%), X-Tra Care 300 EC (0.05%) against white rust disease in the Experimental Farm of Regional Agricultural Research Station of BARI in Jamalpur, Bangladesh during 2009-2010 under natural condition. The lowest disease incidence and best yield were found in the plot which was sprayed with Ridomil Gold 68WG (0.2%).

Rathi *et al.* (2009) conducted an experiment in Panjab, India during 2008-2009, using chemical fungicides to control the white rust disease. They reported foliar application of Ridomil MZ-72 WP containing active ingredient of 8% Metalaxyl and 64% Mancozeb @ 2g/L can reduce the incidence and severity of white rust disease effectively.

Goswami (2009) conducted an experiment during 2005-2006 under natural condition at Bangladesh Agricultural Research Institute (BARI), Bangladesh to control white rust disease of red amaranth. Five fungicides namely Tilt 250 EC (0.05%), Contaf (0.05%), Sunvit (0.2%), Bavistin (0.2%) and Diathane M-45 (0.2%) were sprayed 3 times at 10 days interval starting from the appearance of disease. Lowest severity was recorded with the spray of Tilt (Propiconazole) followed by Contaf, Sunvit, Bavistin, Diathane M-45. The highest seed yield was found with spraying of fungicides Sunvit followed by Diathane M-45.

Rahman and Goswami (2009) conducted an experiment at Bangladesh Agricultural Research Institute (BARI) in Rahmatpur, Barisal, Bangladesh during 2007-2008 to produce quality seed of red amaranth using variety BARI Lalshak-1. Five different fungicides viz. Sunvit 50WP, Bavistin DF, Contaf 50WP, Tilt 250EC and Diathane M-45 were sprayed 3 times at 14 days' interval from the first appearance of disease. They observed the lowest disease severity in the plot spray with Tilt (Propiconazole) followed by Contaf, Sunvit, Bavistin and Diathane M-45.

Huq and Rahman (2009) conducted an experiment to manage white rust disease by using different cultural practices and chemicals namely Sunvit (0.02%), Sanitation, Contaf 25 EC (0.01%), Orazim 50WP (0.05%), Zoom 50WP (0.01%), Ridomil Gold 68WG (0.02%), X-Tra Care 300 EC (0.05%) under natural condition at Regional Agricultural Research Station of BARI, Rahmatpur, Barisal, Bangladesh in 2008-2009. The lowest disease incidence was observed in the plot which was sprayed with Ridomil Gold 68WG followed by Sunvit.

Islam and Momotaz (2008) reported that white rust caused by *Albugo candida* is the most important hindrance for the production of red amaranth seed. Five fungicides namely Tilt (0.05%), Contaf (0.05%), Bavistin (0.2%), Sulphur (0.2%) and Diathane M-45 (0.2%) were sprayed for three times at 14days interval from the first appearance of disease. Lowest disease severity was found with the spray of Diathane M-45 followed by Bavistin and Sulphur. Maximum and statistically similar seed yield was obtained from Dithane M-45 and Bavistin treated plots.

Yuming (2004) carried out an investigation for pathogen identification, and control of *Amaranthus paniculatus* white rust and found that the disease is caused by *Albugo sp*. And this disease is more serious in autumn than summer. Control measures include timely sowing, reasonable planting density, along with leaf spraying of 58% Metalaxyl+Mancozeb wettable powder (WP) (500X dilution), 64% Oxadixyl + Mancozeb WP (400X dilution), 69% Acrobat-MZ WP (600 X dilution), and 70% Cymoxanil WP (800X dilution), which achieved over 94% protection.

Palada and Chang (2003) said red amaranth is known to be a low management crop that can grow in poor soils but white rust disease incidence is higher and studies have shown that its yields could be improved by application of fertilizers.

Kaur and Kolte (2001) showed that foliar treatment of mustard plants by Benzothiadiazole protects them against foliar and stag head phase of white rust disease by activating plants own defense response. The highest seed yield was found with spraying of fungicide Dithane M-45, but there was no significantly different with the other fungicides spray.

2.5.3 Management of white rust disease by Bordeaux mixture

Neeraja *et al*. (2018) conducted an experiment on Bud rot disease of coconut is fatal if timely control caused by *Phytophthora palmivora* and stated that effect of different chemicals viz., Azoxystrobin 23% EC, Kresoxim methyl 44.3% SC, Pyroclostrobin + Metiram 60% WG, Fenamidone + Mancozeb 60% WG, Bordeaux mixture 1%, Copper oxychloride 50% WP, Mancozeb 75% WP, Metalaxyl + Mancozeb, 68% WP and Iprovalicarb + Propineb 6675 WP 5.5% + 61.25% W/W were assessed against P. palmivora under in vitro conditions. Among the chemicals, Bordeaux mixture 1%, Copper oxychloride 50% WP showed complete inhibition of the mycelia growth of the pathogen after eight days inoculation under in vitro screening.

Nair (2010) reported that there are several leaf spot diseases in cashew. *Pestalotia microspore* causes the gray blight, *Phyllostica sp*. Causes the red leaf spot, and brown leaf spot is caused by *Colletotrichum gloeosporioides* spraying 1% Bordeaux misture or 0.3% Benlate is recommended to control the disease.

Lee *et al.* (2009) carried out an experiment to investigate disease control efficacy of Bordeaux mixture against powdery mildew on omija (*Schizandra chinensis*) medicinal plants and reported that when the Bordeaux mixture was foliar applied by different modes, it showed potent control efficacy against powdery mildew disease on omija medicinal plants, with control values between 87 and 96%. These results indicate that Bordeaux mixture is highly effective at controlling powdery mildew disease on omija medicinal plants.

2.5.4 Management of White Rust by Botanicals or Plant Extracts

Madeha *et al.* (2018) reported that Garlic exhibits a significant antifungal activity against four fungal species. The antifungal activity of the selected plants may be due to presence of some chemical compounds such as terpenoids, flavonoids and phenols. In conclusion; these plants may have a potential use in pharmaceutical and preservative products. Further studies are needed to explore the novel antifungal bioactive molecules.

Haron *et al* (2013) stated that A significantly lower disease incidence, severity, and index were observed in Allamanda treated papaya fruits. Fruits coated with chloroform extracts of *A. blanchetti A. cathartica* 'Alba', and *A. cathartica* 'Jamaican Sunset' showed maximum reduction in anthracnose incidence and severity scores were always (1-25%) and 0 (0%). Antifungal effects of the most effective extracts were supported by the presence of chemical constituents indentified by GC-MS. Campesterol, -sitosterol, stigmasterol, plumericin, squalene, and α-Tocopherol were detected as major compounds in Allamanda species that were possibly responsible for the antifungal activity.

Islam and Faruq (2012) reported that effect of some plant extracts against damping-off disease of some winter vegetable was studied in the net house. Seed treatment with neem leaf, garlic clove, allamonda leaf, ginger rhizome, kalijira seed, bel leaf, turmeric rhizome, katamehedi leaf and onion bulb were evaluated against damping-off, seed germination and growth characters of tomato, eggplant and chilli seedlings. All the treatments were significantly reduced percent damping-off of these three vegetable over untreated control. The most effective treatment was neem leaf extract followed by garlic clove and allamonda leaf extracts in terms of suppressing damping-off disease incidence with increasing plant growth characters.

Suleiman and Emua (2009) evaluated some plant extracts against *Pythium aphanidermatum* (damping-off causing pathogen) and found 55% growth inhibition when fungus was grown on neem leaf extract containing PDA plate. While ginger rhizome extract reduced 70% infection of *Pythium aphanidermatum* on cowpea in vivo.

Islam *et al.* (2006) reported that garlic, ginger, biskhatali and neem extract showed statistically similar effect as of seed treatment with Vitavax-200 against *Bipolaris sorokiniana*. This result indicates that plant extracts as an excellent alternative of chemicals for seed extracts as an excellent alternative of chemicals for seed treatment.

Islam (2005) tested 11 botanicals to control fungal disease of vegetables. Out of 11 botanicals garlic bulb and Allamanda leaf extract were found promising to inhibiting mycelial growth of fungus under *in vitro* condition. These two extract also reduced the disease incidence and severity of vegetables in field condition.

Sithananatham *et al*. (2004) reported that botanical pesticides 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 and diseases.
Mostafa (2004) conducted an experiment and reported that allamanda leaf extract reduces the incidence and severity of fungal diseases as well as other diseases. He observed that in case of rust disease, the lowest percentage of plant incidence and maximum plant height, branch length, leaf length, leaf breadth and petiole length while plot was treated with Allamanda extract.

Meena *et al.* (2003) said that the effectiveness of plant extracts of neem, onion and garlic against white rust pathogen have been reported earlier.

Hawlader (2003) stated that allamanda leaf extract (3%) effectively reduced the infection of some fungal disease of eggplant. Botanicals from *Allamanda cathertica* as an excellent potential fungicide for control of phomopsis blight disease of eggplant.

Obagwn (2003) conducted an experiment to evaluate the efficiency of garlic extract either alone or in combination with reduced quantities of Benlate (benomyl 50% a.i. WP) for control of brown blotch of Bambara groundnut caused by fungus and reported that Garlic bulb extract in combination with Benlate provides satisfactory results to control diseases.

Meah *et al.* (2002) stated that plant extracts might be a substantial alternative of chemical pesticides in controlling plant diseases. Allamanda leaf extract is one of them which shows miracle result in controlling plant diseases.

Ahmed and Islam (2000) conducted a field experiment to know the efficacy of plant extract and reported that among 4 plant extract namely Neem (*Azadirachta indica*), Garlic (*Allium sativum*), Onion (*Allium cepa*) and Biskathali (*Polygonum hydropiper*), Neem and Garlic bulb extract showed effective fungicidal activity against *Bipolaris oryzae* at 1:1 dilution.

Rahman *et al.* (1999) conducted an experiment by using Biskatali, Garlic, Ginger and Neem extract against seed borne infections of *Alternaria tenuis, Alternaria alternate, Bipolaris sorokiniana, Curvularia lunata, Fusarium* s*pp.* of wheat. They reported that Garlic was found superior to the other extract followed by Ginger and Neem extract.

Panda *et al*. (1996) conducted an experiment to know the efficacy of leaf extracts of debdaru, thuja, allamanda, bael and kathgolap against fungal disease of eggplant and reported that among these extracts allamanda leaf extract showed higher efficiency against fungal disease of eggplant.

Fakir and Khan (1992) reported that seed treatment with garlic bulb extract at different concentrations significantly reduced the seed borne infection of *Colletotrichum corchori, Fusarium spp.* and *Macrophomina phaseolina* in jute. Both concentrated garlic extract and Vitavax 200 were more or less equally effective in controlling infection of seed borne pathogen. More than 80% control of seed borne infection of *Fusarium spp.* was achieved with concentrated and 1:4 Garlic extract.

2.5.5 Management of White Rust Disease by Bio-agents (*Trichoderma sp.*)

Cumagun (2012) said that *Trichoderma* is a genus of asexually reproducing fungi that is present in all types of soils. *Trichoderma* species have been recognized as antagonists of soil-borne and foliage pathogens and as efficient decomposers of cellulosic waste materials. Moreover, they have the ability to increase plant growth and induce plant resistance. Along with mycoparasitism, antibiotics and competition, induced resistance is one of the most important mechanisms of *Trichoderma* action against fungal plant pathogens.

Pareek *et al*. (2012) tested the efficacy of bio-control agents viz. *Trichoderma harzianum, T. viride and Aspergillus niger* against fungal pathogen (*Alternaria alternata*) and reported that the most effective antagonist against fungal pathogen (*A. alternata*) was *T. harzianum.*

Tran (2010) stated that *Trichoderma spp*. are fungi that occur worldwide, they are not only parasites of fungal plant pathogens but also can produce antibiotics. In addition, certain strains can induce systemic and localized resistance to several plant pathogens. Moreover, some strains may enhance plant growth and development. Experiments conducted on several crops such as: peanut, tomato, cucumber and durian indicate that selected *Trichoderma* strains could reduce significant diseases caused by fungal pathogens including: *Phytophthora palmivora, Rhizoctonia solani, Fusarium spp., Sclerotium rolfsii* and *Pythium spp*. The efficacy of Trichoderma species on soil borne fungal disease is higher than fungicides and maintain longer.

Mohamed *et al.* (2010) reported that fungus is a valuable source for the commercial production of enzymes and helpful in recycling cellulosic waste materials while producing useful byproducts. *Trichoderma* received the most attention as fungal antagonists not only of soil-borne pathogens but also of foliage pathogens. This is because of the ability of some of its species to produce enzymes which inhibit other fungi.

Galletti *et al*. (2008) reported that a way of reducing chemical inputs could be to use biocontrol agents (*Trichoderma harzianum*) to replace or supplement fungicide treatments against cercospora leaf spot disease of sugar beet.
Ngo *et al.* (2006) reported that application of *Trichoderma* species can control a large number of foliar and soil borne fungi i.e. *Fusarium spp., R. solani, Pythium spp., S. sclerotium, S. rolfsii,* in vegetables, field, fruit and industrial crops.

Harman *et al*. (2004) said that due to effective control of plant diseases, several commercial biological products based on *Trichoderma* species are manufactured and marketed in Asia, Europe and USA for use on a wide range of crops. These can be efficiently used as conidia, mycelium and chlamydospores which are produced in either solid state or liquid fermentation.

CHAPTER III

MATERIALS AND METHOD

3.1 Experimental Site

Field experiment was conducted in the Central Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207. Laboratory experiment was conducted in the Plant Disease Clinic of Sher-e-Bangla Agricultural University. Disease survey was conducted in eight districts of Bangladesh (Appendix II).

3.2 Experimental Period

The field experiment was conducted in *Rabi* season of 2018 (November 2018 to February 2019) and *Kharif* season of 2019 (20 March to 20 June 2019). Field survey was conducted in *Rabi* season of 2018.

3.3. Soil Characteristics

The experimental plot was a medium high land belonging to the Modhupur tract under the Agro Ecological Zone (AEZ) 28. The soil texture was silty loam, non-calcarious, dark grey soil of Tejgaon soil series with a pH 6.7. The characteristics of soil is given in Appendix III.

3.4. Weather Condition

The experiment was carried out during the period from October, 2018 to June 2019. So the average temperature, precipitation and relative humidity of those months are given below:

Table 1. Average weather conditions in Dhaka, Bangladesh in 2018-19

Season and year	Average Temperature (°C)	Average Precipitation (mm)	Average Humidity (%)
Winter, 2018	20.5	16.67	72
Summer, 2019	30	233.33	84.67

Source: Metrological Department of Bangladesh

3.5 Test Materials

The red amaranth variety used in the experiment was BARI Lalshak-1. This variety is open pollinated and moderately susceptible to white rust disease of red amaranth. Details are given below:

Common name: Lalshak
English name: Red amaranth
Scientific name: *Amaranthus tricolor*
Family name: Amaranthaceae

3.6 Collection of Seed

The seed of red amaranth was collected from BADC office of Gabtoli, Dhaka, Bangladesh (Plate 1).

3.7 Survey Locations

Eight districts from three divisions of Bangladesh was survey in *Rabi* season of 2018 to estimate disease incidence and severity of white rust of red amaranth (Appendix II). Details of survey locations is presented in Table 2.

Table 2. Details of survey locations

Districts	**Villages**	**Number of field**
Manikganj	Chargar para	3
Gazipur	Board bazar	3
Bogura	Ashekpur	3
Nilfamari	Kochukata	3
Panchagarh	Sonahar	3
Kushtia	Sonkorpur	3
Meherpur	Amdoh	3
Chuadanga	Belgachi	3
Total		**24**

3.8 Survey Procedure

Plant Disease Survey Sheet (Appendix I) was used to collect information on symptomology of diseases and to record disease incidence and severity data.

Standard data collection procedure was maintained for collection of data from the survey locations. The surveys were conducted in *rabi* season of 2018 at maturity stage of crop under natural epiphytic condition. Data was collected with three replications. Three fields from each district were surveyed for recording amount of disease. Firstly, an amaranth field was selected. Then the plot was divided into 5 parts. Then one square meter place was selected randomly from each part. Then the total number of plant, number of disease plants, number of infected leaves was counted and recorded. After that, disease incidence and disease severity was calculated by using formulae.

3.9 Identification of Causal Organism

The diseased leaves of red amaranth plants were collected and kept in polythene bags and tagged. The samples were then taken to the laboratory. The collected sample was observed under stereoscopic microscope. The temporary slides were prepared from the diseased samples by picking, scraping and sectioning methods to observe causal organism under compound microscope. The causal pathogens were identified according to reference materials (Plate 10).

3.10 Preparation of Soil

At first the soil of the selected field was ploughed with tractor. Cross ploughing was done for two times to make the soil suitable for seed germination. After that the weed was removed from the field. Then recommended dose of fertilizer was applied as total amount of TSP, MOP, Gypsum and half of urea was applied during final land preparation. Rest amount of fertilizer was applied in 3 split during cultivation.

3.11 Fertilizer Dose

Chemical fertilizers Urea, TSP, MOP, Gypsum were used in the experimental field. Moreover, organic fertilizer - cowdung also used in field to improve soil health condition.

Table 4. Fertilizer used in the experimental plot

Fertilizer name	Applied dose ($Kg/200m^2$)	Recommended dose* (Kg/ha.)
Urea	2	55-60
TSP	1	12-15
MOP	1.2	12-18
Gypsum	.250	5-6
Cowdung	60	5000

* Fertilizer Recommendation Guide (2015)

3.12 Seed Sowing

After three days of land preparation, seeds were sown in the field. Before seed sowing field was divided into three blocks. Each block consists of nine plots. Then the plot was selected randomly for different treatments**.** Seeds were sown in line. Every plot consists of seven lines. Line to line distance was 7 cm.

3.13 Treatments

The following five chemical fungicides including Bordeaux mixture, two botanicals or plant extracts and one bio-fungicide or bio-agent were evaluated against white rust disease of red amaranth.

Table 3. Details of the treatments used for management of white rust disease of red amaranth

Sl. No.	Trade Name/ Name	Common Name / Active Ingredient	Rate of Application (%)
1.	Ridomil Gold 68 WG	Mencozeb+ Metalaxyl	0.2
2.	Autostin 50 WP	Carbendazim	0.2
3.	Dithane M 45	Mancozeb	0.2
4.	Goldton 50WP	Copper oxychloride	0.2
5.	Bordeaux Mixture	Copper	1
6.	G-derma	Bio agent (*Trichoderma* sp.)	2
7.	Garlic bulb extract	*Allium sativum*; Botanicals	3
8.	Alamanda leaf extract	*Allamanda cathartica* Botanicals/ plant extract	3

3.13.1 Collection of Treatments

Chemical fungicides Goldton 50WP, Autostin 50WP, Ridomil Gold 68WG, Diathane M-45 were collected from the Central Farm of SAU. G-demra was collected from the GME Agrochemicals office, Dhaka. For Bordeaux mixture, CaO and $CuSO_4$ were collected from the Krishi Market, Mohammadpur, Dhaka. For botanicals, Garlic bulb was collected from Agargaon bazar and the Allamanda leaves were collected from the SAU campus.

3.13.2 Preparation of Fungicidal Suspension /Solution

Suspensions were prepared at recommended doses by mixing thoroughly of requisite quantity of fungicide with normal clean water. For example, 4 gram Dithane M-45 was mixed in two-liter water to prepare 0.2% doses. The remaining fungicides also prepared as same procedure (Plate 2(a).

3.13.3 Preparation of Bordeaux Mixture

Copper sulphate, lime and water were mixed in the ratio of 1:1:100 to prepare one per cent Bordeaux mixture. In order to prepare 2 liter of Bordeaux mixture, 20g copper sulphate ($CuSO_4$) was dissolved in 1 L water in a plastic bucket. In another plastic bucket, 20g fresh quick lime powder (CaO) was mixed with another 1 L water. Then the copper sulphate ($CuSO_{4)}$ solution was poured into lime (CaO) solution and stirring the mixture. The prepared Bordeaux mixture was sieved through a cloth before spraying. Bordeaux mixture suspension was sprayed at the same day of preparation.

3.13.4 Preparation of Plant Extract/ Botanicals

The extracts were prepared by following the method of Ashrafuzzaman and Hossain (1992). For preparation of extracts, collected leaves and bulbs were weighted in an electric balance and then washed in the water. After washing the big leaves were cut into small pieces. For getting extract, weighted plant parts were blended in an electric blender and then distilled water was added into the jug of the blender. The pulverized mass was squeezed through 3 folds of fine cotton cloth. For getting 1:1 (w/v) ratio 100 ml of distilled water was added with 100 g plant parts. Botanical solutions were also prepared in the day of spraying (Plate 2.b).

3.13.5 Preparation of Bio-agent Suspension

Commercial formulation of *Trichoderma* (G-derma) was collected from GME Agrochemicals Ltd. for this experiment. Two ml G-derma solution was mixed with one-liter water to prepare 2% solution as per recommendation. The bio-agent suspension was prepared just before spraying.

3.14 Intercultural Operations

After emergence of seedling the field was kept with require amount of moisture for the easy growing of seedlings. After 10 days of germination thinning operation was done to maintaining minimum plant to plant distance. Then weeding and irrigation was done at a regular interval to keep the field free from unwanted plants and weeds. The remaining dose of urea fertilizer was applied in three splits. First split after 20 days of sowing, second split after 35 days and final dose was applied at 50 days after sowing.

3.15 Field Observation

The experiment was conducted under natural epiphytic condition. Scouting and monitoring was done regularly to find out the disease symptom on the leaf of plants. The first disease incidence was observed 30 days after sowing.

3.16 Spray Schedule

For controlling white rust disease, above mentioned plant extract, bio-agent and chemicals were applied for four times at 7days interval after disease appearance. In *rabi* season of 2018, spray was done on 07 December at 33 days after sowing (DAS) (1st spray), 14 December at 40 DAS (2nd spray), 21 December at 47 DAS (3rd spray) and on 28 December at 54 DAS (4th spray). In *kharif* season of 2019, spray was done on 18 April at 29 DAS (1st spray), 26 April at 36 DAS (2nd spray), 3rd May at 43 DAS (3rd spray) and on 9 May at 50 DAS (4th spray) (Plate 3).

3.17 Data Recording on Diseases

Five plants from each plot were tagged randomly for data collection. In *rabi* season of 2018, disease incidence and severity data were recorded on 07 December at 33 DAS (before spray), 14 December at 40 DAS (7 days after 1st

spray), 21 December at 47 DAS (7 days after 2nd spray), 28 December at 54 DAS (7 days after 3rd spray) and 4 January 2019 at 61 DAS (7 days after 4th spray). In *kharif*-1 season of 2019, disease incidence and severity data were recorded on 18 April at 29 DAS (before spray), 26 April at 36 DAS (7 days after 1st spray), 3rd May at 43 DAS (7 days after 2nd spray), 10 May at 50 DAS (7 days after 3rd spray) and 16 May at 57 DAS (7 days after 4th spray) (Plate 3).

Data on white rust disease was collected on the following parameters:

1. % Disease Incidence (Plants)
2. % Disease Incidence (Leaves)
3. % Disease Severity
4. % Disease Incidence Reduction over Control
5. % Disease Severity Reduction over Control.

3.18 Measurement of Diseases

Amount of disease of white rust of red amaranth was recorded in terms of % disease incidence and % disease severity. After the appearance of disease symptom disease incidence, disease severity, number of spot per leaf, no of infected leaf per plant were collected in a regular interval of seven days.

3.18.1 Measurement of Disease Incidence

Disease incidence was calculated in the number of proportion of the plant units diseased in relation to the total number of units examined. Plant units mean the leaves, stems etc. that show any symptoms. Disease incidence data was calculated by following formulae (Nutter *et al*., 2006; Agrios, 2005; Kranz, 1988):

$$\text{Plant incidence (\%)} = \frac{\text{Numbers of infected plants}}{\text{Numbers of inspected plants}} \times 100$$

$$\text{Leaf incidence (\%)} = \frac{\text{Numbers of infected leaves}}{\text{Numbers of inspected leaves}} \times 100$$

Reduction of disease incidence over control was calculated by using the following formula (Abbott, 1925):

$$\text{Disease Incidence Reduction over Control (\%)} = \frac{C - T}{C} \times 100$$

Where,

C = Percent disease incidence on control plot

T = Percent disease incidence on treatment plot

3.18.2 Measurement of Disease Severity

Disease severity was calculated in the proportion of amount of plant tissues infected in relation to the total amount of tissue examined. Disease severity data was calculated by following formula (Nutter *et al*., 2006; Agrios, 2005; Kranz, 1988):

$$\text{\% Disease severity} = \frac{\text{Area of leaf tissues infected}}{\text{Area of leaf tissues inspected}} \times 100$$

Reduction of disease severity over control was calculated with the following formula (Abbott, 1925):

$$\text{Disease Severity Reduction over Control (\%)} = \frac{C - T}{C} \times 100$$

Where,

C = Percent disease severity on control plot

T = Percent disease severity on treatment plot

3.18.4 Seed yield increase over control

Seed yield increase over control was calculated by using the following formula (Abbott, 1925):

$$\text{Seed yield increase over control (\%)} = \frac{T - C}{C} \times 100$$

Where,

T = Yield of respective treatment plot (g/m^2)

C = Yield of control plot (g/m^2)

3.19 Data Recording on Plant Growth and Yield

The agronomic data on plant growth and yield were recorded to see the effect of disease on seed yield and yield contribution parameters of crop. Data were collected from five tagged plants of each plot after harvesting. The following parameters were considered for data collection:

1. Plant height (cm)
2. Shoot length (cm)
3. Root length (cm)
4. Number of inflorescence
5. Plant fresh weight (g)
6. Shoot fresh weight (g)
7. Root fresh weight (g)
8. Seed yield per plot (g)
9. Seed yield per meter square area (g)
10. Seed yield increase over control (%)

3.19.1 Measurement of Shoot and Root Length

The fresh plant sample was collected from the field (5 plants/plot randomly) in the morning. Then soil was removed from plant roots by running tap water. Then the plants were divided into shoot and root portion and measured shoot and root length by measuring tape. The summation of root and shoot indicates the length of full plant. Data were recorded in centimeter (cm).

3.19.2 Measurement of Fresh Shoot and Root Weight

For measuring fresh shoot and root weight, plants were collected and washed as before. Then it cut into two piece (shoot and root) and then weighted by digital balance. The sum of shoot weight and root weight is the total fresh weight of plant. Weight of plant was measured in gram (g).

3.19.3 Measurement of Number of Leaves and Inflorescence

From the harvested fresh plant samples, the shoots were separated and then the number of remaining leaves was counted. After that, the number of axial inflorescence with its apical inflorescence was counted.

3.20 Experimental Design

Randomized Complete Block Design (RCBD) was followed in the experiment. Thus the field was divided into 3 blocks. There were 9 different treatments with control in each block. The experiment was conducted with three replications. Treatments were distributed in each block randomly. Tagging was done each plot accordingly. The plot size was 3 m^2 (2 m × 1.5 m). Block to block distance was 75 cm and plot to plot distance was 50 cm. The name plate with detail information of experiment was put in the experimental field (Plate 4). The layout of experiment is given in Appendix IV.

3.21 Statistical Analysis

The collected data was statistically analyzed by Statistics 10 computer package program. Analysis of variance (ANOVA) was used to find out the variation of result from experimental treatments. Treatment means were compared by Least Significant Difference (LSD) Test.

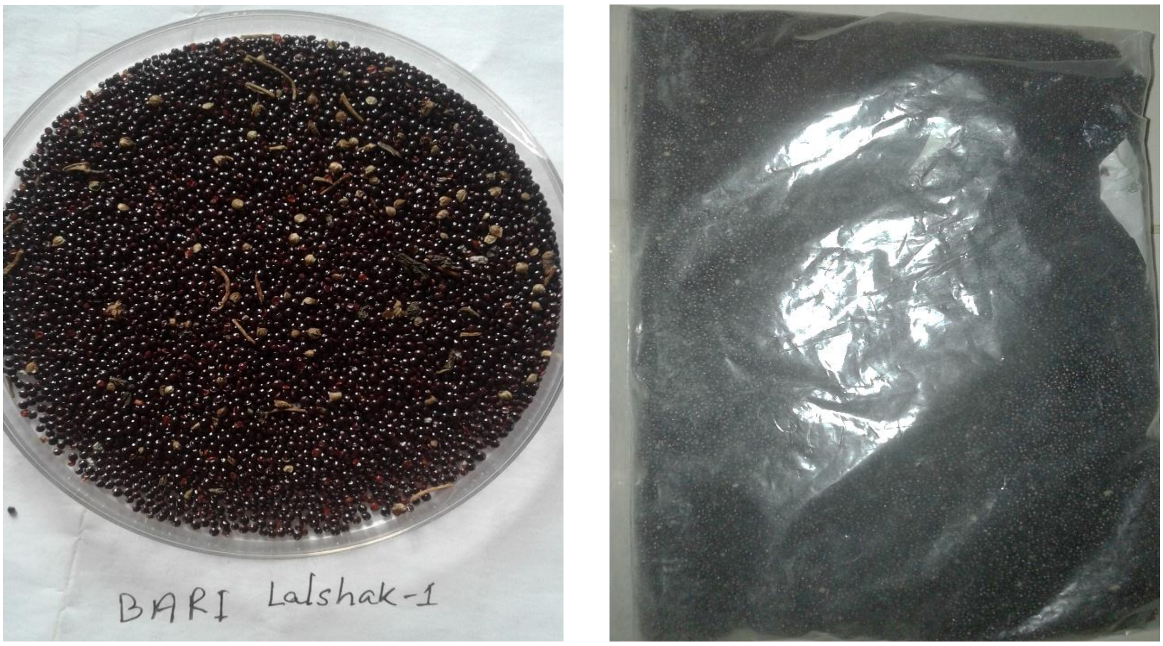

Plate1: Seeds of red amaranth (BARI Lalshak-1**)**

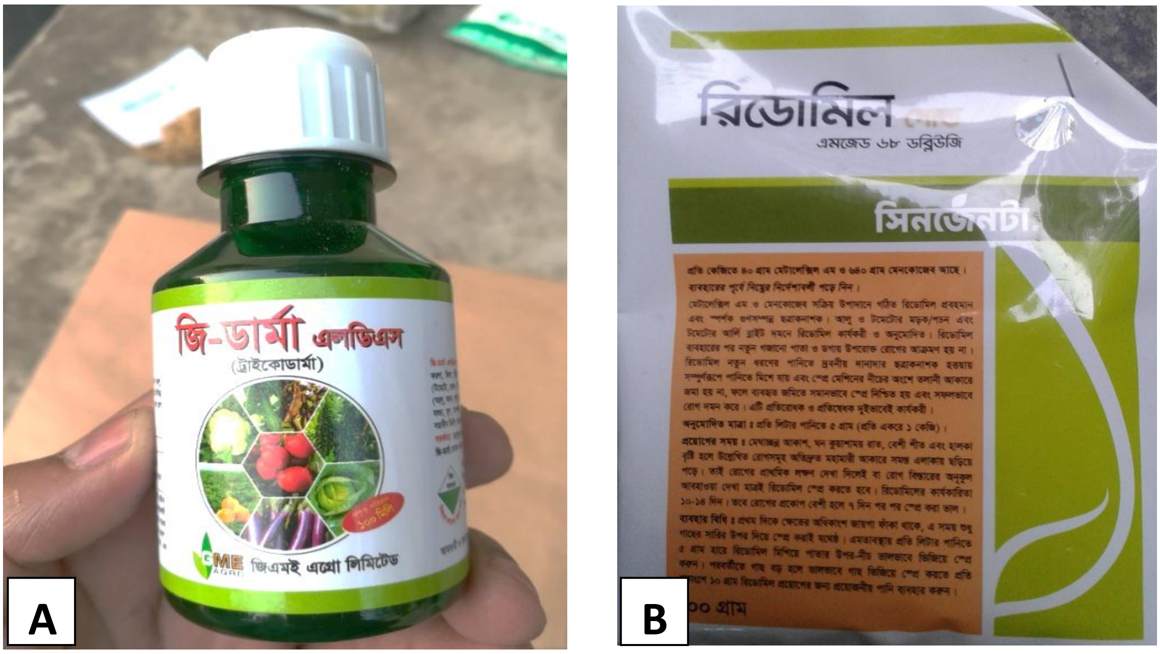

Plate 2(a). Used treatments in the experiment.

A. G-derma **(**Bio pesticide)

B. Ridomil Gold 68 WG (Chemical fungicide)

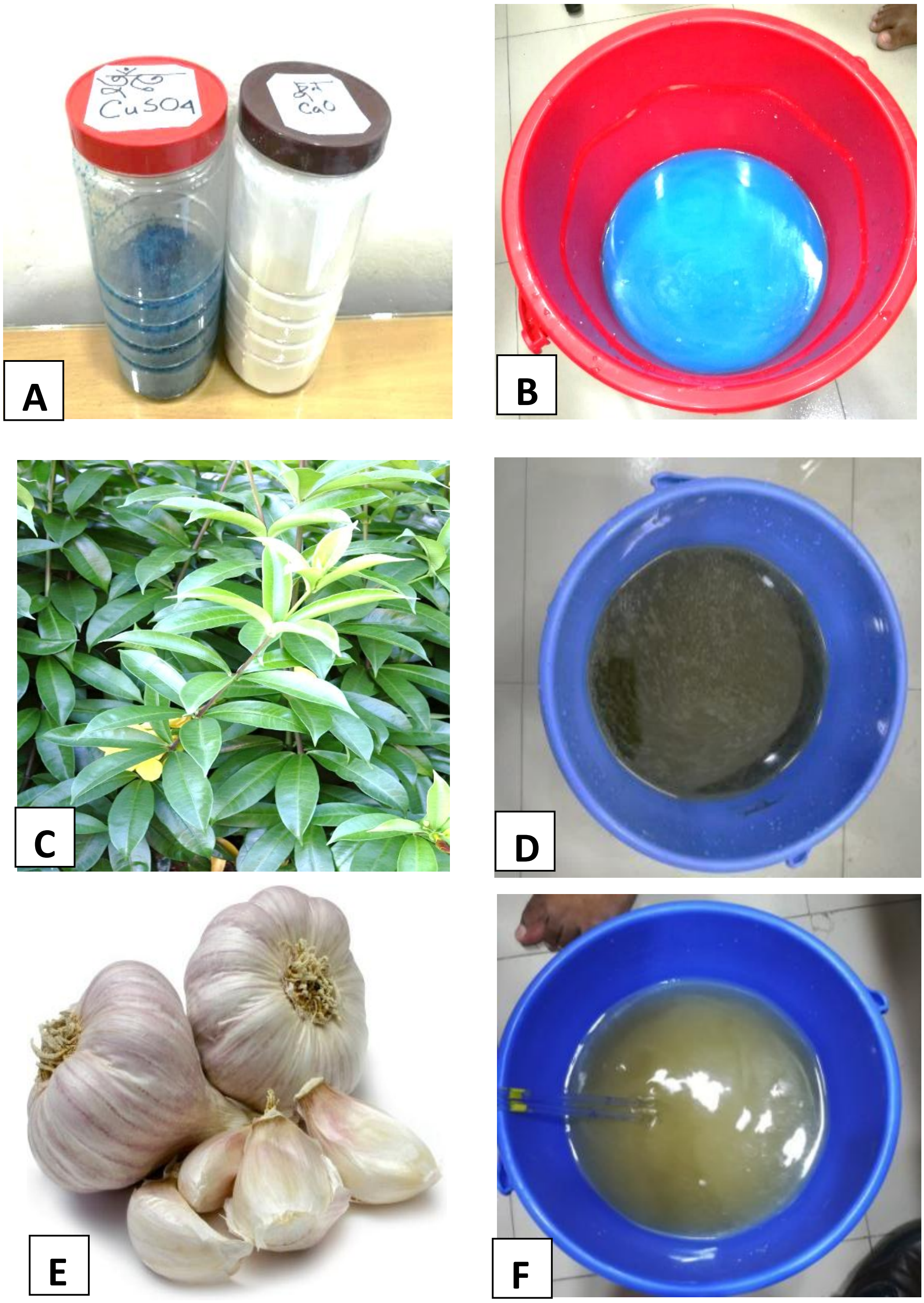

Plate 2(b). Used treatments in the experiment. A. Powder Lime (CaO)**; B.** Bordeaux solution**; C.** Allamanda (*Allamanda cathertica*) leaf**; D.** Allamanda leaf extract solution**; E.** Garlic (*Allium sativum*) clove**; F.** Garlic bulb extract solution**.**

Plate 3. Research activities in the field.

A. Spraying of treatments in the plot

B&C. Data collection on disease incidence and severity in field

Plate 4. Field view of experimental plot. **A.** In *rabi* season of 2018, **B.** In *kharif* season of 2019.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Symptoms of White Rust Disease of Red Amaranth

During the survey in different districts, a typical white rust symptom was observed on the leaf surface of red amaranth in the infected fields. The characteristics white rust symptoms also observed in the experimental field of SAU under natural epiphytic conditions (Plate 6).

Symptoms of white rust disease are characterized by round to oval shape small pustules (blister like appearance) on lower surface of leaves. Each pustule was about 1-3 mm in diameter. Powdery whitish outgrowth was present on pustules (plate 5). In advances of disease, several pustules coalesced together and made irregular shape large pustules. Blister like growth (pustules) of fungi commonly observed on underside of leaves. Initially lower leaves of plant were affected by the disease but in course of time the disease was progress towards younger leaves, buds and inflorescence.

Initially pin pointed whitish area observed on lower leaf surface. The area increased into circular pustule with tan to light brown powdery tissue. As, these pustules enlarge, center of the lesion became to brown color. Average diameter of the pustules was 1-3 mm and the size of the necrotic areas increased by coalescing several pustules (Plate 7). The pustules on infected leaves may produce more spore masses on older lesions under high humid condition. In advances of disease the infection progress towards petiole. In severe infection, several spots coalesced together and leaves become necrotic. The affected area lost the photosynthetic ability due to chlorosis that leads to death of infected leaves. The severely infected leaves become dry off and drop out from the plant. White rust, sometimes called white blister, is easily recognized by the chalk-white, cheesy, raised sporemasses (sori) which occur mostly on the under leaf surfaces. Symptoms of localized infections are white ‘blisters’, which in the early stages are seen on the underside of leaves. These blister-like masses cannot be scraped off without damaging the leaf. As infection progress, discoloration appear on the upper leaf surface, corresponding to white blisters on the underside of the leaves (Plate 8). The blisters contain white powdery spores which are spread by wind when released. Symptoms develop 6 to 21 days after infection of pathogen and severely infected plants become die (plate 9).

The disease is characterized by both local and systemic symptom expression. Local infection appears as white or creamy yellow pustules or “blisters” on leaves and stems. Systemic infection results in abnormal growth and distortion of inflorescence and sterility of flowers. The first and often overlooked symptom of white rust is the appearance of small, irregular yellow areas (chlorotic lesions) on the upper leaf surface which range in size from minute dots to one-half inch or more in diameter. Within one to three days of infection, the lesions become visible on the lower leaf surface. The white, raised sori, often arranged concentrically. The blister like sori, which are variable in size and shape, form beneath the host epidermis in the chlorotic lesions. One or more sori may appear in each lesion. Anthocyanin may be produced around the sori resulting in reddish violet blotches that are most prominent on the upper leaf surface. The domelike surface over the white rust pustules ruptures the host epidermis to expose the dusty masses of spores (sporangia) in small, circular to elongate cavities. Host leaf tissues beneath the sori die after spore dispersal, becoming reddish brown to brown (necrotic), and may be difficult to distinguish from other diseases (Babadoost, 1990).

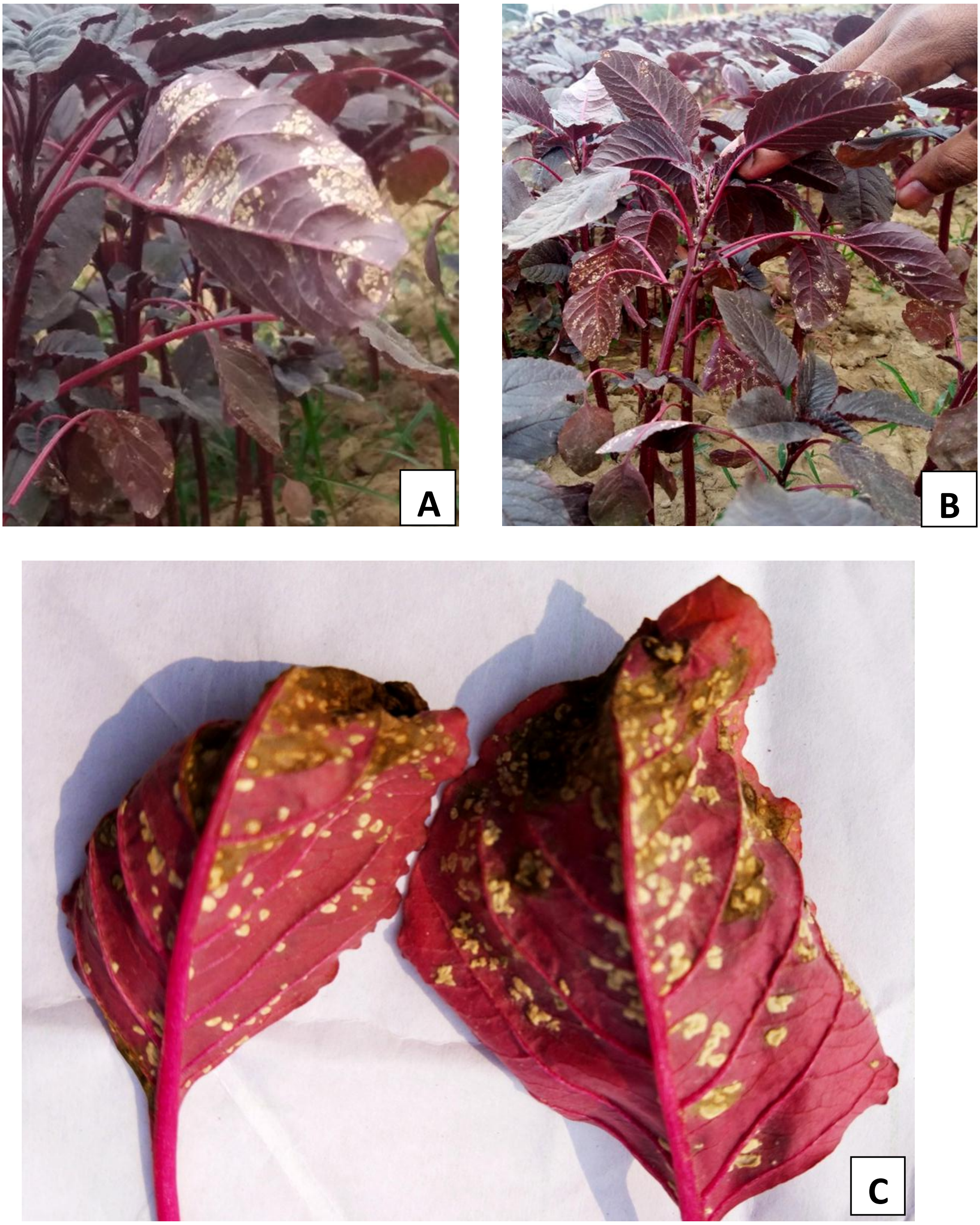

Plate 5. Symptom of white rust disease on leaves of red amaranth. **(A&B).** Sympoms showing in standing plants; **C**. Blister like pustules appear on lower surface of leaves.

Plate 6. Typical symptoms of white rust disease on lower site of leaves: **A**. Disease symptom in whole leaf (Normal view); **B&C**. Powdery asexual spore (sporangia) on pustules of white rust disease (Macro view).

Plate 7. Macro view of different shape pustules of white rust disease on leaf surface of red amaranth

Plate 8. Symptoms showing on both sides of infected leaves (Left: upper surface; Right: lower surface of leaf)

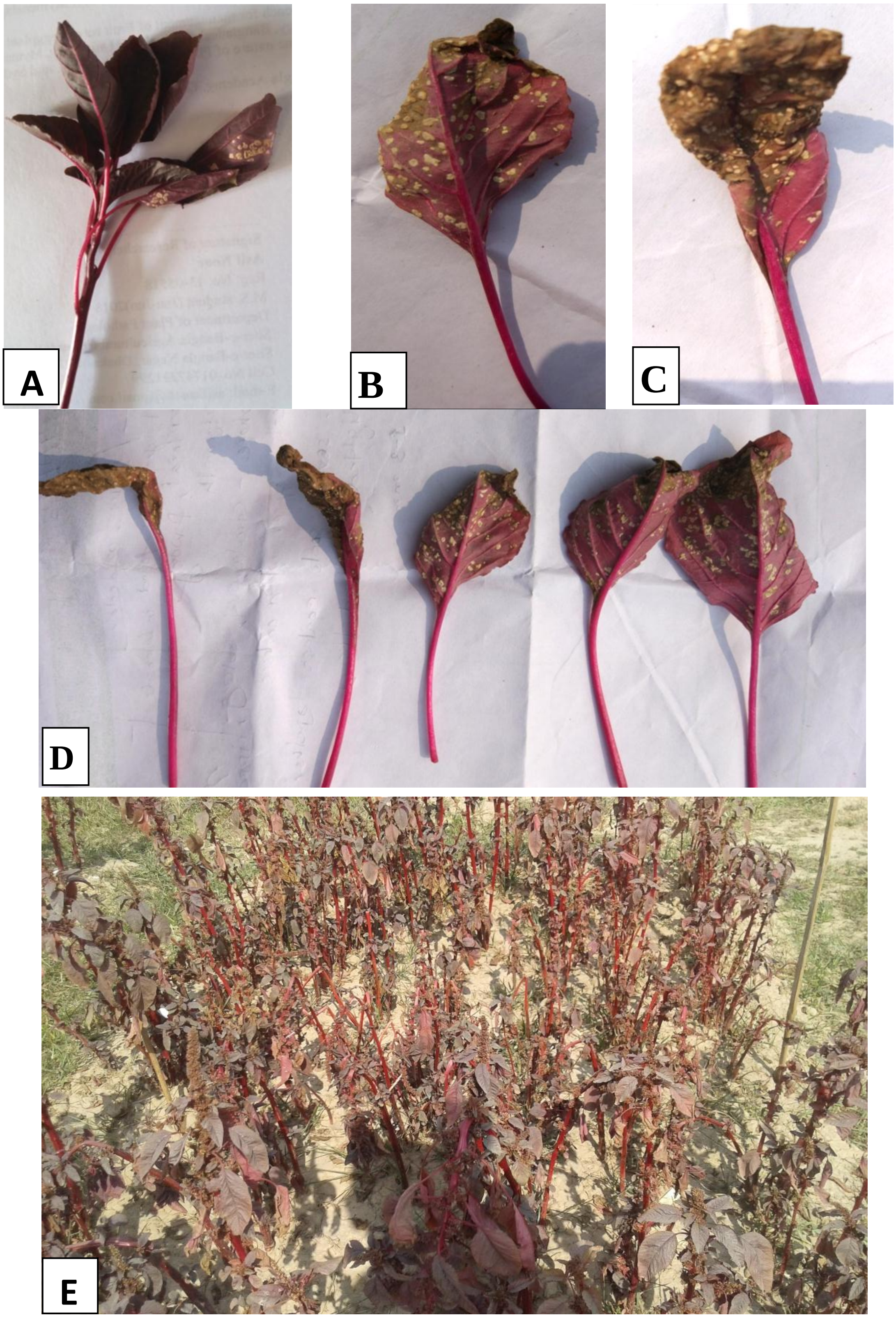

Plate 9. Progress of white rust disease of red amaranth; **A.** Disease start from the older leaves of plant; **B.** Necrosis start from apex of leaf; **C.** Necrosis of leaf due to white rust disease under severe infection; **D**. Symptom showing advanced of disease on leaves (from right to left), **E.** Seriously infected plot showing less leaves due to defoliation of infected lower leaves.

4.2 Causal Organism of White Rust Disease of Red Amaranth

Albugo candida was identified as the causal organism of the white rust of red amaranth by microscopic study. Thousands of sporangia and chain of sporangium of *Albugo candida* were observed under compound microscope. The sporangia are hyaline and globose to spherical shape. *Albugo candida* is obligate parasites that can develop only in living host tissues. The fungi reproduce by asexual spores (sporangia) and thick-walled sexual spores (oospores). *Albugo candida* is a fungus-like organism that present under the Domain: Eukaryota; Kingdom: Chromista; Phylum: Oomycota; Class: Oomycetes; Order: Peronosporales and Family: Albuginaceae.

The mycelium of *Albugo candida* is endophytic, branched, hyline and having knob shaped haustoria. It is intercellular in host tissues and very small spherical haustoria present in each host cell which serve to supply the white rust fungus with nourishment. Sporangiophores are sub epidermal, clavate and simple those bears sporangial chain at the apex. Sporangiophore produce sporangial chain in besipetally, that means youngest sporangia present at the base of conidial chain. As the sporangia mature, they become detached from the disjunctor and are free in the space between the sporangiophore and the epidermis of host. Upon the bursting of the epidermis, the sporangia are released and form a white crust on the surface of the host. Individually the sporangia are normally globose but pressure during their formation results in flattened sides so that some of them are cuboids or polyhedral. Pustules develop on the lower surface of the leaf due to the deposition of the sporangium and sporangiophore which is creamy white in colour.

The oospores and perennial mycelium in host tissues enable *Albugo candida* to overseason in a few, systemically infected, living crop and weed hosts. A few infected plants may serve as a source of inoculum for one or more fields. In systemically infected plants, white rust fungus invades the shoot and produces pustules. The colorless, nearly spherical to rectangular sporangia are borne on short, club-shaped stalks (sporangiophores), each of which produces a chain of spores. As sporangia are produced they become tightly packed and eventually rupture the host epidermis.

The powdery sporangia are disseminated by air currents, splashing rain, farm implements, workers, and insects. With cool temperatures and free water on the host tissue, each sporangium can germinate directly by producing a germ tube or, more commonly, by forming 4 to 18 motile zoospores. The zoospores soon come to rest, become spherical, form a cell wall, lose their flagella, and produce a germ tube. The germ tubes grow and penetrate leaf or other host tissue through stomata. Cool dewy nights and slightly warmer days are ideal for disease development. Free water in the form of light drizzly rains, heavy dews, and fogs are necessary for germination by sporangia and zoospores. Heavy rains and irrigation, however, tend to wash the sporangia off the foliage. When the conditions become unfavorable or during the later phase of the growing season, the fungus begins sexual reproduction producing oospores, which are thick-walled, and can withstand the unfavorable conditions.

The first external symptoms of white rust appear 5 to 20 days after infection depending on the temperature. Within 3 to 14 days a new crop of sporangia is released, starting a secondary cycle. A number of secondary cycles may occur during a growing season. Under ideal conditions (cool and moist), a complete cycle may be completed every 8 to 10 days. Hot, dry weather checks the disease. The sporangia require some drying before they can germinate. Most spores exposed to sunshine for a few hours are viable. In dry and cool weather, sporangia may remain alive for as long as two weeks (Babadoost, 1990).

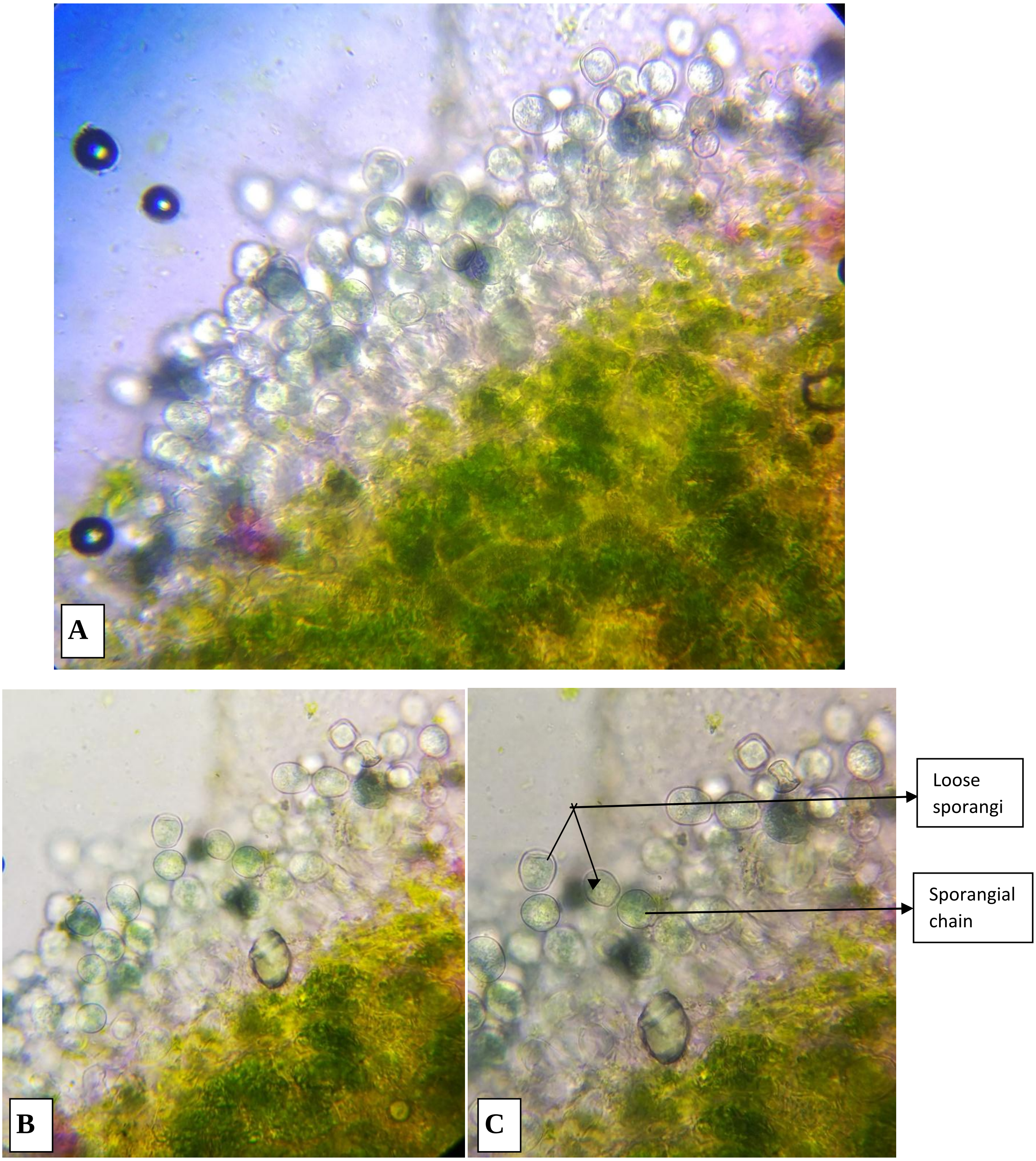

Plate 10. Section of infected host tissue of red amaranth showing *Albugo candida* (40X); A. Production of sporangia on sporangiophore of *Albugo candida* from host tissue; B. Cross section of sorus showing chain of sporangia borne on short stalks (sporangiophores); C. Close-up view of sporangiophores with sporangial chain and loose sporangia

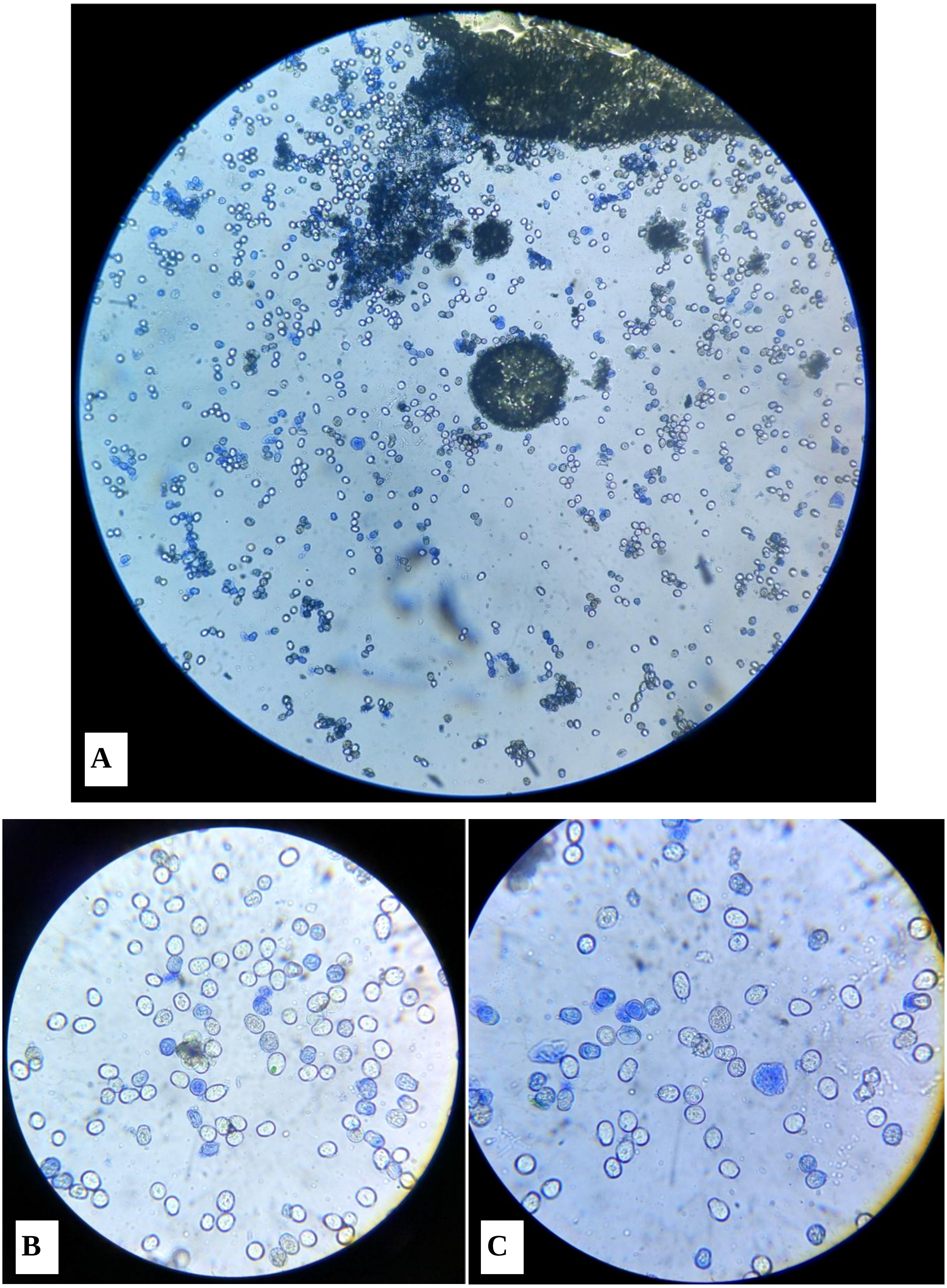

Plate 11. Sporangia (asexual spore) of *Albugo candida* observed under compound microscope (A. 10X; B&C. 40X)

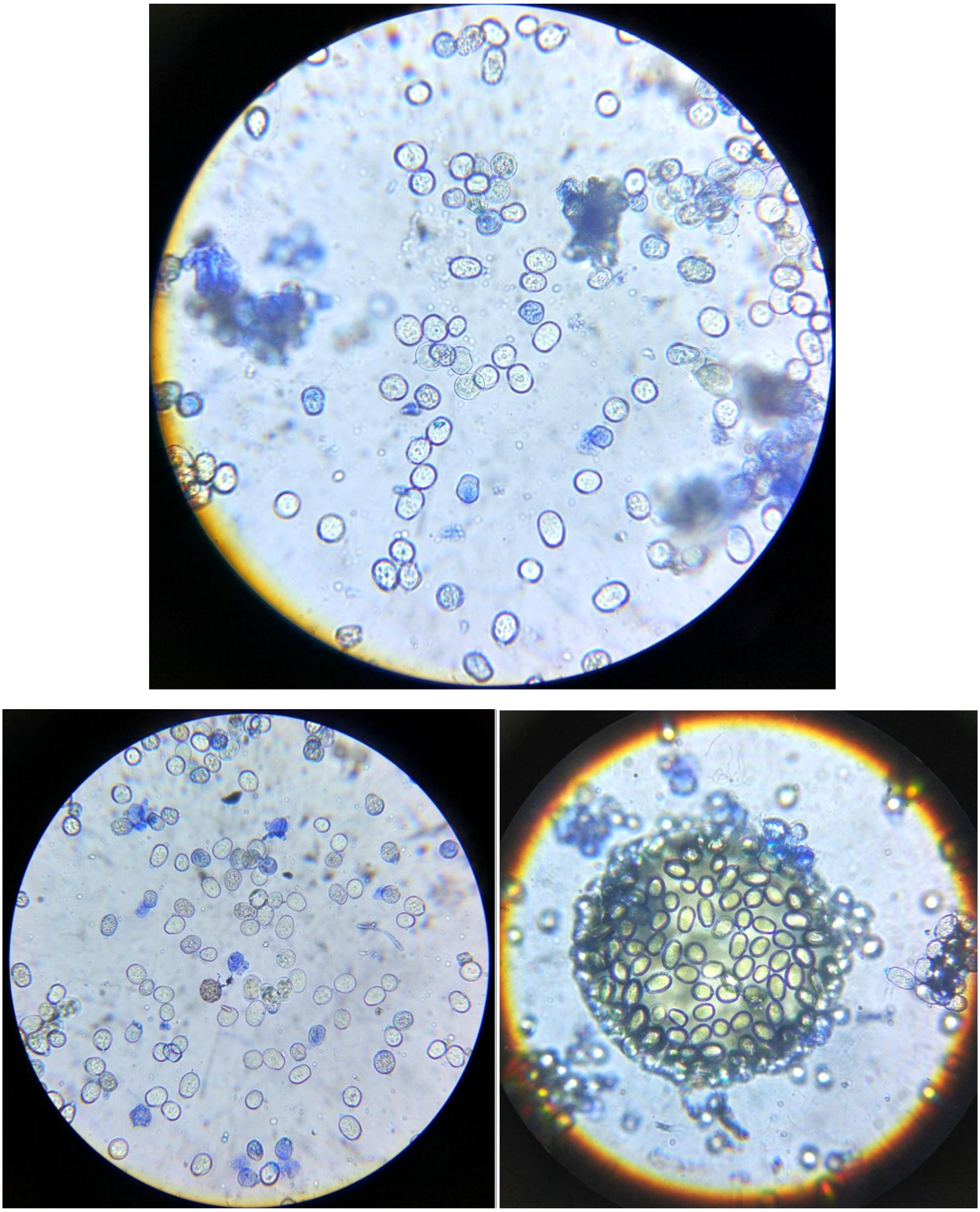

Plate 12. Globose to spherical shape asexual spore (sporangia) of *Albugo candida* under compound microscope (40X)

4.3 Survey on diseases of white rust of red amaranth in maturity stage in different districts of Bangladesh

Survey was conducted at maturity stage of crop and white rust disease of red amaranth was observed in all investigated locations. Incidence and severity of red amaranth infected plant varied significantly among the locations (Table 5). Percent plant incidence varied from 47% to 66.67% where percent leaf incidence varied from 36.67% to 58.33%. However, disease severity varied from 12% to 18% among the locations.

The highest plant disease incidence was recorded in Kochukata village (66.67%) of Nilfamari and the lowest disease incidence was found in Sonkorpur village (47.0%) of Kushtia. Similarly, the highest leaf incidence was recorded in Kochukata village (58.33%) of Nilfamari and the lowest disease incidence was found in Sonkorpur village (28.33%) of Kushtia district. In case of disease severity, similar trends were observed where the lowest disease severity was observed in Sonkorpur (12%) of Kushtia but the highest severity was observed in Chargerpara (18%) village of Manikgonj district. Disease incidence and severity were comparatively higher in surveyed locations because the survey was conducted at maturity stage of crop.

Table 5. Incidence and severity of white rust disease of red amaranth in maturity stage in different districts of Bangladesh in 2018

Districts	Villages	Disease Incidence (%)		Disease Severity (%)
		Plant Incidence (%)	Leaf Incidence (%)	
Manikganj	Chargarpara	63.33 ab	45.00 b	18.00 a
Gazipur	Board Bazar	56.67 a-c	45.00 b	15.33 a-c
Bogura	Ashekpur	61.67 ab	48.33 b	15.67 a-c
Nilfamari	Kochukata	66.67 a	58.33 a	14.00 bc
Panchagarh	Sonahar	53.33 bc	42.33 bc	17.00 ab
Kushtia	Sonkorpur	47.00 c	28.33 d	12.00 c
Meherpur	Amdoh	48.33 c	36.67 c	12.33 c
Chuadanga	Belgachi	59.00 a-c	46.66 b	14.67 a-c
LSD (0.05)		13.04	8.29	3.81
CV (%)		13.06	10.81	14.64

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4 Management of white rust disease of red amaranth by selected treatments in *Rabi* season of 2018

4.4.1 Incidence and severity of white rust disease of red amaranth before treatments spray in 2018

The experiment was conducted in *rabi* season in the Central Farm of SAU under natural epiphytic conditions. Before spraying, plant incidence (%), leaf incidence (%) and disease severity (%) were measured under each treatment plot. In *rabi* season of 2018, disease incidence and severity data were recorded before treatment spry on 07 December at 33 days after sowing (DAS). The plant incidence, leaf incidence and disease severity were varied from 7% to 10%, 6.33% to 10% and 0.05% to 0.12%, respectively (Table 6).

Table 6. Disease incidence and severity of white rust of red amaranth before spray in *rabi* season of 2018

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	8.33 ab	10.00 a	0.11 a
T_2 (Autostin 50WP)	8.33 ab	6.33 b	0.09 a
T_3 (Dithane M 45)	10.00 a	6.67 b	0.10 a
T_4 (Goldton 50WP)	8.33 ab	6.33 b	0.10 a
T_5 (Bordeaux Mixture)	8.67 ab	8.33 ab	0.11 a
T_6 (G-derma)	7.00 b	7.00 b	0.09 a
T_7 (Garlic bulb extract)	7.67 ab	7.00 b	0.05 b
T_8 (Allamanda leaf extract)	8.67 ab	8.33 ab	0.12 a
T_9 (Control)	10.00 a	10.00 a	0.10 a
LSD (0.05)	2.70	2.63	0.03
CV (%)	18.27	19.58	19.81

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4.2 Incidence and severity of white rust disease of red amaranth after 7 days of 1st foliar spray in 2018

Effect of treatments against white rust disease of red amaranth after seven days of first spray at 40 DAS is presented in Table 6. The efficacy of the treatments was assessed based on different parameters like diseased plant incidence, diseased leaf incidence and disease severity. In seven days after 1st spray, the effect of different treatments in terms of diseased incidence (plant) and severity were differed significantly from 13.0% to 24.0% and 0.93% to 1.83%, respectively. However, leaf incidence was not varied significantly among the treatments. Among the treatments, Ridomil Gold and Dithane M-45 showed better effect than the other treatments.

Table 7. Disease incidence and severity of white rust of red amaranth after 7 days of 1st spray in *rabi* season of 2018

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	13.00 c	13.33 b	0.93 d
T_2 (Autostin 50WP)	16.67 bc	15.67 b	1.16 cd
T_3 (Dithane M 45)	18.67 b	14.6 b	1.50 a-c
T_4 (Goldton 50WP)	16.00 bc	13.33 b	1.67 ab
T_5 (Bordeaux Mixture)	20.00 ab	16.00 b	1.33 b-d
T_6 (G-derma)	18.67 b	17.33 b	1.33 b-d
T_7 (Garlic bulb extract)	19.00 ab	15.67 b	1.16 cd
T_8 (Allamanda leaf extract)	17.00 bc	14.33 b	1.00 d
T_9 (Control)	24.00 a	25.67 a	1.83 a
LSD (0.05)	5.11	6.17	0.48
CV (%)	16.32	22.00	21.23

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4.3 Incidence and severity of white rust disease of red amaranth after 7 days of 2nd foliar spray in 2018

The effect of treatments differed significantly for disease incidence and severity after seven days of 2nd foliar spry at 47 DAS (Table 8). Plant disease incidence was varied significantly to different treatments from 19% to 35%, where the lowest plant incidence was recorded in Ridomil Gold (19%). Leaf disease incidence was varied significantly among the treatments from 20.0% to 40.0%, where the lowest leaf incidence was recorded in Ridomil Gold (20%). Similarly, disease severity was ranged from 1.4% to 4.0% and the lowest severity was also observed in Ridomil Gold (1.4%) that was statistically similar with allamanda leaf extract (1.6%). The highest incidence and severity was recorded in control plot.

Table 8. Disease incidence and severity of white rust of red amaranth after 7 days of 2nd spray in *rabi* season of 2018

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	19.00 c	20.00 c	1.40 d
T_2 (Autostin 50WP)	25.67 b	29.00 b	2.33 c
T_3 (Dithane M 45)	29.00 ab	24.33 bc	3.00 b
T_4 (Goldton 50WP)	26.67 b	24.33 bc	2.80 bc
T_5 (Bordeaux Mixture)	30.00 ab	26.67 bc	2.50 bc
T_6 (G-derma)	29.33 ab	26.00 bc	2.50 bc
T_7 (Garlic bulb extract)	29.00 ab	25.00 bc	2.67 bc
T_8 (Allamanda leaf extract)	24.67 bc	23.00 bc	1.60 d
T_9 (Control)	35.00 a	40.00 a	4.00 a
LSD (0.05)	6.35	8.27	0.65
CV (%)	13.30	18.05	14.99

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4.4 Incidence and severity of white rust disease of red amaranth after 7 days of 3rd foliar spray in 2018

The effect of different treatments differed significantly in controlling the disease after seven days of 3rd foliar spray at 54 DAS (Table 9). Plant disease incidence was varied significantly to different treatments from 26% to 48.33%, where the lowest disease incidence was recorded in Ridomil Gold (26%). Similarly, diseased leaf incidence was varied significantly from 22.33% to 51%, where the lowest leaf incidence was recorded in Ridomil Gold (22.33%). Percent disease severity was ranged from 1.76% to 6.16% in different treatment and the lowest severity was observed in Ridomil Gold (1.76%) that was statistically similar to Allamanda leaf extract followed by Autostin. However, the highest incidence and severity was recorded in control plot.

Table 9. Disease incidence and severity of white rust of red amaranth after 7 days of 3rd spray in *rabi* season of 2018

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	26.00 d	22.33 d	1.76 d
T_2 (Autostin 50WP)	35.33 bc	35.00 bc	3.33 c
T_3 (Dithane M 45)	38.33 b	32.33 bc	4.33 b
T_4 (Goldton 50WP)	37.33 bc	32.67 bc	4.16 bc
T_5 (Bordeaux Mixture)	41.67 ab	36.00 b	3.50 bc
T_6 (G-derma)	40.00 b	32.67 bc	3.60 bc
T_7 (Garlic bulb extract)	40.00 b	32.67 bc	4.00 bc
T_8 (Allamanda leaf extract)	31.33 cd	27.67 cd	2.16 d
T_9 (Control)	48.33 a	51.00 a	6.16 a
LSD (0.05)	6.79	7.40	0.92
CV (%)	10.44	12.73	14.55

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4.5 Incidence and severity of white rust disease of red amaranth after 7 days of 4th foliar spray in 2018

The effect of different treatments differed significantly among them for disease incidence and severity after seven days of 4th foliar spray at 61 DAS (Table 10). Disease plant incidence was varied significantly to different treatments from 24% to 65%. The lowest diseased plant incidence was recorded in Ridomil Gold (24%) where the highest plant incidence was observed in untreated control plot (65%). Similarly, diseased leaf incidence was also varied significantly to different treatments from 22.33% to 60%, where the lowest leaf incidence was recorded in Ridomil Gold (22.33%) that was statistically similar to Allamanda leaf extract (28.33%). The highest disease leaf incidence was recorded in control plot (60%). Moreover, disease severity was ranged from 1.83% to 11.67% and the lowest severity was observed in Ridomil Gold (1.83%) treated plot that was statistically similar to Allamanda leaf extract (2.43%) followed by Bordeaux Mixture. The highest disease severity was recorded in control plot (11.67%).

Table 10. Disease incidence and severity of white rust of red amaranth after 7 days of 4th spray in *rabi* season of 2018

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	24.00 c	22.33 c	1.83 d
T_2 (Autostin 50WP)	40.00 b	36.67 b	4.50 c
T_3 (Dithane M 45)	42.00 b	38.33 b	5.50 bc
T_4 (Goldton 50WP)	42.00 b	39.33 b	5.50 bc
T_5 (Bordeaux Mixture)	45.00 b	41.00 b	4.67 bc
T_6 (G-derma)	42.00 b	38.33 b	4.67 bc
T_7 (Garlic bulb extract)	45.00 b	40.00 b	6.16 b
T_8 (Allamanda leaf extract)	31.00 b	28.33 c	2.43 d
T_9 (Control)	65.00 a	60.00 a	11.67 a
LSD (0.05)	8.11	8.16	1.60
CV (%)	11.18	12.33	17.81

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.4.6 Reduction of incidence and severity of white rust disease of red amaranth over control after 7 days of 4th foliar spray in 2018

In different treatments, reduction of disease incidence and severity over control were recorded after seven days of 4th foliar spray at 61 DAS (Table 11). The result indicates that, the highest plant disease incidence reduced in Ridomil Gold sprayed plot (63.07%) followed by Allamanda leaf extract (52.30%) and Autostin (38.46%). In case of diseased leaf incidence, the highest reduction over control was recorded in Ridomil Gold sprayed plot (62.78%) followed by Allamanda leaf extract (52.78%) and Autostin (38.8%). Similarly, the highest disease severity reduced in Ridomil Gold sprayed plot (84.31%) followed by Allamanda leaf extract (79.17%) and Autostin (59.98%). Considering all findings, Ridomil Gold treated plot gave best results in respect of disease reduction over control.

Table 11. Reduction of incidence and severity of white rust of red amaranth after 7 days of 4th spray in *rabi* season of 2018

Treatments	% Reduction of Disease Incidence over control		% Reduction of Disease Severity over control
	% Reduction of Plant Incidence	% Reduction of Leaf Incidence	
T_1 (Ridomil Gold)	63.07	62.78	84.31
T_2 (Autostin 50WP)	38.46	38.88	59.98
T_3 (Dithane M 45)	35.38	35	55.87
T_4 (Goldton 50WP)	35.38	36.11	56.98
T_5 (Bordeaux Mixture)	30.76	31.11	47.43
T_6 (G-derma)	35.38	36.11	56.98
T_7 (Garlic bulb extract)	30.76	33.33	51.21
T_8 (Allamanda leaf extract)	52.30	52.78	79.17
T_9 (Control)	-	-	-

4.4.7 Effect of different treatments on yield contribution growth characters and seed yield of red amaranth at 61 DAS in 2018

Data on yield contribution growth characters and seed yield of red amaranth were recorded from each plot. Effect of different treatments on yield contribution growth characters and seed yield of red amaranth at 61 DAS in 2018 are given in Table 12. Data on growth, development and yield of red amaranth were recorded in terms of number of plant/plot, plant height (cm), number of leaf/plant, number of inflorescence/plant, seed yield/plot (g) and seed yield/ m^2 area. Number of plant per plot ranged from 118.33 to 122.67.

Moreover, plant height varied from 55.67 to 64.66 cm. Number of leaf per plant ranged from 7.0 to 10.33 at 61 DAS, where the highest leaves present in Ridomil Gold treated plot. The highest number of inflorescence per plant was recorded in Ridomil Gold (8.33) treated plot whereas the lowest was recorded in control (6) plot. Seed yield of red amaranth varied significantly among the treatments from 165 to 253 g/plot and 84.33 to 55 g/m^2 area. The highest seed yield was achieved from Ridomil Gold (253g) treated plot followed by allamanda leaf extract treated plot (228 g).

Considering the overall growth and yield performance, Ridomil Gold 68WG applied plot gave best result followed by Allamanda leaf extract sprayed plot. Seed yield of red amaranth was recorded at 61 DAS and seed yield increase over control was calculated later. The result indicates that, the highest seed yield increase over control was recorded in Ridomil Gold treated plot (53.32%), followed by Allamanda leaf extract (38.18%) and Autostin (24.83%).

Table 12. Effect of the different treatments on yield contributing characters and seed yield of red amaranth in *rabi* season of 2018

Treatments	Total no of Plant/ Plot	Plant Height (cm)	No. of Leaf/ Plant	No. of Inflorescence /Plant	Seed Yield/Plot (g)	Seed Yield/m^2 area (g)	% Seed yield increase over control
T_1 (Ridomil Gold)	122.67 a	64.66 a	10.33 a	8.33 a	253 a	84.33	53.32
T_2 (Autostin 50WP)	116.33 b	58.66 bc	7.67 bc	7.0 b-d	206 bc	68.66	24.83
T_3 (Dithane M 45)	119.67 ab	58.66 bc	7.33 b-d	7.33 a-c	185 cd	61.66	12.1
T_4 (Goldton 50WP)	119.0 ab	58.66 bc	7.33 b-d	6.33 cd	203 c	67.66	23.01
T_5 (Bordeaux Mixture)	118.33 b	60.33 b	7.0 cd	6.67 b-d	186 cd	62	12.72
T_6 (G-derma)	118.33 b	55.67 c	7.67 bc	7.0 b-d	186 cd	62	12.72
T_7 (Garlic bulb extract)	118.00 b	56.66 c	6.67 d	6.67 b-d	183 cd	61	10.9
T_8 (Allamanda leaf extract)	119.67 ab	60.67 b	8.0 b	7.67 ab	228 b	76	38.18
T_9 (Control)	117.67 b	56.67 c	7.0 cd	6.0 d	165 d	55	-
LSD (0.05)	4.29	3.09	0.91	1.09	24.88	-	-
CV (%)	2.09	3.03	6.87	9.07	7.19	-	-

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5 Management of white rust disease of red amaranth by selected treatments in *Kharif*-1 season of 2019

4.5.1 Incidence and severity of white rust disease of red amaranth before treatment spray in 2019

The experiment was conducted in *kharif*-1 season in the central research field of SAU. Before spraying, plant incidence, leaf incidence and disease severity were measured under each treatment plot. The plant incidence, leaf incidence and disease severity were varied from 5% to 7%, 5.66% to 09% and 0.07% to 0.13%, respectively (Table 13).

Table 13. Disease incidence and severity of white rust of red amaranth before spray in *kharif*-1 season of 2019

Treatments	Disease Incidence (%)		Disease Severity (%) *
	Plant Incidence (%) *	Leaf Incidence (%)	
T_1 (Ridomil Gold)	5.00	8.00 a-c	0.13
T_2 (Autostin 50WP)	7.00	5.66 d	0.07
T_3 (Dithane M 45)	5.66	7.00 b-d	0.11
T_4 (Goldton 50WP)	6.00	8.33 ab	0.10
T_5 (Bordeaux Mixture)	6.66	8.00 a-c	0.10
T_6 (G-derma)	5.66	6.66 a-c	0.10
T_7 (Garlic bulb extract)	5.00	7.66 a-c	0.12
T_8 (Allamanda leaf extract)	6.33	9.00 a	0.13
T_9 (Control)	6.33	7.33 bc	0.10
LSD (0.05)	2.32	1.39	0.04
CV (%)	22.51	10.71	23.43

*NS= Non Significant

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5.2 Incidence and severity of white rust disease of red amaranth after 7 days of 1st foliar spray in 2019

After first spray, the effect of eight treatments against leaf spot disease of red amaranth are presented in Table (Table 14). The efficacy of the treatments was assessed based on different parameters like plant incidence, leaf incidence and disease severity. In seven days after 1st spray, the effect of different treatments in terms of plant incidence, leaf incidence and severity varied from 8.33% to 13.33%, 13.33% to 22.66% and 0.93% to 3.33%, respectively.

Table 14. Disease incidence and severity of white rust of red amaranth after 7 days of 1st spray in *kharif*-1 season of 2019

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	10.00 bc	15.00 ab	0.93 d
T_2 (Autostin 50WP)	11.33 ab	14.33 b	1.50 b-d
T_3 (Dithane M 45)	8.33 c	17.66 ab	1.66 bc
T_4 (Goldton 50WP)	11.00 ab	13.33 b	1.83 b
T_5 (Bordeaux Mixture)	12.66 a	15.33 ab	1.83 b
T_6 (G-derma)	10.00 bc	20.00 ab	2.16 b
T_7 (Garlic bulb extract)	12.00 ab	18.33 ab	1.83 b
T_8 (Allamanda leaf extract)	8.33 c	18.33 ab	1.00 cd
T_9 (Control)	13.33 a	22.66 a	3.33 a
LSD (0.05)	2.36	5.67	0.66
CV (%)	12.66	19.04	21.59

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5.3 Incidence and severity of white rust disease of red amaranth after 7 days of 2nd foliar spray in 2019

The effect of treatments differed significantly for plant incidence, leaf incidence and severity at 14 days after spray (Table 15). plant incidence was varied significantly to different treatments from 15.0%to 28.33%, where the lowest plant incidence was recorded in Ridomil Gold (15.0%) that was statistically similar to Allamanda leaf extract. Leaf incidence was varied significantly to different treatments from 24% to 41.66%, where the lowest leaf incidence was recorded in Ridomil Gold (24%) that was statistically similar to Autostin. Similarly, disease severity was ranged from 1.50% to 6.67% and the lowest severity was observed Allamanda leaf extract (1.50%). The highest incidence and severity was recorded in control plot.

Table 15. Disease incidence and severity of white rust of red amaranth after 7 days of 2nd spray in *kharif* -1 season of 2019

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	15.00 c	24.00 c	1.76 cd
T_2 (Autostin 50WP)	17.67 bc	29.00 bc	2.76 bc
T_3 (Dithane M 45)	18.33 b	28.33 c	3.00 b
T_4 (Goldton 50WP)	20.00 b	26.33 bc	3.10 b
T_5 (Bordeaux Mixture)	20.00 b	31.00 bc	3.00 b
T_6 (G-derma)	20.00 b	34.66 ab	3.16 b
T_7 (Garlic bulb extract)	20.00 b	29.33 bc	3.16 b
T_8 (Allamanda leaf extract)	14.67 c	23.33 c	1.50 d
T_9 (Control)	28.33 a	41.66 a	6.67 a
LSD (0.05)	3.19	7.83	1.01
CV (%)	9.54	15.23	18.82

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5.4 Incidence and severity of white rust disease of red amaranth after 7 days of 3rd foliar spray in 2019

The effect of treatments differed significantly for leaf incidence and severity at 21 days after spray (Table 16). plant incidence varied significantly to different treatments from 20%to 46.66%, where the lowest plant incidence was recorded in Ridomil Gold (20%). Leaf incidence varied significantly to different treatments from 25% to 60%, where the lowest leaf incidence was recorded in Allamanda leaf extract (25%). Similarly, disease severity was ranged from 2 to 10.33% and the lowest severity was observed in Allamanda leaf extract (2%) that was statistically similar to Ridomil Gold 68 WG. The highest incidence and severity was recorded in control plot.

Table 16. Disease incidence and severity of white rust of red amaranth after 7 days of 3rd spray in *kharif*-1 season of 2019

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	20.00 d	27.33 c	2.16 c
T_2 (Autostin 50WP)	29.00 c	37.66 b	3.66 b
T_3 (Dithane M 45)	30.66 bc	38.33 b	4.00 b
T_4 (Goldton 50WP)	33.33 bc	35.66 b	4.33 b
T_5 (Bordeaux Mixture)	32.33 bc	38.33 b	4.16 b
T_6 (G-derma)	34.00 b	41.00 b	4.33 b
T_7 (Garlic bulb extract)	34.00 b	38.33 b	4.00 b
T_8 (Allamanda leaf extract)	20.00 d	25.66 c	2.00 c
T_9 (Control)	46.66 a	60.00 a	10.33 a
LSD (0.05)	4.49	5.39	1.06
CV (%)	8.35	8.20	14.26

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5.5 Incidence and severity of white rust disease of red amaranth after 7 days of 4th foliar spray in 2019

The effect of treatments differed significantly for leaf incidence and severity at 28 days after first spray (Table 17). plant incidence varied significantly in different treatments from 18.66% to 61.66%, where the lowest plant incidence was recorded in Ridomil Gold (18.66%) that was statistically similar to allamanda leaf extract. Leaf incidence was varied significantly to different treatments from 24% to 70%, where the lowest leaf incidence was recorded in Ridomil Gold (24%) that was statistically similar to allamanda leaf extract. Similarly, disease severity was ranged from 1.93% to 16.66% and the lowest severity was observed in Ridomil Gold (1.93%) that was statistically similar to allamanda leaf extract. The highest incidence and severity was recorded in control plot.

Table 17. Disease incidence and severity of white rust of red amaranth after 7 days of 4th spray in *kharif*-1 season of 2019

Treatments	Disease Incidence (%)		Disease Severity (%)
	Plant Incidence (%)	Leaf Incidence (%)	
T_1 (Ridomil Gold)	18.66 d	24.00 c	1.93 c
T_2 (Autostin 50WP)	31.66 c	39.33 b	4.33 b
T_3 (Dithane M 45)	35.00 bc	42.66 b	4.83 b
T_4 (Goldton 50WP)	33.66 bc	42.33 b	5.16 b
T_5 (Bordeaux Mixture)	35.33 bc	42.00 b	4.83 b
T_6 (G-derma)	37.33 b	44.00 b	5.06 b
T_7 (Garlic bulb extract)	37.66 b	42.33 b	4.83 b
T_8 (Allamanda leaf extract)	22.00 d	27.66 c	2.23 c
T_9 (Control)	61.66 a	70.00 a	16.66 a
LSD (0.05)	4.60	5.52	1.06
CV (%)	7.65	7.67	11.09

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

4.5.6 Reduction of incidence and severity of white rust disease of red amaranth over control after 7 days of 4th foliar spray in 2019

In different treatments, reduction of disease incidence and severity over control were recorded after seven days of 4th foliar spray at 57 DAS (Table 18). The result indicates that, the highest plant disease incidence reduced in Ridomil Gold sprayed plot (69.73%) followed by Allamanda leaf extract (64.32%), Autostin (48.65%) and Goldton (45.41%). In case of diseased leaf incidence, the highest reduction over control was recorded in Ridomil Gold sprayed plot (65.71%) followed by Allamanda leaf extract (60.48%) and Autostin (39.52%). Simillarly, the highest disease severity reduced in Ridomil Gold sprayed plot (88.41%) followed by Allamanda leaf extract (86.61%) and Autostin (74%). Considering all findings, Ridomil Gold 68WG treated plot gave best results in respect of disease reduction over control.

Table 18. Reduction of incidence and severity of white rust of red amaranth after 7 days of 4th spray in *kharif*-1 season of 2019

Treatments	% Reduction of Disease Incidence over control		% Reduction of Disease Severity over control
	% Reduction of Plant Incidence	% Reduction of Leaf Incidence	
T_1 (Ridomil Gold)	69.73	65.71	88.41
T_2 (Autostin 50WP)	48.65	43.81	74.0
T_3 (Dithane M 45)	43.23	39.52	71.0
T_4 (Goldton 50WP)	45.41	39.67	69.02
T_5 (Bordeaux Mixture)	42.70	39.52	71.0
T_6 (G-derma)	39.45	37.14	69.20
T_7 (Garlic bulb extract)	38.92	39.52	71.0
T_8 (Allamanda leaf extract)	64.32	60.48	86.61
T_9 (Control)	-	-	-

4.5.7 Effect of different treatments on yield contribution growth characters and seed yield of red amaranth at 57 DAS in 2019

Data on yield contribution growth characters and seed yield of red amaranth were recorded from each plot. Effect of different treatments on yield contribution growth characters and seed yield of red amaranth at 57 DAS in 2019 are given in Table 19. Data on growth, development and yield of red amaranth were recorded in terms of no. of plant/plot, plant height (cm), number of leaf/plant, no. of inflorescence/plant, seed yield/plot (g) and seed yield/ m^2 area. Number of plant per plot ranged from 111 to 116.

Moreover, plant height varied from 50.83 to 59.16 cm. Number of leaf per plant ranged from 5.33 to 9.33 at 61 DAS, where the highest leaves present in Ridomil Gold treated plot. The highest no. of inflorescence per plant was recorded in Ridomil Gold (10) treated plot whereas the lowest was recorded in control (6) plot. Seed yield of red amaranth varied significantly among the treatments from 153 to 262 g/plot and 51 to 77.33 g/m^2 area. The highest seed yield was achieved from Ridomil Gold (262g) treated plot followed by Allamanda leaf extract treated plot (210 g).

Considering the overall growth and yield performance, Ridomil Gold 68WG applied plot gave best result followed by Allamanda leaf extract sprayed plot. Seed yield of red amaranth was recorded at 57 DAS and seed yield increase over control was calculated later. The result indicates that, the highest seed yield increase over control was recorded in Ridomil Gold treated plot (51.63%), followed by Allamanda leaf extract (37.25%) and Autostin (32.01%).

Table 19. Effect of the different treatments on yield contributing characters and seed yield of red amaranth in *kharif*-1 season of 2019

Treatments	Total no of Plant/ Plot	Plant Height (cm)	No. of Leaf/ Plant	No. of Inflorescence /Plant	Seed Yield/Plot (g)	Seed Yield/m^2 area (g)	% Seed yield increase over control
T_1 (Ridomil Gold)	116 a	59.16 a	9.33 a	10.0 a	232 a	77.33	51.63
T_2 (Autostin 50WP)	112 bc	55.16 b-d	6.67 bc	7.33 bc	202 bc	67.33	32.01
T_3 (Dithane M 45)	114 a-c	55.50 bc	6.33 bc	7.33 bc	180 cd	60	17.64
T_4 (Goldton 50WP)	113 bc	55.03 b-d	6.33 bc	6.33 cd	175 cd	58.33	14.37
T_5 (Bordeaux Mixture)	112 bc	56.06 ab	6.0 bc	6.67 b-d	173 cd	57.66	13.05
T_6 (G-derma)	112 bc	50.83 e	6.67 bc	7.0 b-d	180 cd	60	17.64
T_7 (Garlic bulb extract)	111 c	52.70 c-e	6.0 bc	6.67 bd	177 cd	59	15.68
T_8 (Allamanda leaf extract)	114 ab	56.67 ab	7.33 b	7.66 b	210 b	70	37.25
T_9 (Control)	113 bc	52.0 de	5.33 c	6.0 d	153 d	51	-
LSD (0.05)	2.60	3.34	1.39	1.17	21.18	-	-
CV (%)	1.32	3.53	12.12	9.37	8.85	-	-

Means followed by the same letters in a column did not differ at 5% level of significance by LSD.

In *Rabi* season 2018, four spray was done with selected treatments in an interval of 7 days. After first spray, at 40 days after sowing (DAS), plant incidence ranged from 13.0% to 24.0%, leaf incidence ranged from 13.33% to 25.67%, and disease severity ranged from 0.93% to 1.83%. Moreover, after 2nd spray at 47 DAS, the range of plant incidence, leaf incidence and disease severity were 19.0% to 35.0%, 20.0% to 40.0% and 1.40% to 4.0%, respectively. Furthermore, after 3rd spray at 54 DAS, plant incidence ranged from 26.0% to 48.33%, leaf incidence ranged from 22.33% to 51.0%, and disease severity ranged from 1.76% to 6.16%. Finally, after 4th spray at 61 DAS, the range of plant incidence, leaf incidence and disease severity were 24.0% to 65.0%, 22.33% to 60.0% and 1.83 to 11.67%, respectively. Among the treatments the highest disease reduction over control was observed in Ridomil Gold 68 WG followed by Allamanda leaf extract and Autostin 50 WP. Ridomil Gold reduced 63.07% plant incidence, 62.78% leaf incidence and 84.31% disease severity over control. However, Allamanda leaf extract reduced 52.30% plant incidence, 52.78% leaf incidence and 79.17% disease severity over control. In other treatments plant incidence reduction was within 30% to 39% and disease severity reduction was within 47% to 60% over control. Moreover, the highest seed yield increased over control was also found in Ridomil Gold (53.32%) followed by Allamanda leaf extract (38.18%). In other treatments, seed yield increased remain within 10% to 25% over control. The result indicates that, more than 60% plant incidence and 80% disease severity were reduced and 53% seed yield was increased due to application of Ridomil Gold 68 WG.

In *Kharif* -1 season 2019, four spray was done with selected treatments in an interval of 7 days. After first spray, at 36 days after sowing (DAS), plant incidence ranged from 8.33% to 13.33%, leaf incidence ranged from 15.0% to 22.66%, and disease severity ranged from 0.93% to 3.33%. Moreover, after 2nd spray at 43 DAS, the range of plant incidence, leaf incidence and disease severity were 15.0% to 28.33%, 24% to 41.66% and 1.76% to 6.67%, respectively. Furthermore, after 3rd spray at 50 DAS, plant incidence ranged from 20.0% to 46.66%, leaf incidence ranged from 27.33% to 60.0%, and disease severity ranged from 2.16% to 10.33%. Finally, after 4th spray at 57 DAS, the range of plant incidence, leaf incidence and disease severity were 18.66% to 61.66%, 24.0% to 70.0% and 1.93% to 16.66%, respectively. Among the treatments the highest disease reduction over control was observed in Ridomil Gold 68 WG followed by Allamanda leaf extract and Autostin 50 WP. Ridomil Gold reduced 69.73% plant incidence, 65.71% leaf incidence and 88.41% disease severity over control. However, Allamanda leaf extract reduced 64.32% plant incidence, 60.48% leaf incidence and 86.61% disease severity over control. In other treatments plant incidence reduction was within 38% to 46% and disease severity reduction was within 69% to 74% over control. Moreover, the highest seed yield increased over control was also found in Ridomil Gold (51.63%) followed by Allamanda leaf extract (37.25%). In other treatments, seed yield increased remain within 15% to 32% over control. The result indicates that, more than 69% plant incidence and 88% disease severity were reduced and 51% seed yield was increased due to application of Ridomil Gold 68 WG.

Similar results were found by Talukder *et al.* (2012), Rahman (2010), Huq and Rahman (2009), Rathi et al. (2009), Mostofa (2004) and Rohilla *et al*. (2001). Rahman (2010) conducted an experiment in Jamalpur, Bangladesh during 2009-2010 and stated that, white rust caused by *Albugo candida* is one of the most important constraints to production of good quality seed of red amaranth in Bangladesh.

Talkuder *et al*. (2012) also conducted similar experiment and found Ridomil Gold 68 WP most effective against control white rust disease of red amaranth among the applied chemical fungicides.

Huq and Rahman (2009) conducted an experiment to manage white rust disease by using different cultural practices and chemicals under natural condition at Regional Agricultural Research Station of BARI, Rahmatpur, Barisal, Bangladesh in 2008-2009. They found that the lowest disease incidence was observed in the plot which was sprayed with Ridomil Gold 68WG followed by Sunvit.

Rathi *et al.* (2009) conducted an experiment in Panjab, India during 2008-2009, using chemical fungicides to control the white rust disease. They reported foliar application of Ridomil MZ-72 WP can reduce the incidence and severity of white rust disease effectively.

Rohilla *et al*. (2001) evaluated foliar spray of Ridomil MZ-72 WP which effectively reduced *Albugo candida* inoculum in open field conditions. They found it helpful in reducing the disease incidence quickly on brassica. They used Apron 35-SD (Propineb) as a foliar spray mixed with Ridomil MZ-72. This combination resulted in significant reduction of white rust disease.

Mostafa (2004) reported that Allamanda leaf extract reduces the incidence and severity of white rust disease of mustard. He observed the lowest percentage of plant incidence and maximum plant height, branch length, leaf length, leaf breadth and petiole length while plot was treated with Allamanda extract.

Considering the overall performance of the treatments, Ridomil Gold 68WG showed the best effect in controlling white rust disease. Thus, Ridomil Gold 68WG could be used for seed production of red amaranth. Moreover, Allamnada leaf extract could be used as eco-friendly approach for white rust disease management and safe crop production.

CHAPTER V

SUMMARY AND CONCLUSION

Red amaranth (*Amaranthus tricolor* L.) is an important leafy vegetable in Bangladesh member of the family Amaranthaceae. Red amaranth has been growing in Bangladesh both in winter and summer seasons. It can be harvested within a very short time. It is annual, ascending or erect herb, attaining 1.2 m high or more in cultivation, stem stout, usually much branched, branches angular, glabrous. Inflorescence a head, axillary and terminal. Fruit bearing start from below the middle, ovoid, 1.5 mm long. Seeds ovoid, 1.5 mm in diameter, shining, brown, smooth, lenticular. Red amaranth is a good source of minerals and vitamins. In our country, its cultivation is increasing day by day.

Fungi are the great threat for vegetable as well as amaranth production. White rust caused by *Albugo candida* is noted as the major one considering its higher incidence, wider distribution and adverse effect on yield and quality of the crop. The Oomycetes fungus, *A. candida* is known to be present wherever red amaranth is grown. *A. candida* causes economically significant yield and quality losses in seed and vegetable produce of crucifers in several different ways. White rust disease on the foliage reduces the photosynthetic capacity of plants and affects yield and normal plant development. Disease on the foliage affects and downgrades the leaves for sale and its human consumption as a vegetable. White rust disease mainly appeared on the leaves. Disease symptom firstly appeared on the lower side of leaves. This research work was designed to identify the causal organism of white rust disease of red amaranth, to measure amount of disease and to find out suitable management practices for white rust disease of red amaranth in Bangladesh.

Symptomology of white rust of red amaranth was studied in the field. The causal organism of the disease was identified by microscopic study (scraping & sectioning). Amount of disease was measured in terms of disease incidence (%) and disease severity (%). Moreover, yield contributing characters viz. plant height, no. of leaves per plant and no. of inflorescence per plant and seed yield were recorded after harvesting the crops. From the primary data, reduction of disease incidence and severity over control and seed yield increase over control were calculated.

Moreover, a survey on white rust disease of red amaranth was conducted in 8 districts under 4 division of Bangladesh in *Rabi* season 2018. The survey locations were Chargarpara of Manikganj, Board bazar of Gazipur, Ashekpur of Bogra, Kochukata of Nilfamari, Sonahar of Panchagarh, Sonkarpur of Kustia, Amdoh of Meherpur and Belgachi of Chuadanga. Three fields of each location were considered for data recording. Amount of disease was measured under natural epiphytic condition. Data was recorded on % Disease severity and % Disease incidence viz. % plant incidence and % leaf incidence.

The field experiments were conducted in research field of SAU, Dhaka-1207, in two different seasons *Rabi* and *Kharif*-1. First experiment was conducted in winter season (*Rabi*). To confirm the previous findings, the experiment was re-tested in 2019 at the same field in rainy season (*Kharif*-1) under natural environmental condition. Eight treatments including four commercial fungicides (Ridomil gold 68 WG, Autostin 50 WP, Goldton 50 WP and Diathane M-45), one homemade fungicide (Bordeaux mixture), one bio-pesticide named G-Derma (*Trichoderma* sp.) and two botanicals Garlic bulb extract (*Allium sativum*) and Allamanda leaf extract (*Allamanda cathertica*) were tested against the disease in field condition in 2018 and 2019. The experiments were conducted in the field under natural epiphytic condition. Three spots from each plot were selected randomly for measurement of leaf incidence and severity. Four sprays of the selected treatments were done at seven days' interval from 14 December 2018 to 17 January in 2019 (*Rabi*) and from 1 April to 7 May in 2019 (*kharif*-1). Spraying started from 7 days after disease appeared in field under natural condition.

From the experiments conducted in both season (*rabi and kharif*-1), the effect of different fungicides against white rust disease of red amaranth showed significant difference among them. Ridomil Gold 68WG showed most effective against white rust in terms of plant incidence, leaf incidence and disease severity.

In *Rabi* season of 2018, After 4^{th} spray, the best treatment was Ridomil Gold 68WG followed by Allamanda leaf extract and Autostin 50WP with the lowest disease severity of 1.83%, 2.43% and 4.67%, respectively. Moreover, similar results were observed for disease incidence. in case of plant incidence, the best treatment was also Ridomil Gold followed by Allamanda leaf extract, and

Autostin where plant incidence was 24%, 31% and 40%, and leaf incidence were 22.33% ,28.33%, and 39%, respectively. Treatments had significant effect on the growth and seed yield of red amaranth. The overall plant growth of red amaranth was better in *rabi* season of 2018 than the *kharif*-1 season of 2019. The highest plant height was 64.66 cm, the highest number of inflorescence was 8.33 and the highest seed yield was 84.33 g/m^2 were recorded in Ridomil Gold 68 WG treated plot. Among the treatments the highest disease reduction over control was observed in Ridomil Gold 68 WG followed by Allamanda leaf extract and Autostin 50 WP. Ridomil Gold reduced 63.07% plant incidence, 62.78% leaf incidence and 84.31% disease severity over control. However, Allamanda leaf extract reduced 52.30% plant incidence, 52.78% leaf incidence and 79.17% disease severity over control. In other treatments plant incidence reduction was within 30% to 39% and disease severity reduction was within 47% to 60% over control. Moreover, the highest seed yield increased over control was also found in Ridomil Gold (53.32%) followed by Allamanda leaf extract (38.18%). In other treatments, seed yield increased from 10% to 25% over control. The result indicates that, more than 60% plant incidence and 80% disease severity were reduced and 53% seed yield was increased due to application of Ridomil Gold 68 WG.

In *Kharif*-1 season of 2019, After 4th spray, the best treatment was Ridomil Gold 68WG followed by Allamanda leaf extract and Autostin 50WP with the lowest disease severity of 1.93%, 2.23% and 4.33%, respectively. Moreover, similar results were observed for disease incidence. In case of plant incidence, the best treatment was also Ridomil Gold followed by Allamanda leaf extract, and Autostin where plant incidence was 18.66%, 22.00% and 31.66% and leaf incidence were 24.00%, 27.66% and 39.33%, respectively. Treatments had significant effect on the growth and seed yield of red amaranth. The highest plant height was 59.16 cm, the highest number of inflorescence was 10.0 and the highest seed yield was 51.63 g/m^2 were recorded in Ridomil Gold 68 WG treated plot. Among the treatments the highest disease reduction over control was observed in Ridomil Gold 68 WG followed by Allamanda leaf extract and Autostin 50 WP. Ridomil Gold reduced 69.73% plant incidence, 65.71% leaf incidence and 88.41% disease severity over control. However, Allamanda leaf extract reduced 64.32% plant incidence, 60.48% leaf incidence and 86.61% disease severity over control. In other treatments plant incidence reduction was within 38% to 46% and disease severity reduction was within 69% to 74% over control. Moreover, the highest seed yield increased over control was also found in Ridomil Gold (51.63%) followed by Allamanda leaf extract (37.25%). In other treatments, seed yield increased remain within 15% to 32% over control. The result indicates that, more than 69% plant incidence and 88% disease severity were reduced and 51% seed yield was increased due to application of Ridomil Gold 68 WG.

It was observed that disease incidence and severity were more in *Rabi* season of 2018 than *kharif*-1 season of 2019. Temperature, rainfall and relative humidity may have significant influence on disease incidence and severity. Among these environmental parameters, rainfall was most influential to reduce disease incidence and severity of white rust of red amaranth as per opinion of the scientist and the growers. This is because, the pathogen is obligate and cannot survive without living hosts. During rainfall, the spores (sporangiospores) of *Albugo candida* wash out from the host surface and died due to fall down to soil. Thus disease infestation reduced by rainfall in *Kharif*-1 season.

White rust disease is an important hindrance to seed production of red amaranth. The primary infection of the disease appeared about 28 – 30 days after sowing in the older leaves of the plants. The white blister like postules appeared in the lower surface of leaves of the infected plants. As the disease progress, spread towards younger leaves and several postules coalesced together to produce large lesion. Finally, the highly infected leaves become necrosis the apex and defoliated. At mature stage, during inflorescence emergence few leaves remain in the infected plants. As a result, the inflorescence size become smaller due to less photosynthetic activities of infected plants. Thus the seed yield was drastically reduced in infected plants.

So, finally it could be said that among the treatments, Ridomil Gold 68 WG gave best result against this disease. Moreover, Allamanda leaf extract showed better effect against the disease than other treatments. Considering the overall performance of the treatments, Allamanda leaf extract could be used as an eco-friendly approach. Moreover, use of Ridomil Gold 68WG is better for controlling the disease for seed production. However, similar experiments on management of white rust disease of red amaranth including more treatments is recommended in different AEZ of Bangladesh.

CHAPTER VI

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APPENDICES

Appendix I. Plant Diseases Survey Sheet for Red Amaranth

<u>Plant Diseases Survey Sheet</u>

Name of the growers/farmers: **Date of Data collection:**

Address: Village: **Union:** **Upazilla:** **District:**

Host common name: **Scientific name:** **Age of Plant/Crop**:

Seedling/Vegetative/Flowering

Name of disease	Infected plant part(s)	Distribution			Status		Plant Incidence %	Leaf Incidence %	Stem incidence %	Bud/ Flower Incidence %	Other incidence %	Disease Severity %
		EF	Edge	R	New	Old						
White Rust												

Distribution: Entire field / Edge of field /Random

Symptomological Study

Description of symptoms	**White Rust of Red Amaranth**
Size of spot or lesion	
Shape of spot or lesion	
Margin of spot or lesion	
Appearance of symptom	
Yellow helo present or not	
Wet/dry spot or lesion	
Sunken/raised lesion or spot	
Sign present with disease	
Scattered/ coalesce	
Infection on upper/lower surface of leaf	
Older/ middle/ younger leaf affected	
Others infected areas of plant	
Other important observations	

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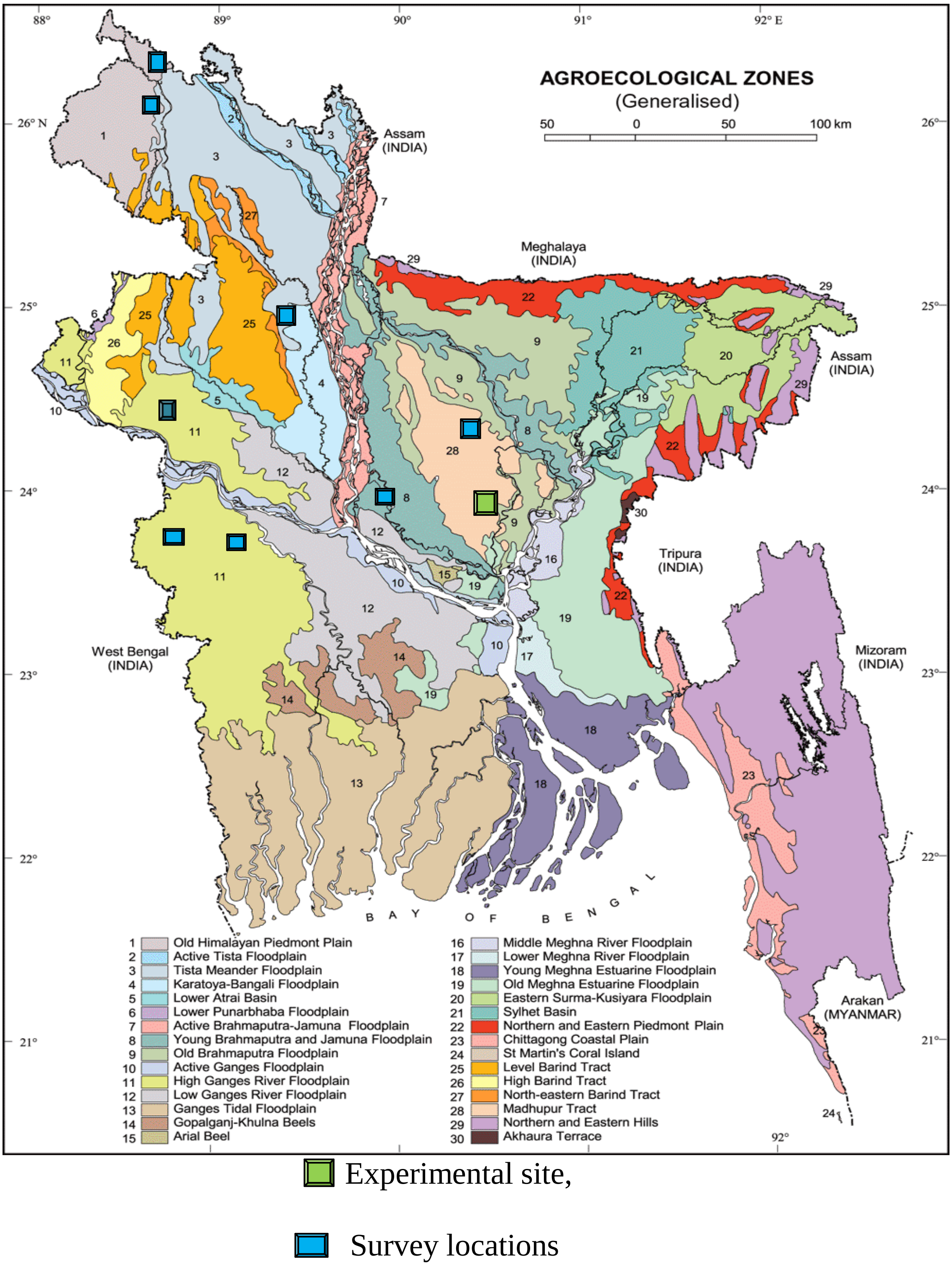
Name and Signature of Surveyor **Name and Signature of Supervisor**

Date: / /2018 **Date: / /2018**

Appendix II. Map showing the experimental site under study.



Experimental site,

Survey locations

Appendix III. The experimental site under study.

Morphological Features	**Characteristics**
Location	Sher-e-Bangla Agricultural University Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Soil Series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

Appendix IV: Experimental Layout in Rabi (2018) and *Kharif*-1 (2019)