MANAGEMENT OF POWDERY MILDEW DISEASE OF BOTTLE GOURD (*Lagenaria siceraria*) USING POTASSIUM AND SULPHUR CONTAINING MODERN PHYTO-CHEMICALS

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CERTIFICATE

*This is to certify that thesis entitled, "**MANAGEMENT OF POWDERY MILDEW DISEASE OF BOTTLE GOURD (Lagenaria siceraria) USING POTASSIUM AND SULPHUR CONTAINING MODERN PHYTO-CHEMICALS**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in PLANT PATHOLOGY** embodies the result of a piece of bona-fide research work carried out by **SANGITA SHARMIN**, Registration no. **13-05553** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

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MANAGEMENT OF POWDERY MILDEW DISEASE OF BOTTLE GOURD (*Lagenaria siceraria*) USING POTASSIUM AND SULPHUR CONTAINING MODERN PHYTO-CHEMICALS

ABSTRACT

Powdery mildew of bottle gourd is one of the important disease responsible for lower yield of bottle gourd in many countries. Management of powdery mildew disease is required to maintain the quality and quantity of the fruit. Different management approaches have been led to control the disease. In this experiment, we evaluated silica and salicylic acid-based fungicide, Peak Performance Nutrient (PPN), Potassium silicate, Phosphorus silicate and sulphur-based fungicide (McSulphur 80 WP) against control. The experiment was conducted from November 2019 to May 2020. BARI Lau-4 variety was selected for the present experiment. In the present POinvestigation the highest reduction of disease incidence (36.89%) was recorded by the application of potassium silicate (T_2). The nearest reduction of disease incidence was found in Peak Performance Nutrient (T_5) (24.18%) followed by Silica (T_1) (20.49%) and Phosphorus silicate (T_3) (20.08%). At 107 days after transplanting, the PDI (Percent Disease Index) values were observed and it was found that the maximum PDI was calculated from the control (64.17%). At 107 DAT, potassium silicate (T_2) showed the highest performance (60.52%) in reduction of disease severity. The second highest reduction of disease severity was recorded in case of Peak Performance Nutrient (T_5) (38.06%) followed by Silica (T_1) (31.82%), Phosphorus silicate (T_3) (30.74%), McSulphur 80 WP (T_6) (21.04%) and Salicylic acid (T_4) (3.90%). The maximum number of fruit (10.00) was recorded from application of potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (9.67) and Silica (T_1) (8.33). In case of weight, the maximum average weight of bottle gourd fruit (2.52 kg) was recorded from application of potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (1.99), Phosphorus silicate (T_3) (1.87 kg) and Peak Performance Nutrient (T_5) (1.85). Potassium silicate (K_2SiO_3) was found effective against powdery mildew disease of bottle gourd. It also gave the best result in giving large sized and heaviest fruits. Potassium silicate may be used as an alternative of ‘sulphur containing fungicide’.

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAT	Days After Transplanting
eds.	Editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
L.	Linnaeus
LSD	Least Significant Difference
i.e.	id est (that is)
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	Variety
viz.	Namely

CHAPTER I

INTRODUCTION

Bottle gourd [*Lagenaria siceraria* (Mol.) Stand.] is a popular winter vegetable in Bangladesh. It belongs to the family Cucurbitaceae. The climatic condition of winter in Bangladesh favours better growth and yield of bottle gourd. The average day temperature of 20–27°C with lower night temperature of 18–23°C is optimum for growth and fruiting (Quamruzzaman *et al.*, 2017). Although it is commonly grown in winter in Bangladesh, bottle gourd is also cultivated during summer and rainy season throughout the country. Significant variation of plant type, fruit type, fruit shape, fruit colour is found among the genotypes.

Bottle gourd is one of the lowest-calorie vegetables; carrying just 14 calories per 100 g. It is one of the vegetables recommended by dieticians in weight-control programs. Fresh gourds contain small quantities of folates, contain about 6 µg/100g (Provide just 1.5% of RDA). Folate helps reduce the incidence of neural tube defects in new-borns when taken by anticipant mothers during their early months of pregnancy. It is a modest source of vitamin C (100 gm of raw fruit provides 10 mg or about 17% of RDA). Vitamin C is one of the powerful natural antioxidants that help scavenge harmful free radicals.

Bottle gourd facilitates easy digestion and movement of food through the bowel until it is excreted from the body. Thus, it helps in relieving indigestion and constipation problems. Also, the vegetable is also a modest source of thiamine, niacin (vitamin B-3), pantothenic acid (vitamin B-5), pyridoxine (vitamin B-6), and minerals such as calcium, iron, zinc, potassium, manganese, and magnesium. Its tender leaves and tendrils are also edible; indeed, carry higher concentrations of vitamins and minerals than the bottle gourd fruit.

At present the acreage and annual production of bottle gourd is 49,096 acre and 2,50,613 metric tons (MT) respectively in Bangladesh with an average yield of 12.61 tons per hectare (BBS, 2020) which is very low as compared to other bottle gourd producing countries like India. Several factors are responsible for this low yield and among them fungi, virus and nematodes are found as major constraints. Powdery Mildew (PM), a fungal disease caused by *Erysiphe cichocearum* is considered a threat for yield reducing factor of the crop (Talukdar, 1974, Singh, 1985, Agrios, 1997).

Erysiphales fungi are widely distributed all over the world and cause diseases on numerous wild and cultivated plants. The powdery mildew pathogen can attack most of the cucurbitaceous crops. The primary symptoms are white, powder-like spots on the leaves and stems. Powdery mildew is first evident as pale-yellow leaf spots. White powdery spots can form on both upper and lower leaf surfaces, and quickly expand into large blotches which ultimately can cover entire leaf, petiole, and stem surfaces. When the majority of the foliage is infected, the plant is weakened and the fruit ripens prematurely and hence reduced healthy seed production (McGrath, 2011). Due to air-borne nature of spores, once the leaves are infected with powdery mildew it is difficult to control. It can spread rapidly and became devastating to the crop. After infection it hampers normal growth and development of the host. Severely infected crop was found to fail to set fruits. Yield loss increased with the increase of disease severity of the crops (Ghoil *et al*. 1988, Khosla et al. 1988, Bhatia and Thakur 1989, Singh et al. 1991). An early heavy infection with mildew had about 30% loss of production compared to a later, higher infection. Powdery mildew generally causes 10–15% yield loss in different crops. In sweet gourd, powdery mildew is the most common disease and can result in yield losses exceeding 30% in the crop (Tisserat, 2006). The disease is most damaging if it appears three to four weeks before harvest (Smith, 2006). In USA, Karathane (Waraitch *et al.,* 1975), Thiovit, Bavistin and Karathane (Jain and Srivastava, 1977, Bhatia and Thakur,1989) and Chlorothalonil, copper (McGrath, 2011) had been recommended as fungicide for controlling powdery mildew. Early application of those fungicide could prevent powdery mildew effectively.

McSulphur 80 WP, Sulfolac 80% WG, Haysulf DF 80%, Prosulf 80% DF, Thiovit 80 WG, Agrovet DF, Sulfochem 80 WDG, Greensul 80 WG, Arozim 80 WG, CP-Vit 80 WDG, PolySuf 80 WG, Forstrobin 25 SC, Kasmira 28 SC, Keramoti 28 SC, State 32.5 SC, M-Zole 32.5 EC, Zozopa 32.5 SC, Agrobin 56 EC, Haydazim 50 WP, Goldazim 500 SC, Shelter 52.5 WP etc. are some of the registered fungicides used for controlling powdery mildew disease in Bangladesh.

The acute toxicity of chemical fungicides to humans is generally considered to be low, but fungicides can be irritating to the skin and eyes. Inhalation of spray mist or dust from these pesticides may cause throat irritation, excessive sweating, sneezing, and coughing, burning eyes and fatigue among farmers. Chronic exposures to lower concentrations of fungicides can cause adverse health effects.Excessive and irrational use of fungicides causes environment deterioration and has non-target effects on plants and animals. The fungicides are responsible for residue problems, resistance development in pathogens and different health hazards to other living organisms including cattle, fishes, domesticated birds.

Silicon dioxide, also known as silica, is an oxide of silicon with the chemical formula SiO_2, most commonly found in nature as quartz and in various living organisms. Si has shown to lower severity of fungal disease in many plants (Datnoff *et al.,* 1997, Cai *et al.,* 2008). It acts as physical barrier, preventing physical penetration and or making the plant cells less susceptible to enzymatic degradation by fungal pathogen (Heine *et al.,* 2007). Silica functions as signal to induce the production of various chemical defence against pathogen and activates defence mechanism in cucumber against *Pythium* by showing enhanced activity of chitinases, peroxidases, polyphenol oxidases and accumulation of phenolic compounds.

Peak Performance Nutrient (PPN) contains a plenty of water-soluble nutrients in a balanced way, which is carefully extracted from the natural sources. It stimulates growth, yield, quality, nutrient concentration and taste of agricultural crops. It can also mitigate the problem of crop productivity because it is an eco-friendly mineral nutrient supplement serving as a liquid concentrate of natural assortment for agricultural crops.

Salicylic acid (SA) is a monohydroxy benzoic acid ($C_7H_6O_3$ or HOC_6H_4COOH) and thus a phenolic compound that occurs as a natural compound in plants. Many benzoates and their derivatives are known as fungicides, and although most researchers have stated that salicylic acid has no antimicrobial effect, others have shown a direct effect. Salicylic acid indeed is a key plant hormone regulating plant immunity. It can regulate many different responses such as tolerance to abiotic stress, plant growth and development and soil microbiome. It is also a defence related plant hormone that plays a key role in resisting to different microbial pathogen such as virus, bacteria, fungi and oomycetes.

Phosphorus is an essential plant nutrient. It can be key to plant wellness. It is responsible for assisting with the growth of roots and flowers and also helps plants withstand environmental stress. It is an important nutrient to encourage root growth on any plants. Roots are the foundation of the plant, and having a healthy, web-like root system is crucial to ensuring a healthy plant. It improves flower formation and seed production because paying attention to flower formation is crucial for any landscaper or homeowner installing a landscape. But, it's also important for growers, because flower formation is the leading indicator to a healthy fruit set. Phosphorus improves plant resilience against disease and helps strengthen the plant for unfavourable environment.

Potassium (K) is an essential nutrient that affects most of the biochemical and physiological processes that influence plant growth and metabolism. It also contributes to the survival of plants exposed to various biotic and abiotic stresses. Potassium is associated with the movement of water, nutrients and carbohydrates in plant tissue. It’s involved with enzyme activation within the plant, which affects protein, starch and adenosine triphosphate (ATP) production. The production of ATP can regulate the rate of photosynthesis. Potassium also helps regulate the opening and closing of the stomata, which regulates the exchange of water vapor, oxygen and carbon dioxide. If K is deficient or not supplied in adequate amounts, it stunts plant growth and reduces yield. K fertilizer is widely reported to decrease insect infestation and disease incidence in many host plants. Perrenoud (1990) found that the use of K significantly decreased the incidence of fungal diseases by 70%, bacteria by 69%, insects and mites by 63%, viruses by 41% and nematodes by 33%. Meanwhile, K increased the yield of plants infested with fungal diseases by 42%, bacteria by 57%, insects and mites by 36%, viruses by 78% and nematodes by 19%.

Fungicide is being used to control this disease now a days. But the practice is highly risk for public health as the green fruit is eaten with cooking. These toxic chemicals directly enter into human tissue, get deposited and at critical concentration cause serious health hazards. This realization emphasizes the importance of eco-friendly/organic chemical approach in controlling the disease, which are safe for human health as well as for the environment.

Therefore, in light of the above facts, the present study was carried out with the following objectives:

-To study disease development with respect to symptoms, signs and identify the pathogen

-To detect and evaluate the fungicidal performances in respect of yield and yield containing characters

-To evaluate the efficacy and suitability of Potassium and sulphur containing fungicides to control powdery mildew disease in field conditions

CHAPTER II

REVIEW OF LITERATURE

Powdery mildew is a common fungal disease of bottle gourd. Research works on management of this disease of bottle gourd in various parts of the world including Bangladesh is not adequate and conclusive. The present chapter was attempted to collect the literature regarding the severity and various management aspects of this disease of bottle gourd and other cucurbitaceous crops. Some of the important findings have been reviewed below, which would be useful and relevant to the present study:

2.1. Etiology

There have been one genus and four species of the casual organism of powdery mildew recorded on the major species of the family cucurbitaceae. These include *Erysiphe cichoracearum* Dc ex Mecat, *Erysiphe communis* (Wallr) link, *Erysiphe polygoni* (DC) St-Amm., and *Erysiphe polyphaga* Hammarlund. The most commonly recorded species is *Erysiphe Cichoracearum*. More than one species may occur in the same locality and on the same plant (Spencer, 1978).

The cucurbit powdery mildew pathogens are classified as being in the class ascomycetes, order erysiphales, family erysiphaceae and genus and species as *Erysiphe cichoracearum*. Classification to genus has been based on the perfect stage, characteristics of mycelium location, the type of appendages on cleistothecium and the number of asci in the cleistothecium (Ainsworth and Bisby, 1950).

The mycelium grows closely appressed to the host, tending to follow the depressions at the contact of two epidermal cells. Hyphal cells are thin walled, uninucleate and vacuolate with large nuclei. Along the hyphae are lateral swellings or appressoria, one on each alternate hyphal cell. Appressoria are lobed. Haustoria arise from the center of attachment and penetrate host cell by a very narrow penetration tube. Most haustoria are uninucleate and globular (Yarwood, 1957). Cleistothecia of *Erysiphe cichoracearum* which occur very infrequently are 80–140 pm in size and contain 10–50 asci. Each ascus is narrowly to broadly ovate, more or less stalked and 30–35 µm × 55–90 µm in size (Spencer, 1978). (Dixon, 1981).

Conidia of the species are 4–5 µm × 5–7 µm in size, continuous, elliptic, hyaline and are borne in chains on short unbranched conidiophores. Conidiophores occur at right angles to the host surface. There is a stipe of one or more cells attached to the vegetative hyphae or generative cell (Walker, 1952). The conidia of *Erysiphe cichoracearum* does not contain any fibrosis bodies (Dixon, 1981). Chupp (1960) indicated that *Erysiphe cichoracearum* produces a somewhat flour white fruiting layer on the foliage.

2.2. Host range

Spencer (1978) stated that there are about 90 genera and 750 species in the family cucurbitaceae that are susceptible to powdery mildew. Out of these only six genera and twelve species are cultivated by man and these are: watermelon (*Citrullus lanatus* L.), cucumber (*Cucumis sativus L*.), muskmelon (*Cucumis melo* L.), gherkin (*Cucumis anguria* L.), dish rag gourd (*Luffa Cylindrica* Roem), white flowered gourd (*Lageneira Siceraria*), squashes and marrow (*Cucurbita pepo* L.), *Cucurbita maxima*

Dusch, and *Cucurbita moschata*poir, pumpkin (*Cucurbita mixta* Pang), fig leaf gourd (*Cucurbita ficifolia* Beuche) and chayote (*Sechium edule* sev). He indicated that all these species are sensitive to powdery mildew. This list of cultivated cucurbits is inadequate as it excludes some important tropical cucurbits such as karela (*Momordica charantia* L.). Majority of cucurbits both cultivated and wild are sensitive to powdery mildew.

Other hosts of *Erysiphe cichoracearum* are aubergine (*Solanum melongena*), bean (Phaseolus species), okra (*Hibiscus esculentus*), Soybean (*Glycine max*) and Vigna species. A large number of physiological variants have been reported (Dixon, 1981).

2.3. Symptoms and signs

Symptoms on cucurbits are similar to those of powdery mildews on other hosts. The first symptoms are tiny, white round superficial spots on leaves and stems which become powdery in consistency as they enlarge. These white lesions increase in number and coalesce and eventually may cover the stems and both surfaces of the leaves. Infection on young leaves may result in general chlorosis and eventually death of the leaves. Severely affected leaves become brown and shriveled. Under ideal conditions premature defoliation may occur as the fungus covers the leaf surface (Spencer, 1978).

Fruits are usually not infected but may ripen prematurely and lack flavor. The chief effect of the pathogen is to reduce fruit quality rather than weight or fruit number (Dixon, 1981). Roots are not attacked and fungal growth on herbaceous plants usually stops above the ground line.

The sexual stage of the fungus has been found a few times. The diagnostic sign is the number of small, black, globose fruiting bodies on the plant surface. They are large enough to be seen without the aid of a hand lens (Chupp, 1960).

2.4. Epidemiology

Cucurbit powdery mildew is generally favored by dry atmospheric and soil conditions, moderate temperatures, reduced light intensity, fertile soil and succulent plant growth (Yarwood, 1957).

Tolerance of cucurbit powdery mildew to heat is usually lower than that of the host. Cucurbit powdery mildew is able to thrive in hot climates because vines shade the ground and mycelium develops on the underside of the leaves (Walker, 1952).

The optimum relative humidity for germination of fungal spore of powdery mildew is near 100% but spores germinate in relative humidities as low as below 20% (Roberts, 1984; Spencer, 1978). Free water on the infection court is deleterious to spore germination. This fact implies that conidia have a higher water content and extremely efficient water conservation system. Water is needed for germination of spores but it is present in the spores (Yarwood, 1957). The relative importance of cucurbit powdery mildew in different regions is correlated with rainfall in those areas. Incidence of the disease increases as rainfall decreases (Spencer, 1978).

Powdery mildew develops better in the shade than in full light. It is more severe in closely spaced plants and under a high carbohydrate level with its subsequent luxuriant growth. Leaves are most susceptible 2–3 weeks after unfolding. The very young folded leaves appear to be immune

(Chupp, 1960). Powdery mildew is more severe in the glasshouse than in the field because of reduced air circulation, reduced light intensities, higher temperatures and continuous cropping (Wellman, 1972).

2.5. Disease introduction and severity of powdery mildew in cucurbits

FRAC Pathogen Risk List (2019) reported that FRAC (Fungicide Resistance Action Committee) and European and Mediterranean Plant Protection Organization (EPPO) classified powdery mildew species depending on the risk of the pathogen developing resistance to fungicides under specific agronomic conditions. In this regard, *Podosphaera xanthii* (cucurbit powdery mildew) was considered to be pathogens with high risk of resistance development because it showed short disease cycles per season, their dispersal through conidia over time and space is high, and they have evolved resistance to several classes of fungicides after a few years of product use. These characteristics make these pathogens serious threats to the commercial success of site-specific fungicides. Other species, such as *Sphaerothe camacularis* (powdery mildew of several hosts) possess medium risk, meaning that resistance is not a major problem or has been slow to develop, and for this reason, in commercial practice, fungicide resistance has not created major disease control problems.

Rur *et al.* (2018) observed that *Podosphaera xanthii* occurs mostly in warmer months whereas Aguiar *et al.* (2012) recorded that *Erysiphe cichoracearum* occurs mostlyin cooler spring and in early summer months.

Sharma *et al.* (2016) described that powdery mildew affects almost all cucurbits under field and greenhouse conditions. It is caused by airborne fungi *Sphaerotheca fuliginea* [(Schlect. ex. Fr.) Poll.] and *Erysiphe cichoracearum* (D. ex. Merfat), the latter being the perfect stage of the fungi. The disease first appears on older leaves. Conidia are produced profusely in the white powdery mycelium, and these spores spread quickly through wind to the adjacent leaves or plants as well as travel over long distances. Powdery mildew appears as talc-like (white fluffy) colonies or circular patches on the under surface of leaves. As the disease progresses, the entire leaf surface is colonized by the fungus. In case of severe infection, the patches on the leaves coalesce and become yellow and necrotic. Such leaves die within a short span of time. The disease is most severe after fruit set and in densely planted fields. Symptoms and signs can also develop on stems and fruit. The infected plant parts remain stunted and distorted and may drop prematurely. The infected fruits do not develop fully; as a result, yield and quality of fruits is affected.

Ali *et al.* (2013) mentioned that powdery mildew disease development is favoured by vigorous plant growth and moderate temperature. The most favourable conditions for disease development are 35°C temperature and high relative humidity of more than 70%.

El-Naggar *et al.* (2012) recorded that powdery mildew disease is widely distributed and destructive among cucurbits in most areas of the world and can be a major production problem causing yield losses of 30%–50%, which can be up to 70%.

Nunez-Palenius *et al.* (2012) observed that if powdery mildew disease is not controlled in time, symptoms can be severe enough to cause extensive premature defoliation of older leaves and wipe out the crop.

McGrath (2011) described that when the majority of the foliage is infected by powdery mildew disease, the plant is weakened and the fruit ripens prematurely and hence reduced healthy seed production.

Lebeda *et al.* (2010) mentioned that powdery mildew disease caused reduction in plant growth, premature defoliation and as a result, both yield and quality of fruits gets reduced that ultimately leads to major production problem.

Vasant and Ashok (2010) recorded that in kharif season, *Sphaerotheca fuliginea* was dominantly present on *Cucurbita maxima*, *Lageneria siceraria* and *Cucurbita pepo*; where as *Erysiphe cichoracearum* noted on *Citrullus lanatus*was not reported in 2005 and 2006. *Cucurbita maxima*, *Lageneria siceraria*, *Luffa acutangula* and *Luffa cylindrical* showed maximum occurrence of *Sphaerotheca fuliginea* in the rabi season. Incidence of powdery mildew was mainly reported on the mature leaves followed by stem. Whereas in some cases it was reported on tendril, flower and fruit. Dominant association of powdery mildew was mainly reported on basal leaf. However, the incidence of powdery mildew was less on the younger leaves of cucurbits. Incidence of powdery mildew was more prevalent at post flowering and fruiting stage. Although powdery mildew was also reported at seedling stage of *Cucurbita pepo* and *Cucurbita maxima*.

Kristkova *et al.* (2009) reported that *Sphaerotheca fuliginea* cannot be cultured on artificial medium.

Pérez-García *et al.* (2009) stated that the difference between the two species *Podosphaera xanthii* and *Erysiphe cichoracearum* can be made according to morphology of the conidia, the presence or absence of fibrosin bodies in interior of the conidia and the morphology of the germinative tube of conidia.

Queiroga *et al.* (2008) described that powdery mass of powdery mildew disease on the leaves decreases the photosynthetic rate, causing reduction in plant growth, premature foliage loss, and consequently reduction in yield.

Cohen *et al.* (2007) mentioned that pathogen growth of powdery mildew reduces the photosynthetic area of the leaves.

Smith (2006) stated that powdery mildew disease is the most damaging if it appears three to four weeks before harvest.

Tisserat (2006) recorded that powdery mildew is the most common disease and can result in yield losses exceeding 30% in sweet gourd.

Mossler and Nesheim (2005) reported that the yield loss due to powdery mildew disease is proportional to the severity of the disease and the length of time that plants have been infected. Powdery mildew occurs to some extent every year and may not be economically damaging in all affected cultivated areas. The fungi causing powdery mildew can infect under relatively dry conditions if the inoculum level is high enough with spores from nearby infected plants. It can become a severe disease when rainfall is low and conditions are dry, such as during winter and spring in Florida.

Mossler and Nesheim (2003) observed that firstly the mature leaves and stems are infected by the powdery mildew fungus resulting in defoliation, reduced photosynthesis and ultimately low yield

Braun *et al.* (2002) mentioned that the two obligate biotrophs (*Podosphaera xanthii* and *Erysiphe cichoracearum*) produced indistinguishable symptoms but can be easily distinguished by light microscopic studies.

Dik and Albajes (2002) described that plant infection due to powdery mildew fungus resulted in reduced sugar contents that decreased quality of fruits and its market value. They mentioned that there was a negative linear relationship between disease severity and yield in cucumber.

Jahn *et al.* (2002) observed that in cucurbits, powdery mildew is caused by three fungal species, *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea auct. p.p.*), *Golovinomyces cucurbitacearum* (syn. *Erysiphe cichoracearum auct. p.p.*) and *Golovinomyces orontii* (syn. *Erysiphe cichoracearum auct. p.p.*).

Jarvis *et al.* (2002) stated that temperature and humidity must be examined together since it is the water vapor pressure deficit (VPD) that has the greatest effect on host–parasite interactions for disease development. During periods of intensive dew on leaf surfaces, the severity of this disease is enhanced. However, excessive water on the leaf surface is often detrimental to the development of powdery mildew disease.

Kristková and Lebeda (2000) and Vakalounaki s*et al.* (1994) recorded that powdery mildew disease in cucurbits is caused by two obligate biotrophs such as *Sphaerotheca fuliginea* (*Syn. Podosphaera xanthii*) and *Erysiphe cichoracearum* (*Syn. Golovinomyces cichoracearum*).

Agrios (1997), Talukdar (1974) and Singh (1985) described that powdery mildew (PM), a fungal disease caused by *Erysiphe cichocearum* is considered a threat for yield reducing factor of the crop.

McGrath and Thomas (1996) described that *Sphaerotheca fuliginea* fungus causes the most devastating disease powdery mildew.

Zitter *et al.* (1996) observed that leaves infected with powdery mildew fungus generally died and wilted as a result plants senesce prematurely.

Bhatia and Thakur (1989), Ghoil *et al*. (1988) and Khosla *et al.* (1988) recorded increase in yield loss with the increase of powdery mildew disease severity of the crops.

Singh (1985) reported that maximum infection of powdery mildew was noticed during February to March when suitable temperature about 26°C to 28°C whereas initial infection was found to occur in December.

Khan (1983) mentioned that *Erysiphe cichoracearum* was considered to be the primary contingent organism around the world before 1958. Today *Sphaerotheca fuliginea* is more commonly found.

Dave *et al.* (1971) and Khan (1983) described that the powdery mildew infected plants show white powder spots on the leaves and stems. The lower leaves or young leaves are most affected, but mildew can be seen on any upper part of the plant. As the disease progresses, the spots become larger and a large number of asexual spores are formed, and with high humidity and moderate temperature, the mold increases well in the environment.

2.6. Management of powdery mildew disease on bottle gourd plants

Tetarwal *et al.* (2020) conducted a study to test the effect of fungicides and natural products for managing the powdery mildew of bottle gourd caused by *Podosphaera fuliginea* under field conditions. Required quantities of fungicides (Wettable sulphur 80% WP, Dinocap 48% EC, Propiconazole 25% EC, Azoxystrobin 25% EC, Tebuconazole 55% + Trifloxystrobin 25% WG) and natural products (Fermented cow urine 20%, Fermented butter milk 20%, Fermented leaf-extract of neem, dhatura, sitafal 20%, Fermented cow urine, butter milk, leaves of (neem, dhatura, sitafal) in combination 20% Bioformulation of *Trichoderma harzianum* 2×10^6 $cfu \cdot g^{-1}$). Control was maintained by water spraying (400 $lit \cdot ha^{-1}$) and without spraying of any fungicides. All the treatments were found significantly superior over check in controlling the disease and yield. Propiconazole (0.025 %) was the most effective fungicide with 30.30% least mean disease intensity followed by wettable sulphur (0.25%), with 33.10% mean disease intensity. Tebuconazole + trifloxystrobin, dinocap, azoxystrobin and water were found moderately effective with 34.21%, 36.46%, 39.94% and 46.20% disease intensity, respectively. Disease control ranged from 19.03% to 60.78%. Maximum disease control of 60.78% was observed in the treatment of propiconazole followed by wettable sulphur by 53.92% as compared to control. Maximum per cent yield increase was found in the treatment propiconazole (42.76%) followed by wettable sulphur (38.97%). The other treatments like tebuconazole + trifloxystrobin, dinocap, azoxystrobin, and water spray gave 35.66%, 34.13%, 19.41% and 10.75% yield increased, respectively over the control. All the natural products tested reduced the disease significantly as compared to the control. The fermented leaf-extract of neem, dhatura, and sitafal (20%) was the most effective natural products with 35.72% least mean disease intensity followed by fermented cow urine, butter milk, leaves of neem, dhatura, and sitafal in combination (20%) with 37.71% mean disease intensity. Fermented butter milk, fermented cow urine, bioformulation of *Trichoderma harzianum* 2×10^6 cfu·g^{-1} and water were found moderately effective with 40.52%, 40.58%, 42.76% and 44.77% disease intensity, respectively. Maximum disease control of 44.33% was also observed in the treatment of fermented leaf-extract of neem, dhatura, and sitafal followed by treatment fermented cow urine, butter milk, leaves of neem, dhatura, and sitafal in combination by 38.96% as compared to control. All the natural product treatments significantly increased the bottle gourd yield as compared to control. The highest bottle gourd yield of 126 qtl·ha^{-1} was obtained in the treatment of fermented leaf-extract of neem, dhatura, and sitafal followed by fermented cow urine, butter milk, leaves of neem, dhatura and sitafal in combination with 106 qtl·ha^{-1}. The other treatments *viz.*, fermented butter milk, fermented cow urine, bioformulation of *Trichoderma harzianum* 2×10^6 cfu·g^{-1} and water gave significantly higher yield as compared to control.

Rahman and Afroz (2016) carried out an experiment where forty-three germplasm of bottle gourd and six fungicides were evaluated against powdery mildew caused by *Erysiphe cichocearum* under artificially inoculated pot and field conditions. There six fungicidal treatments which were used in this experiment as follows: (i) Score @ 0.05% (ii) Thiovit @ 0.2% (iii) Silika @ 0.2% (iv) Sulpher @ 0.2%, (v) McSulpher @ 0.2%, (vi) Indofil M @ 0.2% and (vii) Control (Water spray). Score, Thiovit, Silika and McSulpher gave enough protection to the crop against powdery mildew by >80%. Additional 20.8–51.8% increased yield obtained from Score, Thiovit and Silika treated plots. The highest yield increased by 51.8% was observed in Score treated plot. The researchers concluded that, S-fungicides along with propiconazole should be used to control powdery mildew of bottle gourd seed crop to get mature seeds and ultimately safe crop from damage.

Srinivas (2006) set up an investigation where attempts were made to explore the potential use of biotic and abiotic agents to induce resistance in bottle gourd against *Sphaerotheca fuliginea* (causal organism of powdery mildew disease) as an alternative to fungicidal application. Green house studies established that foliar spray of cattle manure-based compost teas was significantly superior over control in managing powdery mildew. Disease control ability of compost tea has significantly increased when compost is fortified with toddy. The highest disease reduction of 70.29% was recorded by the treatment of cattle manure + toddy (1:6 + 10%) followed by 62.28% with cattle manure + paddy straw + biocontrol agent, *Pseudomonas fluorescens*. Foliar spray of potassium sodium salts and salicylic acid at different concentrations on lower leaves were evaluated for induction of systemic resistance in upper leaves of bottle gourd against *S. fuliginea*. Maximum mean per cent disease reduction over control was recorded with salicylic acid 15 mM (77.79) followed by salicylic acid 10 mM (71.94), monopotassium phosphate 100 mM (71.13), respectively. Similarly, spray of these chemicals on upper leaves and lower leaves were challenge inoculated with *S. fuliginea*. The maximum mean per cent disease reduction overcontrol was recorded with salicylic acid 15 mM (69.65) followed by monopotassium phosphate (63.71), respectively. The resistance induced by all the chemicals was systemic and it is mobile both apoplastically and symplastically. Foliar spray of talk-based powder formulations of *Pseudomonas fluorescens*, *Bacillus subtilis*, *Trichoderma viride* showed 41.47%, 30.63% and

17.19% disease reduction over control. Foliar spray of compost tea, inducer chemicals and *P. fluorescens* and their combination were evaluated for induction of resistance in bottle gourd against *Sphaerotheca fuliginea* under field conditions. Maximum mean per cent disease reduction of 51.77% was recorded over control with compost tea and salicylic acid (1:6 + 10 mM) followed by compost tea and monopotassium phosphate (1:6 + 75 mM) and salicylic acid alone (10 mM), 45.75 per cent. Foliar application of combined treatments was more effective than the individual treatments in inducing resistance in bottle gourd against *S. fuliginea*.

Tripathi *et al.* (1995) conducted an experiment to study the chemical control of powdery mildew disease of bottle gourd. The researchers from their experiment reported that Dinocap (karathane) was the most effective chemical fungicide to control powdery mildew disease of bottle gourd.

Waraitch *et al.* (1975) set up an experiment to study fungicidal control of powdery mildew of bottle gourd. They reported that powdery mildew disease of bottle gourd could be prevented and effectively controlled by early application of fungicides like karathane.

2.7. Management of powdery mildew disease on different cucurbitaceous plants

Miyamoto *et al.* (2020 a) conducted a study to investigate the sensitivity of the cucurbit powdery mildew pathogen to the benzoylpyridine pyriofenone and flutianil. In that study, which was conducted in Japan, 89 out of 122 *Podosphaera xanthii* isolates were highly resistant to benzoylpyridine pyriofenone, having EC_{50} values of >1000 mg·L^{-1} of the formulated product and a resistance factor (RF, calculated by dividing the mean of EC_{50} values of the resistant population by the mean of EC_{50} values of the sensitive population) of >1840. In case of flutianil, the first case of resistance was documented in Japan. In that study, 89 out of 122 *P. xanthii* isolates were highly resistant to flutianil, exhibiting EC_{50} values of 100 $mg \cdot L^{-1}$ of the formulated product and RF of >375.000. Flutianil resistance remained stable after 46 subcultures of the isolates. In addition, cross-resistance to benzoylpyridine pyriofenone was also suggested.

Miyamoto *et al*. (2020 b) carried out field experiments where 127 Japanese fungal isolates of *Podosphaera xanthii* (causal agent of powdery mildew disease) on cucumber were tested to check their sensitivity to the commercial fungicides isofematid, isopyrazam, penthiopyrad and pyraziflumid. The results showed that 42.5% of the *P. xanthii* isolates had moderate levels of resistance to penthiopyrad (EC_{50} = 335.1–787.6 $mg \cdot L^{-1}$), isopyrazam (EC_{50} = 77.4–266.5 $mg \cdot L^{-1}$) and pyraziflumid (EC_{50} = 9.2–31.2 $mg \cdot L^{-1}$); 44% of the *P. xanthii* isolates had high levels of resistance to penthiopyrad (EC_{50} > 1000 $mg \cdot L^{-1}$), isopyrazam (EC_{50} > 1070 $mg \cdot L^{-1}$) and pyraziflumid (EC_{50} > 1000 $mg \cdot L^{-1}$); finally, only 1.5% of the *P. xanthii* isolates showed high levels of resistance to isofatamid (EC_{50} > 2400 $mg \cdot L^{-1}$).

Yousaf *et al.* (2020) set up a study to minimize significant economic losses occurred due to powdery mildew disease of cucurbits, caused by *Sphaerotheca fuliginea,* by using different combinations of fungicides and nutritional amendments. Fungicides Bravo (Chlorothalonil) and Score (Difenoconazol) and nutrient solutions of Agsil (Potassium silicate) and Peak (mono potassium phosphate) were applied alone and in combination to manage the disease. Bravo and Score were applied @ 1.5 $ml \cdot L^{-1}$ and 2.5 $ml \cdot L^{-1}$, respectively while 0.1% solutions of both Agsila and Peak was used. The findings described the combination of fungicides was the most efficient in decreasing disease incidence as it reduced the powdery mildew incidence up to 60%. In individual fungicidal applications, Bravo treated plants showed less disease incidence (36%) than Score (40%). However, to avoid the environmental hazards, nutritional amendments was the safest option which gave 50% reduction in disease incidence. Agsil was more effective than Peak in individual applications and it showed 47% disease incidence that was 49% in case of Peak.

Abd-Elsayed *et al*. (2019) evaluated the efficiency of some fungicides and resistance inducing chemicals for management of cucumber powdery mildew disease, *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea* auct. p.p.), for their effects against conidial spores' germination of *Podosphaera xanthii* the *in vitro* tests and severity of cucumber powdery mildew disease under greenhouse and field applications. Five fungicides *i.e.* Topas, Score, Flent, Thiovit jet and Actamyl at doses of 30 ml, 50 ml, 20 g, 250 g and 80 g/100 L, respectively and two resistance inducing compounds (RICs), *i.e.* potassium nitrate (KNO_3) and potassium mono-hydrogen-phosphate (K_2HPO_4), were applied. The tested fungicides were significantly inhibited the conidial spore germination of fungus than RICs as well as the control. A significant decrease also was obtained in the disease severity (DS) and the area under disease progress curve (AUDPC) in greenhouse experiment, where the tested fungicides were more effective. Under natural infection, the tested fungicides were highly reduced the DS and AUDPC than other treatments in field experiments during 2017 and 2018 growing seasons. When the tested fungicides alternated with RICs were more effective and resulted highly increased the fruit yield (quality and quantity) than the tested fungicides and RICs individually in both seasons.

Vielba-Fernández *et al*. (2019), Bellón-Gómez *et al*. (2015), Lebeda*et al*. (2010) and Sedláková and Lebeda (2008) performed several field researches separately to observe the resistance to fungicides in cucurbit powdery mildew populations in different countries. Strong selection of MBC-resistant (Methyl-Benzimidazole Carbamates) isolates of cucurbit powdery mildew pathogen with very high frequencies of resistance (> 90%) to thiophanate-methyl was observed in Austria, France, Italy, Spain and the Czech Republic. Cucurbit powdery mildew isolates presenting MIC (Minimal Inhibitory Concentration) values of > 1000 $mg \cdot L^{-1}$ of the formulated product were observed very often; this concentration was considerably higher than that recommended and sprayed in cucurbit fields.

Keinath *et al*. (2018) in South Carolina; McGrath and Wyenandt (2017) in New York and New Jersey and Miazzi and McGrath (2008) in Georgia reported boscalid-resistant isolates of *Podosphaera xanthii* (causal agent of cucurbit powdery mildew disease) separately in their respective research studies in the United States.

McGrath and Sexton (2018) recorded that 73% and 46% of the *P. xanthii* isolates (causal agent of cucurbit powdery mildew disease) which were collected from several cucurbit fields in the United States, showed a reduced sensitivity to cyflufenamid; being able to develop at 10 $mg \cdot L^{-1}$ and tolerate 50 $mg \cdot L^{-1}$ of this commercial fungicide, respectively. In addition, the isolates of *P. xanthii* showed resistance to other non-related chemical groups, such as the aryl-phenyl-ketone metrafenone, the aza-naphthalene quinoxyfen, the DMI (Demethylation Inhibitors) fungicide myclobutanil, the QoI (Quinone outside inhibitors) fungicides and SDHI (Succinate Dehydrogenase Inhibitors, also known as carboxamide) fungicide boscalid.

McGrath (2017) reported that in 2015, 21 out of 57 *Podosphaera xanthii* isolates (causal agent of cucurbit powdery mildew) which were collected from New York, were able to tolerate 200 $mg \cdot L^{-1}$ of the commercial fungicide quinoxyfen.

Mike and Quesada-Ocampo (2017) carried out an experiment to evaluate the fungicides for controlling powdery mildew of winter squash. The researchers showed that cyflufenamid was the lesser effective fungicide against powdery mildew disease of winter squash. The study was performed in the state of Ohio, Cleveland in the US.

Dutta *et al.* (2016), Soad (2010), Ashour (2009) and Abada*et al.* (2008) stated from their separate research works that resistance inducing chemicals had reducing effects on fungal diseases including powdery mildew in many plants.

Sharma *et al.* (2016) suggested spraying of sulfur-based fungicides like Karathane (0.05%) or Hexaconazole (0.1%) for effective control of powdery mildew disease. Most of the fungicides to control powdery mildew are primarily preventive, that is, they are effective when applied before the disease appears. The researchers suggested that fungicides should be applied at an interval of 7–10 days with the appearance of early disease symptoms of powdery mildew.

McGrath (2016), Miazzi and McGrath (2008) and Schepers (1985 b) reported multiple resistance to several DMIs (Demethylation Inhibitors) and non-related fungicides, such as boscalid and quinoxyfen, in the cucurbit powdery mildew in the Netherlands and US.

Bellón-Gómez *et al*. (2015) performed a study to measure the sensitivity of *Podosphaera xanthii* populations to anti-powdery-mildew fungicides in Spain. The researchers reported two highly resistant *P. xanthii* isolates with a minimal inhibitory concentration (MIC) value for bupirimate of 1000 $mg \cdot L^{-1}$ of the formulated product, which was 2.6-fold higher than the maximum dose (375 $mg \cdot L^{-1}$) recommended to control the disease in the field.

Mane (2015) concluded that plants sprayed with Carbendazim (1 $ml \cdot litre^{-1}$ of water) immediately after the appearance of the disease were found effective against powdery mildew of bitter gourd. Two to three sprays were done at an interval of 15 days.

Pirondi *et al*. (2014) reported that *Podosphaera xanthii* isolates(causal agent of powdery mildew), which were collected from melon and zucchini fields in Italy, were uncontrolled with cyflufenamid. The researchers suspected that, in those melon and zucchini fields, the fungicide cyflufenamid was applied above the recommended field rate over a few years.

Stoyka *et al.* (2014) recorded that white mustard oil at 1% as botanical product was found to be effective against powdery mildew on cucumber in greenhouses.

Ali *et al.* (2013) carried out a study to determine effect of mono-potassium phosphate and potassium silicate on powdery mildew (*Sphaerotheca fuliginea*) on pumpkin (*Cucurbita pepo* L.) and environmental conditions conducive for development of disease. A susceptible variety (Mahadeev) was sown. Three sprays of 1% nutrient solution (mono-potassium phosphate and potassium silicate) and their combination were sprayed on pumpkin plants before inoculation of spore suspension at 7 days interval and compared with control under field conditions. Combine effect of mono-potassium phosphate and potassium silicate expressed minimum disease incidence (33.59%) followed by potassium silicate (38.87%) and of mono-potassium phosphate (44.33%) as compare to control (75.65%).

Matheron and Porchas (2013) conducted field trials with cantaloupe to compare powdery mildew disease of cucurbits, caused by *Podosphaera xanthii* (syn.*Sphaerotheca fuliginia* auct. p.p. (Schltdl.) Pollacci), management success provided by conventional fungicides and bio fungicides having different inherent efficacies and modes of action, when applied alone throughout the treatment period or as components of fungicide application programs. When applied alone throughout the treatment period, disease severity in 2008 and 2009 compared with nontreated plants was reduced by values of 100%, 99.3%, and 98.1% by wettablesulfur (Microthiol Disperss), triflumizole (Procure), and quinoxyfen (Quintec), respectively; 83.9%, 76.4%, and 57.4% by trifloxystrobin (Flint), pyraclostrobin (Cabrio), or azoxystrobin (Quadris), respectively; and 39.8%, 31.1%, 30.0% and 28.6% by thiophanate-methyl (Topsin M), potassium bicarbonate (Kaligreen), kresoxim-methyl (Sovran), and *Bacillus subtilis* (Serenade), respectively. Rotational application programs composed of Microthiol Disperss, Procure, and Quintec reduced powdery mildew severity on cantaloupe by 97.5% to 100% in both trials. In comparison, disease reduction of 86.0% to 100% was achieved when the first and third fungicide applications were Quintec or Procure and the second and fourth applications were Cabrio, Flint, Kaligreen, Quadris, Serenade, Sovran, or Topsin M. In field trials designed to elucidate the portion of total disease control provided by each component fungicide within a rotational program, application sequences of Procure, *Streptomyces lydicus* (Actinovate), Procure, and Actinovate or Procure, Kaligreen, Procure, and Kaligreen resulted in reductions in powdery mildew severity of 69.1% and 78.7%, respectively. In comparison, inclusion of only the two Procure applications brought about a mean disease reduction of 85%, whereas inclusion of only the two Actinovate or Kaligreen applications reduced the level of powdery mildew control to 17.6% and 12.9%, respectively.

McGrath (2013) observed from her experiment that 24% and 4% of *Podosphaera xanthii*-resistant isolates (causal agent of cucurbit powdery mildew) collected from New York were able to grow at 40 $mg{\cdot}L^{-1}$ and 80 $mg{\cdot}L^{-1}$ of the commercial fungicide quinoxyfen formulation, respectively.

Dallagnol *et al.* (2012) observed the effects of silicon (Si) supplied in the form of potassium silicate (PS) on epidemic components of powdery mildew of melon under greenhouse conditions. The PS was applied to the roots or to leaves. The area under the disease progress curve was reduced by 65% and 73% in the foliar and root treatments, respectively, compared to control plants, as a consequence of reductions in infection efficiency, colony expansion rate, colony area, conidial production and disease progress rate. However, root application of PS was more effective than foliar application in reducing most of the epidemic components, except for infection efficiency. This can be explained by the high Si concentration in leaf tissues with root application, in contrast to the foliar treatment where Si was only deposited on the external leaf surfaces. The effects of PS reported in this study demonstrated that powdery mildew of melon can be controlled, and that the best results can be achieved when PS is supplied to the roots.

El-Naggar *et al.* (2012) evaluated the efficiency of some biocide's resistance and a systemic fungicide on suppressing of *Sphaerotheca fuliginea* as well as controlling powdery mildew of cucumber under plastic house conditions. Different degrees of reduction in powdery mildew occurred when the tested biocides, i.e. *Trichoderma viride*, *Amplomyces quisqualis*, *Pseudomonas fluroscens*, *Bacillus subtilis*, *Candida tennis* and *Tilleliopsis pallescens* and the systemic fungicide, pyrazophos 12% (Afugan) were used. The systemic fungicide was more efficient than biocides. Spraying cucumber plants with the tested biocides and fungicide for three times at 10–15 days intervals significantly reduced the percentage of infected plants, number of infected leaves and the severity of powdery mildew as well as increased the yield (Kg·plant^{-1}) compared with control treatment. On the other hand, spraying cucumber plants under plastic house during growing season with any of the fungicide or each of biocides alone resulted in a significant decrease in the severity of the disease with significant increment in the cucumber yield compared with the control treatment. In addition, *Ampelomyces quisqualis* and *Tilleliopsis Pallescens* showed the best results to control powdery mildew.

Keinath and DuBose (2012) carried out an experiment on controlling powdery mildew on cucurbit rootstock seedlings in the greenhouse with fungicides and bio fungicides. Powdery mildew (*Podosphaera xanthii*) affects seedlings of inter-specific hybrid squash (*Cucurbita moschata* × *Cucurbita maxima*) and bottle gourd (*Lagenaria siceraria*) used as rootstocks to graft seedless watermelon (*Citrulluslanatus* var. lanatus). Because powdery mildew grows primarily on the leaf surface where contact fungicides are effective, bio fungicides may be effective preventative treatments for powdery mildew. The objectives of this study were to determine which bio fungicides, organic fungicides, and conventional synthetic fungicides provided the best control of powdery mildew and least phytotoxicity on cucurbit rootstock seedlings in the greenhouse. Sixteen treatments (six biopesticides, four additional organic-approved fungicides, and six conventional synthetic fungicides) were tested. Four experiments were conducted and all were repeated once. Hybrid squash 'Strong Tosa' seedlings were used in the first three experiments, and bottle gourd 'Emphasis' seedlings were used in experiment four. In experiments one, two, and four, seedlings were sprayed three times at 5-day intervals and exposed to powdery mildew continuously after the first application. In the third experiment, seedlings were exposed to inoculum for 7 days, sprayed once, and held in a humidity chamber for 7 days under conditions used for healing after grafting. The most effective organic-approved fungicides were sulfur and fish oil + sesame oil, and the most effective conventional fungicides were penthiopyrad, myclobutanil, and cyprodinil plus fludioxonil. Quinoxyfen was phytotoxic to cotyledons of both species, and tebuconazole stunted both species. To manage powdery mildew, one or two preventative applications of sulfur or fish oil + sesame oil and one application of myclobutanil or penthiopyrad, if needed, were recommended.

Naidu *et al.* (2012) conducted a study to observe the effects of microbial-enriched compost tea (CT) on the conidial germination of *Golovinomyces cichoracearum* DC. and development of powdery mildew on melons in a time-dependent manner. In vitro conidial germination was significantly reduced by 94% and 85% upon treatment with Daconil® (fungicide) or microbial-enriched CT, respectively, 96 h after incubation (hai).

Morphological analysis under light microscopy demonstrated that conidia co-incubated with microbial-enriched CT at 48 hai appeared ruptured, which contributed to higher inhibition of conidial germination, increased cell permeability and leakage of cellular contents. These observations may be explained by antibiosis. Moreover, different application time of microbial-enriched CT on melons significantly affected disease development. There was a delay in disease development by 12 days in plants treated with Daconil ®, microbial-enriched CT applied 24 h after inoculation and microbial-enriched CT applied simultaneously with inoculation when compared to the control treatment. Curative application of microbial-enriched CT (24 h after inoculation) delayed the onset of disease, and the efficiency of inhibition was comparable to a fungicidal spray (Daconil ®).

Nunez-Palenius *et al.* (2012) reported that biological control which involved the use of fungal spores of *Ampelomyces quisqualis* Ces., parasitized and destroyed the powdery mildew pathogens. Similarly, they also observed that bacteria *Bacillus subtilis* and fungus *Sporothrix flocculosa* (syn. *Pseudozyma flocculosa*) gave promising results and prevented the powdery mildew from infecting the cucurbit plant. Petroleum spray oils, milk, and bicarbonates offered some level of control. Neem oil helped in effective management, but the harmful effects on beneficial insects render it impractical. However, cinnamon oil was found effective against powdery mildew of cucurbits. Most of these natural oils had to be applied repeatedly during the active growing season in order to achieve a reliable level of control over the disease-causing pathogens. Thus, these natural products for controlling powdery mildew of cucurbit costed much higher than the chemicals.

Sedláková *et al*. (2012) and Lebeda *et al*. (2010) recorded that fungal isolates of *P. xanthii* and *Golovinomyces cichoracearum* showed resistance to strobilurin fungicides or QoI fungicides [Quinone outside inhibitors], developing cucurbit powdery mildew disease at commercial azoxystrobin doses of above 500 mg·L^{-1} in the Czech Republic.

Sedláková *et al*. (2012), Lebeda *et al*. (2010), Sedláková and Lebeda (2008) and Sedláková and Lebeda (2004) performed several surveys from 2001 to 2007 to observe the resistance to fungicides in cucurbit powdery mildew populations in the Czech Republic. They reported that benomyl was not effective in controlling any cucurbit powdery mildew, neither of *P. xanthii* or *G. cichoracearum,* with the frequency of resistant isolates of the aforementioned pathogen being higher than 90% in most of the years sampled.

Ishii *et al*. (2011) from their investigative study showed cross-resistance of *Podosphaera xanthii* (causal agent of powdery mildew disease) to boscalid and penthiopyrad but not to fluopyram.

McGrath (2011) stated that control of powdery mildew disease of cucurbits is best accomplished by using systemic materials (i.e. triadimefon, benomyl, thiophanate-methyl). Another approach to improve the efficacy of contact materials (i.e. chlorothalonil, copper) should be by maximizing spray coverage on under surfaces of leaves of summer squash and pumpkin.

Zhang *et al*. (2011) evaluated efficacy of four microbial products (i.e., Actinovate AG, Companion, BU EXP 1216C, and BU EXP 1216S), which contain microbes as the active ingredient, on summer squash and cantaloupe against powdery mildew, caused by *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea auct. p.p.*), when applied alone or in alternation with a half-rate of conventional fungicide under greenhouse and field conditions. The products evaluated in this study were Actinovate AG, which contains 0.0371% of *S. lydicus* WYEC 108 (1 × 107 CFU g^{-1}; Natural Industries, Inc., Houston); Companion, which contains 0.03% *B. subtilis* GB03 (1.5 × 107 CFU ml^{-1}; Growth Products, Ltd., White Plains, NY); and BU EXP 1216C and BU EXP 1216S, which contain the same active ingredient (i.e., 2.75% *B. subtilis* MBI600, 5.5 × 1010 CFU g^{-1}) but which differ in the diluents used to normalize spore counts and act as the carrier for the products (Becker Underwood, Ames, IA). BU EXP 1216S has a water-soluble diluent whereas BU EXP 1216C has a water-insoluble diluent. Procure 480SC (Chemtura Corporation, Middlebury, CT), a systemic fungicide registered on cucurbits for powdery mildew control, was included in all experiments as a conventional fungicide. In greenhouse experiments, the product BU EXP 1216S significantly reduced the disease severity by nearly 70% relative to the water control. The level of control achieved was not significantly different from that obtained with Procure 480SC (triflumizole), the half-rate of conventional fungicide treatment, in two of four greenhouse experiments. Compared with the untreated water control, BU EXP 1216C and BU EXP 1216S, when applied alternately with Procure 480SC, consistently promoted plant growth measured by plant height, stem caliper, total fresh weight, and chlorophyll content in the leaves. The degree of increase was 11.6% and 11.3% in plant height, 15.6% and 19.8% in stem caliper, 25% and 40.7% in chlorophyll content, and 164% and 250% in total fresh weight, respectively. Alternating applications of these products with Procure 480SC resulted in significantly less powdery mildew disease than in the water control. In the first field trial on summer squash, all products applied individually or in alternation with Procure

480SC significantly reduced the severity of powdery mildew at the early stage (60 days after planting [DAP]) of disease development. Moreover, these alternating treatments resulted in significantly better control than with Procure 480SC alone at the late assessment stage (88 DAP). The products in alternation with Procure 480SC had a level of disease reduction equivalent to Procure 480SC alone on cantaloupe and significantly reduced disease severity in comparison with the water control. Compared with applying the microbial products alone, alternating applications of these products with Procure 480SC significantly reduced disease severity on cantaloupe and improved the marketable fruit number and weight. The data from these studies suggested that these microbial products could be effectively incorporated into disease management programs. In particular, these microbial products could be integrated into the management of powdery mildew on summer squash and cantaloupe in Florida by alternating their application with low rates of conventional fungicides, potentially reducing the development of fungicide resistance in the pathogen population.

Keinath *et al*. (2010) reported that penthiopyrad was effectivefor controlling powdery mildew *on Cucurbita pepo* in the field. Quinoxyfen was also effective in the field against powdery mildew disease.

Langston Jr. and Sanders Jr. (2010) conducted a field experiment for evaluation of selected fungicides for control of powdery mildew in summer squash in Georgia. All the treatments significantly reduced powdery mildew on the upper sides of the leaves, while Adament, Sonata, and Sonata + Procure were the only treatments not significantly better than the nontreated control on the lower leaves. All treatments except those receiving the low rate of Adament, Prevam + Nova, Sonata + Procure and the Sonata alone treatment, significantly reduced powdery mildew on the upper leaf surface while no treatments reduced powdery mildew on the lower leaves. No phytotoxicity was observed.

Lebeda *et al*. (2010) set up a field research to observe the variation for fungicide resistance among cucurbit powdery mildew populations in the Czech Republic. The expansion of DMIs (Demethylation Inhibitors, e.g. fenarimol, imidazole, triadimefon and triforine) resistance to cucurbit powdery mildew populations continued over the years in many countries. The researchers reportedDMI-resistant fungal isolates of *P. xanthii* and *G. cichoracearum* in the Czech Republic.

López-Ruiz *et al*. (2010) in Spain, Kim *et al.* (2008)in South Korea, McGrath (2008) and McGrath and Shishkoff (2001) in the US and Ohtsuka *et al*. (1988)in Japan reported DMI-resistant fungal isolates of *P. xanthii* and *G. cichoracearum* (causal agent of cucurbit powdery mildew) separately in their respective research studies over the years. The expansion of DMIs (Demethylation Inhibitors, e.g. fenarimol, imidazole, triadimefon and triforine) resistance to cucurbit powdery mildew populations continued over the years in many countries.

Miyamoto *et al*. (2010) carried out a research work to investigate the occurrence of boscalid resistance in cucumber powdery mildew in Japan and molecular characterization of the iron–sulfur protein of succinate dehydrogenase of the causal fungus. In Japan, resistance to boscalid was observed, with 34 out of 74 isolates of cucumber powdery mildew causal fungus analysed with MIC (Minimal Inhibitory Concentration) values of >50 $mg \cdot L^{-1}$ of the formulated product and 21 of these isolates growing well at 500 $mg \cdot L^{-1}$ in *in vitro* bioassays.

Vasant and Ashok (2010) presented a paper which dealt with the study of powdery mildew incidence on different cucurbits hosts in different seasons and its biocontrol. Neem leaf extract at 15% concentration, *Parthenium* leaf at 10% concentrations, *Ocimum* leaf at 20% concentration, *Citrus* leaf at 20% concentration, *Annona squamosa* leaf at 10% concentration, *Ipomoea* at 15% and Jowar leaf at 20% controlled the powdery mildew of cucurbits. Cow urine at 15% concentration proved to be effective to control powdery mildew on cucurbit. 20% to 25% of Butter milk spray successfully controlled the powdery mildew of cucurbit. Similarly, 20% ash spray also found to be successful to control the growth of powdery mildew of cucurbits. Spray of Dashparni ark, a bi-product of plant and animal at 10% concentration inhibited the growth of *Erysiphe cichoracearum* and *Sphaerotheca fuliginea*.

Ashour (2009) conducted an experiment in greenhouse and field conditions to evaluate the efficacy of systemic fungicides (Rubigan 12% Master 10%, Topas 10% Vectra 10%) in order to control muskmelon powdery mildew disease and recorded reduced disease severity due to fungicide application.

Dayan *et al.* (2009) mentioned Timorex Gold® manufactured by Stockton group (Switzerland) is the new generation of bio-fungicides based on a plant extract of *Melaleuca alternifolia* for the control of powdery mildews and Mildiomycin™, for controlling powdery mildews mainly in Japan in their research work.

McGrath *et al.* (2009) and Wyenandt et al. (2010) from their separate research works described *P. xanthii* isolate's resistance to myclobutanil in New York, Pennsylvania, Ohio, and Indiana (although not in New

Jersey). *P. xanthii* isolates monitored in 2006–2008 in the north-eastern, mid-Atlantic, and Midwestern US were sensitive to quinoxyfen.

Savvas *et al.* (2009) conducted a study to test the hypothesis as to whether silicon supplied via the nutrient solution was capable of enhancing the tolerance of hydroponically grown zucchini squash (*Cucurbita pepo* L. cv. 'Rival') to salinity and powdery mildew infections. Two experiments were conducted involving a low (2.2 $dS \cdot m^{-1}$, 0.8 mM NaCl) and a high salinity level (6.2 $dS \cdot m^{-1}$, 35 mM NaCl) in combination with a low (0.1 mM) and a high (1.0 mM) Si level in the nutrient solution supplied to the crop. The supply of Si via the nutrient solution suppressed appreciably the expansion of a powdery mildew (*Podosphaera xanthii*) infection in the leaves at both salinity levels. These results indicated that the supply of at least 1 mM of Si via the nutrient solution was capable of enhancing both tolerance to salinity and resistance to powdery mildew in soilless cultivations of zucchini squash.

Hafez *et al.* (2008) mentioned that plant diseases could be controlled by application of chemical fungicides, natural products, oils or biological agents

Miazzi and McGrath (2008) recorded that 62% of the *P. xanthii* isolates (causal agent of cucurbit powdery mildew disease) was analysed from Georgia and New York in 2007, which were able to grow at 10–15 $mg \cdot L^{-1}$ of commercial quinoxyfen.

Hassell *et al.* (2008) reported that application of Tebuconazole fungicide consistently stunted *Cucurbita* and *Lagenaria* seedlings to a degree where they could not have been used in grafting for watermelon production, as the hypocotyls were too short to hold the clips connecting the scion and rootstock hypocotyls.

McGrath (2008) conducted field studies to investigate fungicide sensitivity in *Podosphaera xanthii* and efficacy for cucurbit powdery mildew in NY, USA, in 2003–2006. According to the researcher, SDHI (Succinate Dehydrogenase Inhibitors, also known as carboxamide fungicides) resistance problems was seen in cucurbit powdery mildews. The first report of SDHI control failure was documented in *P. xanthii* in New York (USA) in 2005. In that study, boscalid only controlled 56% of the *P. xanthii* fungal isolates tested; however, the efficacy of boscalid was almost recovered one year later.

Yasmin *et al*. (2008) carried out an experiment to observe the management of powdery mildew in sweet gourd (*Cucurbita moschata*). Sixty-two germplasm of sweet gourd and eight fungicides were evaluated against powdery mildew caused by *Erysiphe cichocearum* under field condition. Eight fungicides which were used in this experiment as follows: Mycosulf 80 WP (0.2%), Censor MZ 72 (0.25%), Insuf 80 WP (0.3%), Sulphochem 80 WP (0.25%), Carbozim (0.1%), Haydazim (0.2%) %), Bendazim (0.1%) Thiovit (0.2%) and a control (spray plain water). Mycosulf, Thiovit and Insuf were found the best in controlling severity of disease by > 80%. Additional yield of 14.58 $t \cdot ha^{-1}$ was found from Thiovit treated plot which was 65.35% higher compared to control. Net income increased almost two times and the farmers having more options for controlling powdery mildew as more than one fungicide were found effective.

Brent and Holloman (2007) stated that one of the widely recommended practices to reduce development of fungicide resistance is to apply fungicides sparingly but at the maximum labelled rates.

Ishii *et al*. (2007) carried out several research work in regard to the stability of QoI [Quinone outside inhibitors] resistance in the cucurbit powdery mildew. The study revealed that under greenhouse conditions, the resistance to azoxystrobin seemed to be unstable, *P. xanthii* isolates of powdery mildew resistant to azoxystrobin were not detected two-and-a-half years after not being applied in the field; however, opposite results were found under laboratory conditions, with *P. xanthii* isolates maintaining high levels of azoxystrobin resistance after three years of subculturing without this fungicide.

Jamali *et al*. (2007) studied the effects of leaf extract of *Reynoutria sachalinensis* on some defense responses of cucumber plants via *in vivo* tests. Changes of defense responses in the extract treated-cucumber plants, with or without pathogen inoculation, were studied and compared with those of non-treated control plants. One of the properties of systemically acquired resistance in plants is their concomitance with the biochemical changes including enhancement of activities of defense-related enzymes. The leaf extract of *Reynoutria sachalinensis* (F. Schmidt) Nakai is known to be an effective compound for the control of a few plant diseases particularly powdery mildew of cucurbits (caused by fungal pathogen *Podosphaera fusca*), by inducing host defense responses. Results indicated that specific activity of peroxidase increased significantly in treated tissues. Enhancement of enzyme activity showed the same patterns in both the pathogen inoculated- and non-inoculated-plants; thus, the pathogen attack did not affect the enzyme activity. Specific activity of phenylalanine ammonia-lyase in the non-inoculated extract treated-plants showed a transient fast increase during 24 hours after the treatment, whereas in the inoculated ones, it showed a permanent slow increase probably due to the interaction between extract treatment and pathogen attack. Phenolic content of extract treated-plant tissues, despite small fluctuations, did not show any definite pattern of changes.

McGrath and Davey (2007) and McGrath (2005) from two separate field experiments on pumpkin recorded that organocide provided 85% control against powdery mildew on upper leaf surfaces and also controlled powdery mildew on the lower leaf surfaces in one of the experiments.

McGrath and Davey (2007) observed that organocide was more effective on the upper leaf surface of pumpkin than potassium bicarbonate in controlling powdery mildew disease.

Davey and McGrath (2006 a) and Davey and McGrath (2006 b)conducted several experiments to study the sensitivity of cucurbit powdery mildew (*Podosphaera xanthii*) to the fungicide quinoxyfen. They reported from their experiments thatregarding the cucurbit powdery mildew *P. xanthii,* a sharp shift to resistance was observed in the American cucurbit fields over a period of years. Quinoxyfen provided good control against cucurbit powdery mildew during the period 1996–2000; however, the sensitive values changed over time, and some isolates collected from New York were able to grow at 10 $mg \cdot L^{-1}$ of the formulated product in 2004.

Fernández-Ortuño *et al*. (2006) reported the occurrence and distribution of resistance to QoI fungicides [Quinone outside inhibitors] in populations of *Podosphaera fusca* in south central Spain. Thirty-two percent of the *P. xanthii* isolates, causal agent of cucurbit powdery mildew, collected from several locations in Spain had MIC values (Minimal Inhibitory Concentration) > 500 $mg \cdot L^{-1}$ for commercial azoxystrobin, trifloxystrobin and kresoxim-methyl. Cross-resistance to all the QoIs tested was observed.

Liang *et al*. (2005) used two cucumber (*Cucumis sativus*) cultivars differing in their resistance to powdery mildew, Ningfeng No. 3 (susceptible) and Jinchun No. 4 (resistant), to study the effects of foliar- and root-applied silicon on resistance to infection by *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea*) and the production of pathogenesis-related proteins (PRs). The results indicated that inoculation with *P. xanthii* significantly suppressed subsequent infection by powdery mildew compared with non-inoculation, regardless of Si application. Root-applied Si significantly suppressed powdery mildew, the disease index being lower in Si-supplied than in Si-deprived plants, regardless of inoculation treatment. Compared to the control (no Si), foliar-applied Si had no effects either on the suppression of subsequent infection by *P. xanthii* or on the activity of PRs, irrespective of inoculation. Based on the findings in this study and previous reports, it was concluded that foliar-applied Si can effectively control infections by *P. xanthii* only via the physical barrier of Si deposited on leaf surfaces, and / or osmotic effect of the silicate applied, but cannot enhance systemic acquired resistance induced by inoculation, while continuously root-applied Si can enhance defence resistance in response to infection by *P. xanthii* in cucumber.

McGrath (2005) reported that hydrogen dioxide was ineffective for managing powdery mildew of pumpkin in the field.

Mossler and Nesheim (2005) recorded that sulfur only provided a moderate level of control against powdery mildew disease in squash, and this lack of control was confirmed by extension personnel. Moreover, several cucurbit species, mostly muskmelons and honeydews, were very sensitive to sulfur and phytotoxicity as scorch occurred when sulfur was applied to the leaves.

Smither-Kopperl *et al.* (2005) concluded from their study on greenhouse cucumber that sulfur and potassium bicarbonate were equally effective for controlling powdery mildew disease on Beit Alpha cucumber. The researchers also stated that potassium bicarbonate but not sulfur was equivalent to a synthetic fungicide standard.

McGrath and Shishkoff (2003) was the first one to report the cucurbit powdery mildew fungus (*Podosphaera xanthii*) resistant to strobilurin fungicides in the United States. The researcher recorded 80% of the American isolates of *P. xanthii* (causal agent of cucurbit powdery mildew), were able to grow at 100 $mg{\cdot}L^{-1}$ commercial trifloxystrobin. Cross-resistance to all the QoIs [Quinone outside inhibitors] tested was observed.

Bélanger and Labbe (2002) stated that biorational materials (prophylactic and biological alternatives) with low toxicity for plants might have a role in disease management systems and could be an alternative way to control of powdery mildew disease without chemicals for horticultural crops.

Hollomon and Wheeler (2002) mentioned that the fungicides continual application as the principal approach for managing the powdery mildews around the world.

Ehret *et al.* (2001) observed that foliar sprays of chlorite mica clay, which contains silicon, demonstrated suppression of powdery mildew disease in long English cucumber.

Ishii *et al*. (2001) and Heaney *et al*. (2000) documented resistance to the fungicides azoxystrobin, famoxadone, fenamidone and kresoxim-methyl [Quinone outside inhibitors (QoI)] in the cucurbit powdery mildew in different parts of the world a few years later after the commercialization of this group of fungicide. The registration and commercialization of the first QoIs were undertaken in 1992. Quinone outside inhibitors (FRAC code 11) are an important class of fungicides that are widely used in agriculture to control powdery mildews in economically important crops, such as cucurbits.

McGrath (2001) and McGrath *et al.* (2009) reported that resistance of the cucurbit powdery mildew to methyl-benzimidazole-carbamate fungicides was widespread, and there was cross-resistance among fungicides in FRAC Group 1.

Paulitz and Bélanger (2001) tested a yeast-like fungus *Sporothrix flocculosa* (syn. *Pseudozyma flocculosa*) for control of powdery mildew in greenhouse-grown cucumbers with promising results. It was formulated as a wettable powder (Sporodex®) for use against powdery mildew on greenhouse crops.

Bettiol (1999) investigated the effectiveness of cow's milk against zucchini squash powdery mildew (*Sphaerotheca fuliginea*) in greenhouse conditions. The researcher concluded that cow's milk sprayed onto the leaves of greenhouse-grown zucchini was shown to be effective in controlling *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea auct. p.p.*).

McGrath and Shishkoff (1999) observed the effect of inoculum level on performance of potassium bicarbonate in field experiments on melon and recorded that potassium bicarbonate significantly reduced powdery mildew on melon field when disease severity on non-sprayed plants ranged from 2% to 13% across rating dates but did not reduce disease when severity ranged from 26 to 67%. Potassium bicarbonate controlled powdery mildew on upper and lower leaf surfaces in two and three of three field trials on melon (*Cucumismelo*) and pumpkin, respectively.

Konstantinidou-Doltsinis and Schmitt (1998) evaluated the efficacy of plant extracts from *Reynoutria sachalinensis* (F. Schmidt) Nakai against powdery mildew in greenhouse-grown cucumbers (*Cucumis sativus* L.) over 3 years under high disease pressure. In most trials, efficacy of the resistance-inducing extracts from *R. sachalinensis* reached about 90% and was comparable with that of fungicide treatments. In all trials extract-treated cucumbers yielded as many or more fruit per plant as fungicide-treated plants. *R. sachalinensis* extract applications enhanced yield up to 49% over the control. The results demonstrated the potency of *R. sachalinensis* plant extracts as effective plant protecting agents even under the high disease pressure prevailing in the Mediterranean region. The researchers concluded that the need to control powdery mildew disease was one of the reasons for the increased use of fungicides in cucurbits.

Mosa (1997) recorded that cucumber powdery mildew infection was significantly reduced by 92% when the plants were treated with 50 mM K_2HPO_4 three days after inoculation by the causal pathogen.

McGrath (1996) and McGrath and Shishkoff (1996) reported from their different research work that the shift of MBC (Methyl-Benzimidazole

Carbamates) resistance increased rapidly up to 68–100% in the cucurbit powdery mildew (*Sphaerotheca fuliginea*) in the United States.

McGrath (1996) conducted a study in the United States where she described a sharp increase in the percentage of resistant fungal isolates of *Podosphaera xanthii* (causal agent of cucurbit powdery mildew) from 0 to 96% in a short period of time and only after two triadimefon [DMIs (Demethylation Inhibitors)] applications.

McGrath and Shishk off (1996) reported from their research work that *P. xanthii* (causal agent of cucurbit powdery mildew) isolates were able to grow at 50 $mg \cdot L^{-1}$ of technical grade triadimefon and tolerating 5 $mg \cdot L^{-1}$ and 20 $mg \cdot L^{-1}$ of technical grade myclobutanil and commercial propiconazole, respectively which were also found in nontreated fields in the US.

Zitter *et al.* (1996) stated that fungicides based on copper salts were to some extent less phytotoxic than sulfur, but they were not completely unharmful. These copper salts (Kocide® 2000, Microcop, etc.) were recommended to be used as a fungicide to control powdery mildew in cucurbits.

Daayf *et al.* (1995) recorded that an aqueous formulation of concentrated extracts (Milsana ® flüssig) from leaves of the giant knotweed, *Reynoutria sachalinensis*, applied weekly at a concentration of 2%, provided control of powdery mildew (*Sphaerotheca fuliginea*)on long English cucumber that was as effective as benomyl. In two separate experiments, this treatment significantly reduced the severity of powdery mildew compared to control plants under greenhouse conditions. Fruit yield was not affected by the treatment, even though repeated applications of Milsana induced a greener and glossier coloration of the leaves, which became brittle to the touch. A rapid and distinct accumulation of fungitoxic phenolic compounds occurred in leaves treated with Milsana, especially in infected leaves. A slight inhibition of conidial germination was the only direct effect of Milsana on *S. fuliginea*. These results supported the hypothesis that Milsana might act indirectly by inducing plant defense reactions and that it might be useful in the integrated management of cucumber powdery mildew.

O'Brien (1994) and O'Brien *et al*. (1988) reported from their studies on fungicide resistance in populations of cucurbit powdery mildew that *P. xanthii* isolates which were able to grow at 50 $mg \cdot L^{-1}$ and 250 $mg \cdot L^{-1}$ of commercial benomyl were also detected in high frequencies in Australia. The expansion of DMIs (Demethylation Inhibitors, e.g. fenarimol, imidazole, triadimefon and triforine) resistance to populations of cucurbit powdery mildew was reported over the years in many countries. *P. xanthii* and *G. cichoracearum* DMI-resistant fungal isolates was also reported in Australia.

O'Brien (1994) conducted experiments to monitor fungicide resistance in populations of cucurbit powdery mildew. He conducted a region-wide resistance monitoring survey in Australia, reporting that 21% of the *P. xanthii* isolates analysed were resistant to pyrazophos.

Menzies *et al.* (1992) examined the effect of soluble potassium silicate applied to cucumber (*Cucumis sativus* L.), muskmelon (*C. melo* L.), and zucchini squash (*Cucurbita* pepo L.) on the severity of powdery mildew. Application methods included amending nutrient solutions to a concentration of 1.7 mM Si and foliar sprays containing 1.7, 8.5, 17, and 34 mM Si. Untreated plants and plants sprayed with distilled water were used as controls. The leaves of all plants were inoculated with known concentrations of conidia of *Sphaerotheca fuliginea* (Schlecht.: Fr.) Poll. (cucumber and muskmelon) or *Erysiphe cichoracearum* DC.: Merat (zucchini squash) 1 day after the sprays were applied. Inoculated leaves on plants receiving the Si-amended nutrient solution or foliar sprays of ≥ 17.0 mM Si developed fewer powdery mildew colonies than those on control plants. Results of a separate experiment that included a potassium spray, indicated that the active ingredient of the potassium silicate sprays appears to be Si. Experiments to test the persistence of Si foliar sprays on cucumber demonstrated that a 17 mM Si spray applied 7 days before inoculation with *S. fuliginea* reduced mildew colony formation.

McGrath (1991) mentioned reduced effectiveness of triadimefon for controlling cucurbit powdery mildew associated with fungicide resistance. In the 1990s, triadimefon-resistant *P. xanthii* isolates were able to develop disease at 200 $mg \cdot L^{-1}$ of the formulated product in *in vitro* bioassays which was also described in the US.

Menzies *et al.* (1991) carried out an experiment to investigate the effects of soluble silicon on the parasitic fitness of *Sphaerotheca fuliginea* on *Cucumis sativus*. In most Floridian soils, (0.1–0.8 mM) silicon is available, but in greenhouse hydroponic systems where clean water may be used, the amounts of this element might be smaller. In hydroponically-grown cucumbers, the addition of 2.3 mM silicon to the nutrient solution (fertigation) can significantly delay and reduce the incidence of disease caused by *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea auct. p.p.*). Colony number per leaf, colony area per leaf, and the germination of conidia collected from inoculated leaves were significantly reduced with increasing silicon concentration in the nutrient solutions. The area of individual colonies was also reduced as silicon concentrations in the nutrient solutions increased from 0.05 to 4.10 mM. The decrease in receptivity of plants to mildew infection was apparently due to silicon accumulation in leaves and was not related to cation or ionic strength effects of the silicon treatments.

Moustafa *et al*. (1990 a) and Moustafa *et al*. (1990 b) performed two studies in 1990 to observe the resistance to fungicides in *Erysiphe cichoracearum*, the causal organism of cucumber powdery mildew in Egypt. They reported a trend of decreased sensitivity after multiple applications of bupirimate and cross-resistance to dimethirimol.

Bhatia and Thakur (1989) conducted field evaluation of systemic and non-systemic fungicides against powdery mildew of different economic crops. The researcher concluded that the disease could be prevented and effectively controlled by early application of fungicides like Thiovit, Bavistin and Karathane.

O'Brien *et al*. (1988) observed that two out of six fungal isolates of *P. xanthii* (causal agent of cucurbit powdery mildew) which were collected from Australia in 1988 were able to develop powdery mildew disease on melon plants treated at 200 $mg \cdot L^{-1}$ of the formulated product from commercial bupirimate [hydroxy-(2-amino) pyrimidine].

O'Brien *et al*. (1988), Schepers (1985 b) and Huggen berger *et al*. (1984) from their different field research work stated that although more cases of reduced sensitivity of *P. xanthii* and *G. cichoracearum* to amine tridemorph and DMIs (fenarimol, imidazole, triadimefon and triforine) were reported during the 1980s, the control of the cucurbit powdery mildew disease in the field appeared to be achieved.

Malathrakis (1986) reported that the fungal isolates of *P. xanthii* (causal agent of cucurbit powdery mildew) collected from Greece in 1986 were able to tolerate the dose of 125 $mg \cdot L^{-1}$ of the commercial bupirimate [hydroxy-(2-amino) pyrimidine]. Cases of resistance to bupirimate have only been described in cucurbit powdery mildew species. The expansion of DMIs (Demethylation Inhibitors, e.g. fenarimol, imidazole, triadimefon and triforine) resistance to cucurbit powdery mildew species was reported over the years in many countries. *P. xanthii* and *G. cichoracearum* DMI-resistant fungal isolates was also been reported in Greece.

Gay *et al.* (1985) described that cultural practices, such as crop rotation, seemed to have a slight or no effect on presence and development of powdery mildew fungus because conidia are so prevalent and are able to germinate under relatively low RH (relative humidity).

Schepers (1985 a, b) reported that DMI-resistant fungal isolates (Demethylation Inhibitors) of *Podosphaera xanthii* (causal agent of cucurbit powdery mildew) did not exhibit any fitness penalty, exhibiting stable resistance in the absence of fungicide over the years.

Schepers (1985 b) and Schepers (1983) carried out several field studies to investigate the sensitivity of *Sphaerotheca fuliginea* to fungicides which inhibit ergosterol biosynthesis. The researcher reported that the cucurbit powdery mildew species *Podosphaera xanthii* and *Golovinomyces cichoracearum* also developed resistance to DMIs (Demethylation Inhibitors). Failure to control of *P. xanthii* with imazalil and triforine was reported in the Netherlands a few years after their registration.

Schepers (1984) conducted a study in the Netherlands in 1981 and 1983 and observed that 13 out of 194 *P. xanthii* isolates were resistant to phosphorothiolates fungicide (pyrazophos), with EC_{50} values > 60 $mg \cdot L^{-1}$ of the pure active ingredient; however, in this case, resistance seemed to be stable over a period of years. The researcher also observed the persistence of resistance to dimethirimol in *P. xanthii* (causal agent of cucurbit powdery mildew) 10 years after the withdrawal of this fungicide in the Netherlands.

Dekker and Gielink (1979) set up research studies to observe decreased sensitivity to pyrazophos of cucumber and gherkin powdery mildew. A limited number of studies have investigated the sensitivity of powdery mildews to phosphorothiolates, a class of fungicides that are not currently available for powdery mildew control. Pyrazophos was the first active ingredient of this class registered to control cucurbit powdery mildew in 1970; however, the first control failure of pyrazophos was reported in the Netherlands a few years later. The researcher reported from that study that 32% and 9% of the *P. xanthii* isolates that were analysed were able to grow at 1 or 3.2 $mg \cdot L^{-1}$ of the formulated product, respectively, 3.3- and 10.6-fold higher than the tolerance of sensitive isolates. Fortunately, the resistant isolates appeared to have fitness penalties, and after a year without using pyrazophos, sensitivity levels returned to baseline levels.

Jain and Srivastava (1977) carried out an experiment to find out the control measure of powdery mildew disease in cucumber. The researchers recommended that the disease could be prevented and effectively controlled by early application of fungicides like Thiovit (Sulphur), Bavistin (Carbendazim) and Karathane.

Bent *et al*. (1971) conducted an experiment to observe the resistance of cucumber powdery mildew to dimethirimol. Dimethirimol was registered in 1968 and was widely employed by growers to control cucurbit powdery mildew in the late sixties. However, this study reported that some *P. xanthii* isolates were able to tolerate even 100-fold higher concentrations than the sensitive isolates, was published in Germany two years after the registration of dimethirimol.

Schroeder and Provvidenti (1968) described the first incidence of cucurbit powdery mildew *P. xanthii* resistance to the MBC (Methyl-Benzimidazole Carbamates) fungicide benomyl in the US in 1967.

CHAPTER III

MATERIALS AND METHODS

This chapter described the materials and methods that were used in carrying out the experiment. It included a description of the management of powdery mildew disease of bottle gourd (*Lagenaria siceraria*) using potassium and sulphur containing modern phyto-chemicals.

3.1 Experimental site

The field experiment was conducted at the farm of Sher-e-Bangla Agricultural University whereas laboratory experiment was conducted in the Plant Disease Clinic, Plant Pathology Department, Sher-e-Bangla Agricultural University, Dhaka-1207.

3.2 Time of experiment

The experiment was conducted from November 2019 to May 2020.

3.3 Selection of variety

BARI Lau-4 was selected for the present experiment and this variety was collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.4 Design of the experiment

The field experiment was conducted following Randomized Complete Block Design (RCBD) with three replications.

3.5 Climate

The experimental area was under the sub-tropical climate had comparatively low rainfall, humidity, temperature, relatively short-day during November to May and high rainfall, humidity, high temperature with long day period during April to September. The annual precipitation and potential evapotranspiration of the site were 2152 mm and 1297 mm, respectively. The average maximum and minimum temperature were 30.34°C and 21.21°C, respectively with mean temperature of 25.17°C. (Appendix II) Temperature during the cropping period ranged from 12.2°C to 31.2°C. The humidity varied from 73.52% to 81.2%. The day length ranged from 10.5-11.0 hours only and there was no rainfall during the experimental period.

3.6 Soil type

The soil of the experimental site belongs to the Agro-Ecological Region of "Madhupur Tract" (AEZ No. 28). It was Deep Red Brown Terrace soil and belongs to "Nodda" cultivated series. The top soil is slightly clay loam in texture. Organic matter content was very low (0.82%) and soil pH varied from 5.5-6.5.

3.7 Fertility status of field soil

The soil of experimental site was analyzed in Soil Resource Development Institute (SRDI), Dhaka and found as loamy soil which contains total Nitrogen (N) 0.061(%), Phosphorus (P) 35022 microgram per gram of soil, Sulphur 22.60 (S) microgram per gram of soil, Potassium (K) 0.030 milliequivalent per 100-gram soil and Calcium (Ca) 2.67 milliequivalent per 100-gram soil.

3.8 Layout of experimental field

The field layout was done as per experimental design on 10th November, 2019. The field was divided into three blocks each of which representing replication. There were 7 treatments including control with 3 replications which results in total 21 plots in experimental field. The experiment details are presented below:

i. Total area = 250.00 m² (25.0 m × 10.0 m)
ii. Plot no. = 06
iii. No. of pit = 21
iv. Plot size = 6.0 m² (2.0 m × 3.0 m)
v. Block to block distance = 0.5 m
vi. Plot to border distance = 0.5 m
vii. Plot to plot distance (Length wise) = 0.5 m
viii. Plot to plot distance (Breath wise) = 0.5 m
ix. Plant to plant spacing = 200 cm
x. Row to row spacing = 250 cm
xi. Total no. of plant = 42
xii. No. of plant in a unit pit = 2

3.9 Land preparation

The land was ploughed thoroughly with a power tiller on 10th November 2019 and then laddering was done to obtain a desirable tilth. The clods of the land were hammered to make the soil into small pieces. Weeds, stubbles and crop residues were cleaned from the land. The final ploughing and land preparation were done on 22nd November, 2019.

Plate 1. Layout of experimental field

3.10 Application of manures and fertilizer

The following dose of fertilizers and manures were applied for the bottle gourd cultivation as per recommendation of Bangladesh Agricultural Research Institute (BARI):

Name of the fertilizer	Dose
a. Urea	100 kg ha^{-1}
b. TSP	70 kg ha^{-1}
c. MOP	50 kg ha^{-1}
d. Gypsum	30 kg ha^{-1}
e. Cow dung	10 t ha^{-1}

At first, one-third Urea and whole amount of other fertilizers were applied as basal dose during land preparation. Rest two-third urea was applied at 30 days and 50 days after planting followed by irrigation.

3.11 Sowing of seed

Healthy and disease-free bottle gourd seeds (BARI Lau-4) were planted in plastic pots in net house. Irrigation was done with the help of watering cane.

3.12. Transplanting of seedlings

At 30 days after sowing, seedlings were transplanted to the main experimental field.

3.13. Treatments

In total seven (7) treatments were selected for this experiment and the treatments were as follows:

i. T_0 = Control
ii. T_1 = Silica (Silicon dioxide, SiO_2)
iii. T_2 = Potassium silicate (K_2SiO_3)
iv. T_3 = Phosphorus silicate (P_2SiO_3)
v. T_4 = Salicylic acid($C_7H_6O_3$ or HOC_6H_4COOH)
vi. T_5 = PPN (Peak Performance Nutrient) and
vii. T_6 = McSulphur 80 WP (Sulphur based fungicide)

3.14. Intercultural operation

3.14.1. Irrigation

Irrigation was done at as per requirement for the field condition.

3.14.2. Weeding

Weeding was done five times in the experimental period starting from 25 days after sowing, 40 days after sowing, 60 days after sowing, 75 days after sowing and 100 days after sowing.

3.14.3. Application of insecticides

Bottle gourd plants are affected by different insects like red pumpkin beetle, fruit fly etc. To minimize the effect of the insect, we applied Actara (25 WG) (200 g / ha foliar application) in the experimental field.

3.15. Collection of fungicides

Six fungicides namely Silica (SiO_2), Potassium silicate (K_2SiO_3), Phosphorus silicate (P_2SiO_3), Salicylic acid, PPN (Peak Performance Nutrient) and McSulphur 80 WP (Sulphur based fungicide) were collected from 145, Siddiq Bazar seed Market, Dhaka.

Plate 2. Salicylic Acid **Plate 3. Sulphur fungicide**

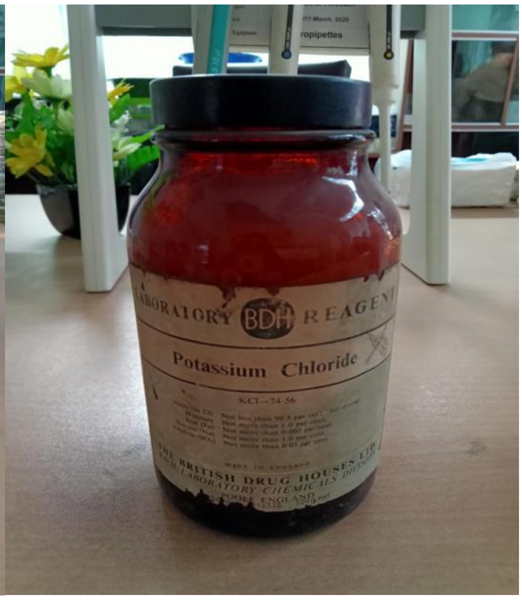

Plate 4. Silica gel **Plate 5. Potassium chloride**

3.15.1. Preparation of fungicide suspension

Recommended doses of fungicidal solution were prepared by mixing thoroughly with required quantity of fungicide and water. 4.50 g Silica, 1 gm Potassium silicate (K_2SiO_3), 1 gm Phosphorus silicate (P_2SiO_3), 2 gm Salicylic acid, 2 gm Peak Performance Nutrient (PPN) and 1 gm McSulphur 80 WP (Sulphur based fungicide were added in 1 L water.

Plate 6. Fungicide suspension

3.15.2. Application of fungicides

At recommended doses, the suspensions/solutions of fungicides were prepared by mixing thoroughly with requisite quantity of normal plain water. Spraying was started from 50 days after sowing. In total, three spraying were done with the 10 days intervals with the help of hand sprayer. To avoid the drifting of the fungicides during application, spraying was done very carefully, especially by observing air motion. A control treatment was maintained in each block where spraying was done with plain water only.

3.16. Data collection

The following parameters were assayed for the experiment:

a. Number of tendrils
b. Number of fruits
c. Length of fruit
d. Diameter of fruit
e. Average fruit weight
f. Disease incidence (%)
g. Disease severity (%)

3.17. Identification of pathogen

The plants showing powdery mildew disease were collected from the experimental field.

Plate 7. Infected Leaf

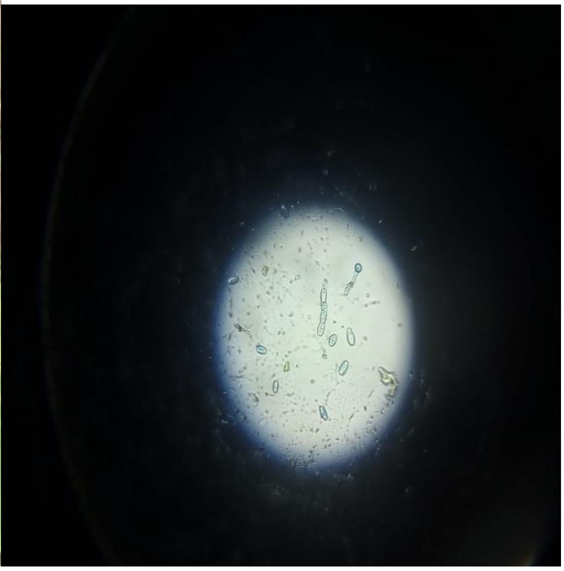

Plate 8. *Erysiphe cichoracearum* conidia under microscope

3.18. Green house experiment

3.18.1. Soil preparation and growing of seedlings

In earthen pots / plastic pots containing the mixture of red soil, sand and farm yard manure (FYM) at the ratio of 2∶ 1∶ 1, seedlings of bottle gourd plant were grown.

3.18.2. Demonstration of Koch's postulates

Spores of *Erysiphe* were selected for incubation purpose. For this, at first, disease affected leaves were collected from the field and then spores were incubated in the leaves by brushing of the spores with the help of a camel's hair brush in thirty days (30 D) older seedlings. The plants were covered with polybag to maintain humidity for 24 to 48 hours for easy penetration of the pathogen. After incubation of 48 hours, polybag was removed and waited for disease appearance. After 10–12 days of inoculation, powdery mildew disease appeared on the inoculated plants. Then the diseased leaves were taken to the lab for identification.

Plate 09. Seedlings of bottle gourd

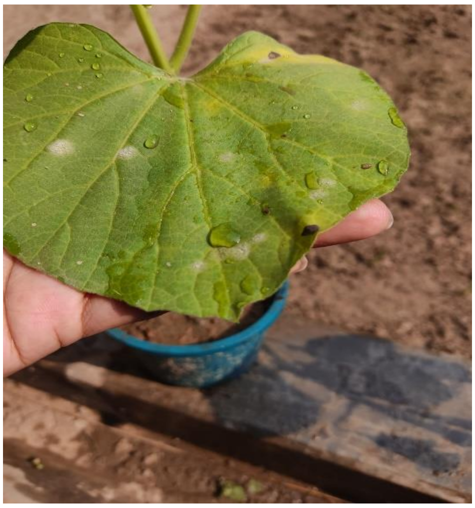

Plate 10. Infected leaf

Plate 11. Brushing of spores healthy leaf

Plate 12. Covering with poly bag

3.19. Calculation of disease incidence and disease severity

Disease incidence is the number of proportions of the plant units diseased in relation to the total number of units examined. Plant units mean the leaves, stems, fruits, tubers, rhizomes, and bulbs etc. that show any symptoms. In some cases, the plant unit represents the plant as a whole.

$$\textbf{Disease incidence(\%)} = \frac{\text{Number of plant diseased} \times 100}{\text{Number of plants inspected}}$$

Disease severity is the proportion of amount of plant tissues infected in relation to the total amount of tissue examined.

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

3.20. Measurement of number of tendrils

Number of tendrils was counted from three plants in each plot and then the mean value of three plants was recorded as tendrils number.

3.21. Measurement of number of fruits

Number of fruits was counted from three plants in each plot and then the mean value of three plants was recorded as fruits number.

Plate 13. Fruits of bottle gourd

3.22. Measurement of length of fruit

Length of each fruit was measured in centimeters with the help of measuring tape and then the mean of three fruits was recorded as fruit length.

3.23. Measurement of diameter of fruit

Diameter of each fruit was measured in centimeters with the help of measuring tape and then the mean of three fruits was recorded as fruit diameter.

3.24. Measurement of fruit weight

The randomly selected three fruits in each plot were weighed with the help of pan balance and the mean was expressed as average weight of fruit (kg).

3.25. Statistical Analysis

The recorded data were compiled, tabulated and subject to statistical analysis. Analysis of variance was done with the help of computer package program MSTAT-C. The mean differences were adjudged by Duncan’s New Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS

Powdery mildew of bottle gourd caused by *Erysiphe cichocearum* is a disease of economic importance. The effects of different phyto-chemicals on the disease incidence, disease severity and yield of bottle gourd was presented in this chapter.

4.1. Symptomatology

Primarily white, powder-like spots were found on the leaves and stems. Later powdery spots appeared on both upper and lower leaf surfaces and quickly expanded into large blotches which ultimately covered the entire leaf.

Plate 14. Leaf showing symptoms

4.2. Effect of phyto-chemicals on powdery mildew disease incidence

The effect of selected phyto-chemicals and fungicides against powdery mildew disease of bottle gourd was presented in Table 1. Plant infection varied significantly among the treatments. The applied treatments showed promising performance in reducing the disease incidence (plant infection) at different days after transplanting (DAT). Fungicides were applied at regular intervals. At 93 DAT, the effect of different treatments was found to be varied significantly in respect of plant infection. Among the fungicides, the lowest plant infection (14.67%) was recorded in case of potassium silicate (T_2) followed by Silica (T_1) (32.00%), Peak Performance Nutrient (T_5) (32.00%), phosphorus silicate (T_3) (33.33%), McSulphur 80 WP (T_6) (34.67%) and salicylic acid (T_4) (36.00%). The highest plant infection (56.00%) was recorded in control plot (T_0) (Table 1).

At 100 DAT, the trend of results of different treatments against plant infection found to be more or less similar to the results of 93 DAT (Table 1). The highest disease incidence (plant infection) (72.48%) was recorded in control (T_0) and the lowest disease incidence (39.07%) was recorded in case of potassium silicate (T_2) application followed by silica (T_1) (44.00%), phosphorus silicate (T_3) (48.33%), Peak Performance Nutrient (T_5) (50.67%), McSulphur 80 WP (T_6) (60.00%) and salicylic acid (T_4) (66.67%).

Again, at 107 DAT, the lowest disease incidence was also recorded in potassium silicate (T_2) (51.33%) followed by Peak Performance Nutrient (T_5) (61.67%), silica (64.67%), phosphorus silicate (T_3) (65.00%), McSulphur 80 WP (T_6) (72.00%) and salicylic acid (T_4) (75.67%) while maximum disease incidence was observed in control (T_0) (81.33%).

Table 1. Effect of phyto-chemicals on disease incidence of bottle gourd at different data recording intervals

Treatment	Disease incidence (%)			%Reduction of Disease incidence at 107 DAT
	93 DAT	100 DAT	107 DAT	
T_0 (Control)	56.00 a	72.48 a	81.33 a	-
T_1 (Silica)	32.00 ab	44.00 f	64.67 d	20.49
T_2 (K_2SiO_3)	14.67 b	39.07 g	51.33 e	36.89
T_3 (P_2SiO_3)	33.33 ab	48.33 e	65.00 d	20.08
T_4 (Salicylic acid)	36.00 ab	66.67 b	75.67 b	6.97
T_5 (PPN)	32.00 ab	50.67 d	61.67 d	24.18
T_6 (McSulphur 80 WP)	34.67 ab	60.00 c	72.00 c	11.48
LSD $_{(.05)}$	**23.41**	**1.85**	**3.39**	**-**
CV (%)	**38.60**	**1.91**	**2.83**	**-**

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

4.2.1. Measurement of disease control

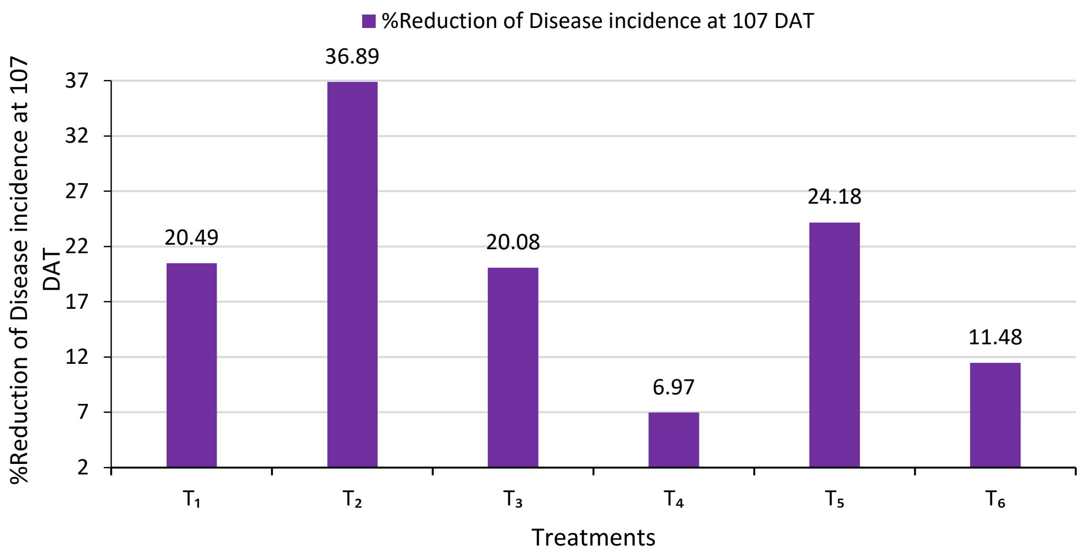

Figure 1. Reduction of % disease incidence over control due to application of phyto-chemicals/fungicides at 107 DAT

Here, note: T_1 = Silica (Silicon dioxide, SiO_2), T_2 = Potassium silicate (K_2SiO_3), T_3 = Phosphorus silicate (P_2SiO_3), T_4 = Salicylic acid, T_5 = PPN (Peak Performance Nutrient) and T_6 = Sulphur based fungicide.

The reduction of disease incidence over control due to the application of different phyto-chemicals/fungicides were calculated at 107 DAT (Figure 1). The highest reduction of disease incidence was estimated by potassium silicate (T_2) (36.89%) which was statistically superior over other treatments. Peak Performance Nutrient (T_5) showed the second-best performance for controlling powdery mildew in bottle gourd plants (24.18%) followed by Silica (T_1) (20.49%) and phosphorus silicate (T_3) (20.08%).

4.3. Effect of phyto-chemicals on powdery mildew disease severity

The treatments explored in the experiment showed significantly difference performance in reducing the powdery mildew disease severity (Table 2). The performance of different treatments was recorded at 93 days after transplanting (DAT), 100 DAT and 107 DAT. At 93 DAT, the lowest disease severity (9.67%) was recorded in case of potassium silicate (T_2) followed by Peak Performance Nutrient (T_5) (18.00%), Silica (T_1) (20.00%), phosphorus silicate (T_3) (22.00%), McSulphur 80 WP (T_6) (25.33%) and salicylic acid (T_4) (31.33%). The highest disease severity (34.33%) was recorded in control plot (T_0) (Table 2).

Table 2. Effect of phyto-chemicals on disease severity of bottle gourd at different data recording intervals

Treatment	Disease severity (%)			%Reduction of Disease severity at 107 DAT
	93 DAT	100 DAT	107 DAT	
T_0 (Control)	34.33 a	52.83 a	64.17 a	-
T_1 (Silica)	20.00 de	32.60 e	43.75 c	31.82
T_2 (K_2SiO_3)	9.67 f	17.12 g	25.33 e	60.52
T_3 (P_2SiO_3)	22.00 d	35.06 d	44.44 c	30.74
T_4 (Salicylic acid)	31.33 b	49.03 b	61.67 a	3.90
T_5 (PPN)	18.00 e	30.09 f	39.75 d	38.06
T_6 (McSulphur 80 WP)	25.33 c	39.16 c	50.67 b	21.04
LSD $_{(.05)}$	**2.13**	**1.66**	**2.60**	**-**
CV (%)	**5.21**	**2.56**	**3.10**	**-**

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

At 100 DAT, the highest disease severity (52.83%) was recorded in control and the lowest disease severity (17.12%) was recorded in case of potassium silicate(T_2) application followed by Peak Performance Nutrient (T_5) (30.09%), silica (T_1) (32.60%), phosphorus silicate (T_3) (35.06%), McSulphur 80 WP(T_6) (39.16%) and salicylic acid (T_4) (49.03%) (Table 2).

Again, at 107 DAT, the lowest disease severity was also recorded in potassium silicate (T_2) (25.33%) followed by Peak Performance Nutrient (T_5) (39.75%), silica (T_1) (43.75%), phosphorus silicate (T_3) (44.44%), McSulphur 80 WP (T_6)

(50.67%) and salicylic acid (T_4) (61.67%). The highest disease severity (64.17%) was recorded in control plot (T_0) (Table 2).

4.3.1. Measurement of disease control

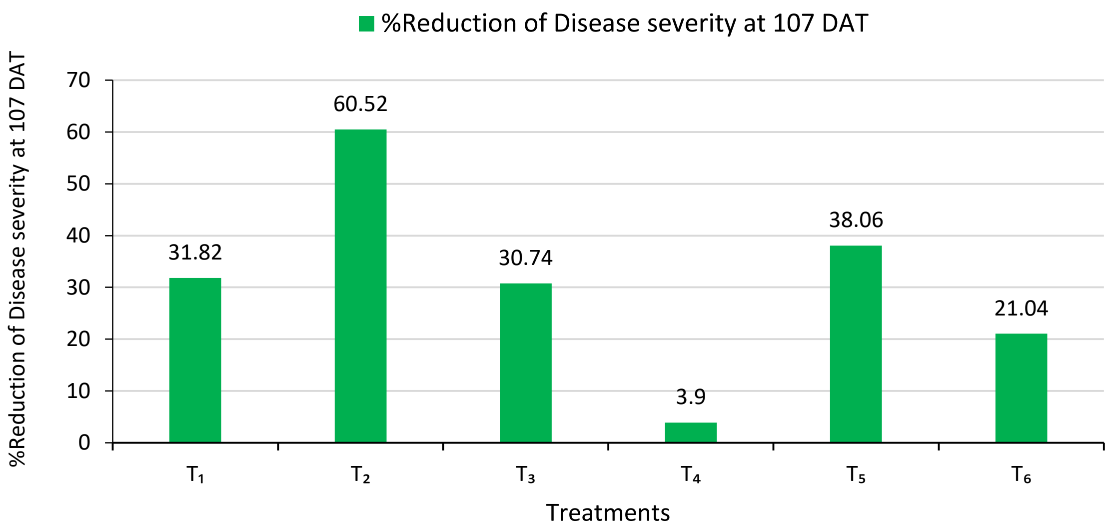

Figure 2: Reduction of % disease severity over control due to application of phyto-chemicals/fungicides at 107 DAT

Here, note: T_1 = Silica (Silicon dioxide, SiO_2), T_2 = Potassium silicate (K_2SiO_3), T_3 = Phosphorus silicate (P_2SiO_3), T_4 = Salicylic acid, T_5 = PPN (Peak Performance Nutrient) and T_6 = Sulphur based fungicide.

As the last recording data at 107 DAT, the Potassium silicate (T_2) showed the best performance (60.52%) in reducing disease severity over control

(Figure 2). The second highest reduction of disease severity was recorded in case of Peak Performance Nutrient (T_5) (38.06%).

4.4. Effect of different phyto-chemicals on number of tendrils of bottle gourd

Different phytochemicals exerted significant effect on number of tendrils of bottle gourd in the present study (Table 3). Potassium silicate (T_2) treated plants had maximum number of tendrils (15.33) followed by silica (T_1) (12.67), salicylic acid (T_4) (12.33), Peak Performance Nutrient (T_5) (12.33), McSulphur 80 WP (T_6) (12.33) and phosphorus silicate (T_3) (11.00). On the other hand, minimum number of tendrils (10.67) were observed from control plants (T_0).

Table 3. Effect of different phyto-chemicals on number of tendrils of bottle gourd

Treatment	Number of tendrils
T_0 (Control)	10.67 b
T_1 (Silica)	12.67 ab
T_2 (K_2SiO_3) $C_7H_6O_3$	15.33 a
T_3 (P_2SiO_3)	11.00 b
T_4 ($C_7H_6O_3$)	12.33 ab
T_5 (PPN)	12.33 ab
T_6 (McSulphur 80 WP)	12.33 ab
LSD $_{(.05)}$	**4.21**
CV (%)	**19.09**

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

4.5. Effect of different phyto-chemicals on number of fruits of bottle gourd

Number of fruits in bottle gourd plant was significantly influenced by different phyto-chemicals application (Table 4). The highest number of fruits per plant (10.00) was recorded from potassium silicate (T_2) treated plants followed by McSulphur 80 WP (T_6) (9.67), Silica (T_1) (8.33), salicylic acid (T_4) (6.33), Peak Performance Nutrient (T_5) (5.67) and phosphorus silicate (T_3) (4.33); whereas the lowest number of fruits (3.67) was obtained from control(T_0).

Table 4. Effect of different phyto-chemicals on number of fruits of bottle gourd

Treatment	Number of fruits/plant
T_0 (Control)	3.67 e
T_1 (Silica)	8.33 ab
T_2 (K_2SiO_3)	10.00 a
T_3 (P_2SiO_3)	4.33 de
T_4 ($C_7H_6O_3$)	6.33 c
T_5 (PPN)	5.67 cd
T_6 (McSulphur 80 WP)	9.67 ab
LSD $_{(.05)}$	**1.78**
CV (%)	**14.58**

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

4.6. Effect of phyto-chemicals on length of fruit (cm) of bottle gourd

Different phyto-chemicals showed significant influence on length of bottle gourd fruit (Table 5). The longest fruit of bottle gourd (63.93 cm) was observed from Potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (56.60 cm), Silica (T_1) (49.67 cm), salicylic acid (T_4) (48.17 cm), phosphorus silicate (T_3) (45.62 cm) and Peak Performance Nutrient (T_5) (44.42 cm); whereas, the shortest fruit (40.72 cm) was recorded from control (T_0).

Table 5. Effect of phyto-chemicals on length of fruit of bottle gourd

Treatment	Length of fruit (cm)
T_0 (Control)	40.72 f
T_1 (Silica)	49.67 c
T_2 (K_2SiO_3)	63.93 a
T_3 (P_2SiO_3)	45.62 e
T_4 ($C_7H_6O_3$)	48.17 d
T_5 (PPN)	44.42 e
T_6 (McSulphur 80 WP)	56.60 b
LSD $_{(.05)}$	**1.21**
CV (%)	**1.37**

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

Table 6. Effect of phyto-chemicals on diameter of fruit of bottle gourd

Treatment	Diameter of fruit (cm)
T_0 (Control)	25.96 d
T_1 (Silica)	26.63 cd
T_2 (K_2SiO_3)	30.78 a
T_3 (P_2SiO_3)	28.83 abc
T_4 ($C_7H_6O_3$)	27.83 bcd
T_5 (PPN)	26.89 cd
T_6 (McSulphur 80 WP)	30.51 ab
LSD $_{(.05)}$	**2.82**
CV (%)	**5.63**

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

4.7. Effect of phyto-chemicals on diameter of fruit (cm) of bottle gourd

Diameter of bottle gourd fruit was significantly affected by different phyto-chemicals application (Table 6). The range of diameter varied from 25.96 cm to 37.78 cm. The narrowest diameter of fruit was observed in control (T_0) which was 25.96 cm. The widest fruit was recorded in potassium silicate (T_2) which was 30.78 cm followed by McSulphur 80 WP (T_6) (30.51 cm), phosphorus silicate (T_3) (28.83 cm), salicylic acid (T_4) (27.83 cm), Peak Performance Nutrient (T_5) (26.89 cm) and Silica (T_1) (26.63 cm).

Table 7. Effect of phyto-chemicals on fruit weight (kg) of bottle gourd

Treatment	Fruit weight (kg)
T_0 (Control)	1.49 d
T_1 (Silica)	1.67 cd
T_2 (K_2SiO_3)	2.52 a
T_3 (P_2SiO_3)	1.87 bc
T_4 (Salicylic acid)	1.71 c
T_5 (PPN)	1.85 bc
T_6 (McSulphur 80 WP)	1.99 b
LSD $_{(.05)}$	**0.20**
CV (%)	**6.06**

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

4.8. Effect of phyto-chemicals on average fruit weight (kg) of bottle gourd

Application of selected phyto-chemicals exerted significant effects on average fruit weight (kg) of bottle gourd (Table 7). The highest fruit weight (2.52 kg) was recorded from potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (1.99 kg), phosphorus silicate (T_3) (1.87 kg), Peak Performance Nutrient (T_5) (1.85 kg), salicylic acid (T_4) (1.71 kg) and Silica (T_1) (1.67 kg) whereas, the minimum average weight (1.49 kg) was obtained from control (T_0).

CHAPTER IV

DISCUSSION

Erysiphe cichocearum is the causal agent of powdery mildew of bottle gourd, hampers the production every year in our country. For minimizing the yield loss, farmers are using 'S' containing fungicides (Sulphur dust, MacSulphur, Sulfolac, Thiovit etc.). At first, those fungicides give promising effect in disease management but now the fungicides are nearly ineffective in disease management. So, the present study was undertaken to test the efficacy of new chemicals against powdery mildew disease.

The plant showed powdery mildew disease appearance and *Erysiphe cichocearum* was identified from infected leaves of bottle gourd. In this disease, premature defoliation and poor growth were observed. Sharma *et al.* (2016) reported that powdery mildew disease first appears on older leaves. Conidia are produced profusely in the white powdery mycelium, and these spores spread quickly through wind to the adjacent leaves or plants as well as travel over long distances. Powdery mildew appears as talc-like (white fluffy) colonies or circular patches on the under surface of leaves. As the disease progresses, the entire leaf surface is colonized by the fungus. In case of severe infection, the patches on the leaves coalesce and become yellow and necrotic. Such leaves die within a short span of time. The disease is most severe after fruit set and in densely planted fields. Symptoms and signs can also develop on stems and fruit.

Spores of *Erysiphe* were selected for incubation purpose. For this, at first, disease affected leaves were collected from the field and then spores were incubated in the leaves by brushing of the spores with the help of a camel's hair brush in thirty days (30 D) older seedlings. The plants were covered with polybag to maintain humidity for 24 to 48 hours for easy penetration of the pathogen. After incubation of 48 hours, polybag was removed and waited for disease appearance. After 10–12 days of inoculation, powdery mildew disease appeared on the inoculated plants. Then the diseased leaves were taken to the lab for identification.

Disease incidence was calculated which was the number of proportions of the plant units diseased in relation to the total number of units examined. Disease severity was measured which was the proportion of amount of plant tissues infected in relation to the total amount of tissue examined. Number of tendrils was counted from three plants in each plot and then the mean value of three plants was recorded as tendrils number. Number of fruits was counted from three plants in each plot and then the mean value of three plants was recorded as fruits number. Length of each fruit was measured in centimeters with the help of measuring tape and then the mean of three fruits was recorded as fruit length. Diameter of each fruit was measured in centimeters with the help of measuring tape and then the mean of three fruits was recorded as fruit diameter. The randomly selected three fruits in each plot were weighed with the help of pan balance and the mean was expressed as average weight of fruit (kg).

The highest reduction percentage of disease incidence (36.89%) were recorded from the plots applied by potassium silicate (T_2). Other treatments also gave better results compared to control. At 93 DAT, the lowest plant infection (14.67%) was recorded in case of potassium silicate (T_2) followed by Silica (T_1) (32.00%), Peak Performance Nutrient (T_5) (32.00%), phosphorus silicate (T_3) (33.33%), McSulphur 80 WP (T_6) (34.67%) and salicylic acid (T_4) (36.00%). The highest plant infection (56.00%) was recorded in control plot (T_0). At 100 DAT, the highest disease incidence (plant infection) (72.48%) was recorded in control (T_0) and the lowest disease incidence (39.07%) was recorded in case of potassium silicate (T_2) application followed by silica (T_1) (44.00%), phosphorus silicate (T_3) (48.33%), Peak Performance Nutrient (T_5) (50.67%), McSulphur 80 WP (T_6) (60.00%) and salicylic acid (T_4) (66.67%).Again, at 107 DAT, the lowest disease incidence was also recorded in potassium silicate (T_2) (51.33%) followed by peak performance nutrient (T_5) (61.67%), silica (64.67%), phosphorus silicate (T_3) (65.00%), McSulphur 80 WP (T_6) (72.00%) and salicylic acid (T_4) (75.67%) while maximum disease incidence was observed in control (T_0) (81.33%). This result was supported by Ali *et al.* (2013), Dallagnol*et al.* (2012), Menzies *et al.* (1992) who mentioned from their individual research work that potassium silicate had significant impact on controlling or reducing powdery mildew diseases in different cucurbits like pumpkin, melon, cucumber, muskmelon and zucchini squash. Foliar spray of the afore-mentioned fungicide was recommended by the researchers. Srinivas (2006) observed the maximum mean per cent powdery mildew disease reduction in upper leaves of bottle gourd with foliar application of salicylic acid 15 mM followed by salicylic acid 10 mM.

In case of reduction of disease severity, the highest performance (60.52%) was recorded from the plots applied by potassium silicate (T_2), whereas the maximum Percent Disease Index (PDI) was calculated from the control (64.17%). Other treatments also gave better results compared to control. At 93 DAT, the lowest disease severity (9.67%) was recorded in case of potassium silicate (T_2) followed by Peak Performance Nutrient (T_5) (18.00%), Silica (T_1) (20.00%), phosphorus silicate (T_3) (22.00%), McSulphur 80 WP (T_6) (25.33%) and salicylic acid (T_4) (31.33%). The highest disease severity (34.33%) was recorded in control plot (T_0). At 100 DAT, the highest disease severity (52.83%) was recorded in control and the lowest disease severity (17.12%) was recorded in case of potassium silicate (T_2) application followed by Peak Performance Nutrient (T_5) (30.09%), silica (T_1) (32.60%), phosphorus silicate (T_3) (35.06%), McSulphur 80 WP (T_6) (39.16%) and salicylic acid (T_4) (49.03%). Again, at 107 DAT, the lowest disease severity was also recorded in potassium silicate (T_2) (25.33%) followed by Peak Performance Nutrient (T_5) (39.75%), silica (43.75%), phosphorus silicate (T_3) (44.44%), McSulphur 80 WP (T_6) (50.67%) and salicylic acid (T_4) (61.67%). The highest disease severity (64.17%) was recorded in control plot (T_0). Reduction of powdery mildew disease severity by Abd-Elsayed *et al*. (2019) on cucumber, Matheron and Porchas (2013) on cantaloupe, El-Naggar *et al.* (2012) on cucumber, Zhang *et al*. (2011) on summer squash and cantaloupe, Ashour (2009) on muskmelon, Yasmin *et al*. (2008) on sweet gourd, McGrath and Shishkoff (1999) on melon, Daayf*et al.* (1995) on long English cucumber and Menzies *et al.* (1992) on cucumber, muskmelon and zucchini squash was reported from the application fungicides, biocides and or substances with fungicidal properties.

Application of different phyto-chemicals or fungicides had significantly positive effect on number and weight of bottle gourd fruit. The maximum number of fruit (10.00) and the maximum average weight of bottle gourd fruit (2.52 kg) was recorded from application of potassium silicate (T_2). Zhang *et al*. (2011).

CHAPTER V

SUMMARY AND CONCLUSION

Powdery mildew of bottle gourd is one of the important disease responsible for lower yield of bottle gourd in many countries. Management of powdery mildew disease is required to maintain the quality and quantity of the fruit. Different management approaches have been led to control the disease.

In this experiment, we evaluated silica and salicylic acid-based fungicide, Peak Performance Nutrient (PPN), Potassium silicate, Phosphorus silicate and sulphur-based fungicide (McSulphur 80 WP). For controlling the powdery mildew disease, excess use of the same fungicide actually lowers the effectiveness of fungicide and hampers the resistance level.

The primary damage of powdery mildew is premature defoliation of the plant. Due to disease, photosynthesis rates gradually decreased and respiration rates increased in powdery mildew infected bottle gourd plants. In the present investigation the highest reduction of disease incidence (36.89%) was recorded by the application of potassium silicate (T_2). The nearest reduction of disease incidence was found in Peak Performance Nutrient (T_5) (24.18%) followed by Silica (T_1) (20.49%) and Phosphorus silicate (T_3) (20.08%).

At 107 days after transplanting, the PDI (Percent Disease Index) values were observed and it was found that the maximum PDI was calculated from the control (64.17%). At 107 DAT, potassium silicate (T_2) showed the highest performance (60.52%) in reduction of disease severity. The second highest reduction of disease severity was recorded in case of Peak Performance Nutrient (T_5) (38.06%) followed by Silica (T_1) (31.82%), Phosphorus silicate (T_3) (30.74%), McSulphur 80 WP (T_6) (21.04%) and Salicylic acid (T_4) (3.90%).

However, the phyto-chemicals/fungicides were also responsible for increasing the number of tendrils, length and diameter of fruit, number and weight of bottle gourd fruit. Potassium silicate (T_2) treated plants had maximum number of tendrils (15.33) followed by silica (T_1) (12.67), salicylic acid (T_4) (12.33), Peak Performance Nutrient (T_5) (12.33), McSulphur 80 WP (T_6) (12.33) and phosphorus silicate (T_3) (11.00). On the other hand, minimum number of tendrils (10.67) were observed from control plants (T_0). The longest fruit (63.93 cm) was observed from Potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (56.60 cm), Silica (T_1) (49.67 cm), salicylic acid (T_4) (48.17 cm), phosphorus silicate (T_3) (45.62 cm) and Peak Performance Nutrient (T_5) (44.42 cm); whereas, the shortest fruit (40.72 cm) was recorded from control (T_0). The narrowest diameter of fruit was observed in control (T_0) which was 25.96 cm. The widest fruit was recorded in potassium silicate (T_2) which was 30.78 cm followed by McSulphur 80 WP (T_6) (30.51 cm), phosphorus silicate (T_3) (28.83 cm), salicylic acid (T_4) (27.83 cm), Peak Performance Nutrient (T_5) (26.89 cm) and Silica (T_1) (26.63 cm). The maximum number of fruit (10.00) was recorded from application of potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (9.67) and Silica (T_1) (8.33). In case of weight, the maximum average weight of bottle gourd fruit (2.52 kg) was recorded from application of potassium silicate (T_2) followed by McSulphur 80 WP (T_6) (1.99), Phosphorus silicate (T_3) (1.87 kg) and Peak Performance Nutrient (T_5) (1.85).

At the end of the above results it can be concluded that-

- Potassium silicate (K_2SiO_3) was found effective against powdery mildew disease of bottle gourd.

- K_2SiO_3 (Potassium silicate) also gave the best result in giving large sized and heaviest fruits.

- K_2SiO_3 may be used as an alternative of 'sulphur containing fungicide'.

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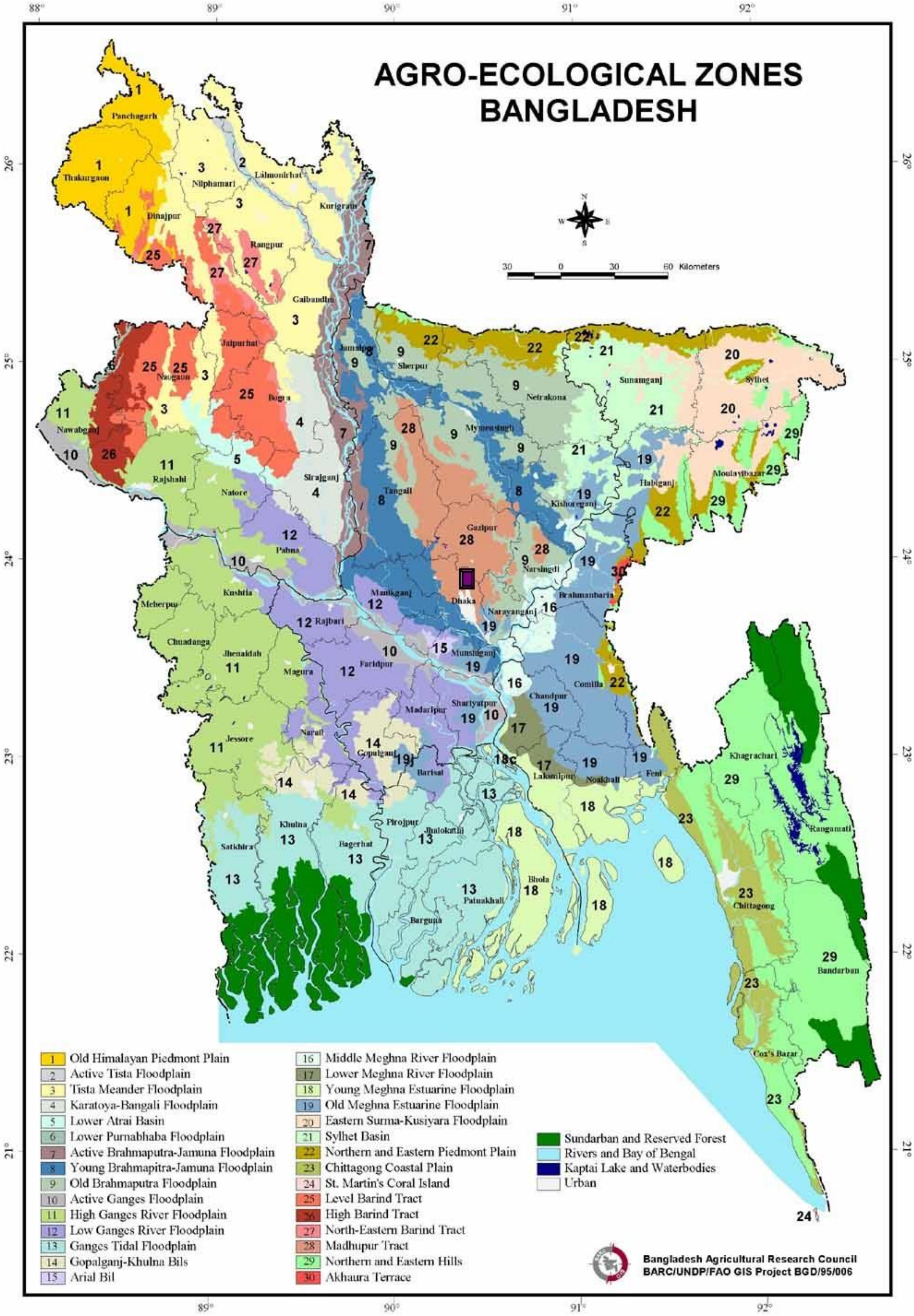
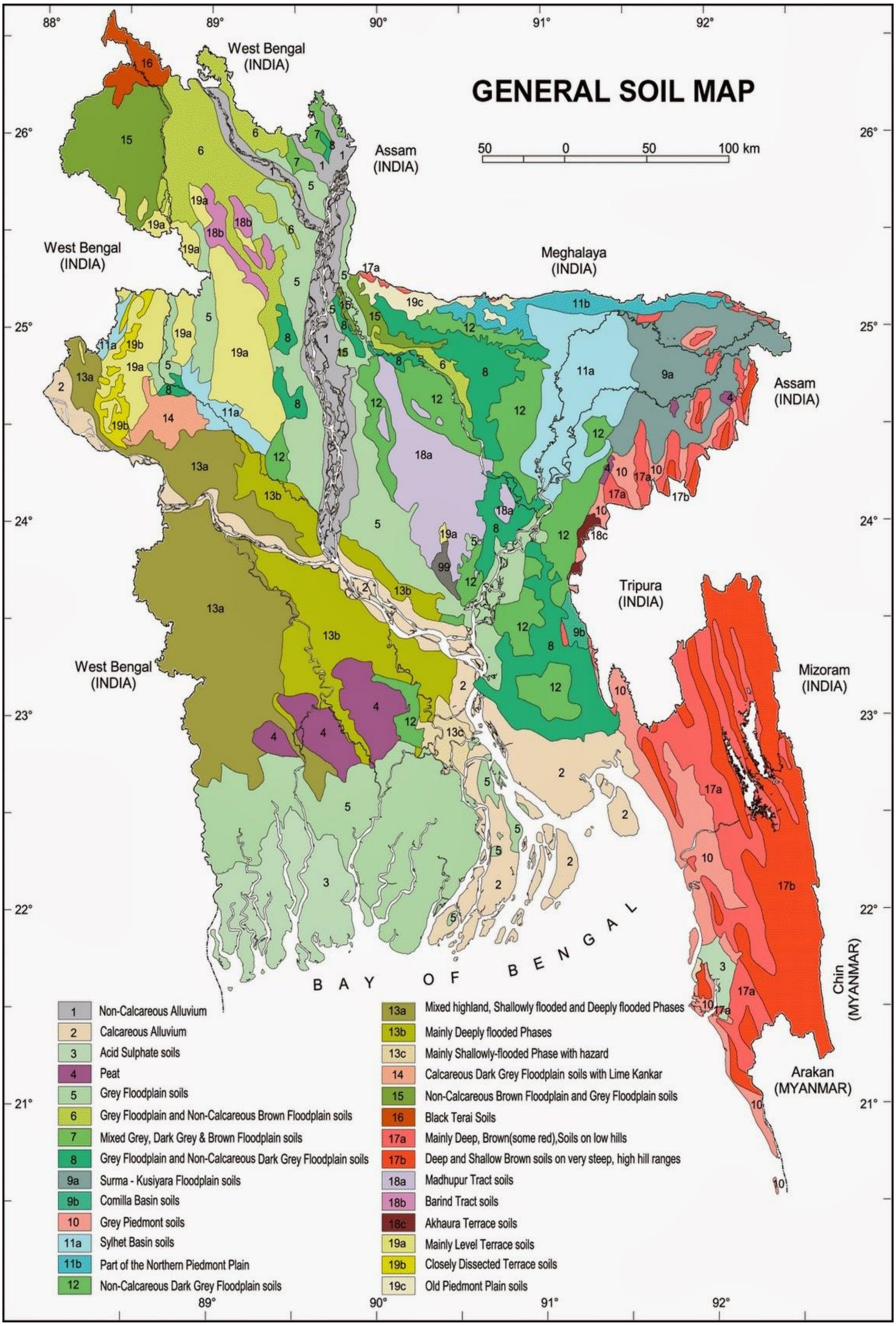
APPENDICES

Appendix I (A): Map showing the experimental sites under study



■ **The experimental site under study**

Appendix I(B): Map showing the general soil sites under study



Appendix II: Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping Pattern	Boro–Aman–Boro

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.5
Organic carbon (%)	0.43
Organic matter (%)	0.75
Total N (%)	0.075
Available P (ppm)	21.00
Exchangeable K (meq/ 100 g soil)	0.11
Available S (ppm)	43

Source: SRDI, 2018

Appendix III: Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2019toMay 2020

Year	Month	Temperature			Relative Humidity (%)	Rainfall (mm)	Sunshine (Hour)
		Max (°C)	Min (°C)	Mean (°C)			
2019	November	32	24	29	65	42.8	349
	December	27	19	24	53	1.4	372
2020	January	27	18	23	50	3.9	364
	February	30	19	26	38	3.1	340
	March	35	24	31	38	19.6	353
	April	38	25	33	54	292.4	315
	May	37	27	33	59	152.5	297

Appendix IV. Mean square value of number of tendril and fruit of bottle gourd from Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean squarevalue of	
		Number of	Number of fruits
Replication	2	2.476	31
Phyto-chemicals	6	6.825*	19.095
Error	12	5.587	0.999

* = Significant at 0.05 level of probability

Appendix V. Mean square value of length and diameter of fruit of bottle gourd from Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean squarevalue of	
		Length of fruit	Diameter of fruit
Replication	2	85.826	48.682
Phyto-	6	188.788*	10.866
Error	12	0.465	2.517

* = Significant at 0.05 level of probability

Appendix VI. Mean square value of average fruit weight per treatment of bottle gourd from Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean squarevalue of
		Average fruit weight
Replication	2	0.0045
Phyto-chemicals	6	0.322
Error	12	0.012

* = Significant at 0.05 level of probability.

Appendix VII. Mean square value of disease incidence of powdery mildew in bottle gourd from Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean squarevalue of		
		Disease incidence at		
		93 DAT	100 DAT	107 DAT
Replication	2	512.761	0.748	2.904
Phyto-chemicals	6	435.301*	451.293*	293.936*
Error	12	173.206	1.086	3.626

* = Significant at 0.05 level of probability

Appendix VIII. Mean square value of disease severity of powdery mildew in bottle gourd from Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean squarevalue of Disease severity at		
		93 DAT	100 DAT	107 DAT
Replication	2	1.761	2.048	0.6276
Phyto-	6	208.047*	432.277*	531.168*
Error	12	1.428	0.873	2.137

* = Significant at 0.05 level of probability