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# Post-Harvest Diseases of Some Common *Rabi* Vegetables

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## Abstract

***At harvest and at storage the vegetables harbour different microbial communities including beneficial and harmful. The harmful microbiome (the pathogens) is responsible for post-harvest losses that dramatically impact vegetable production andquality parameters. Pre-harvest infections remain quiescent until the fruit becomes senescent shortly after harvest or during prolonged storage. Conversely, vast majority of post-harvest infections happen through wounds caused during harvest and subsequent handling. Post-harvest diseases of fruits and vegetables are characterized by latent infections that are asymptomatic throughout the growing season and only develop on mature fruit, after harvest and during storage. Post-harvest deterioration of vegetables limits the period of storage, compromises marketing and consumer's acceptability, and causes great losses. Devastating post-harvest pathogenic fungal generasuchasPenicillium Aspergillus, Geotrichum, Botrytis, Fusarium, Alternaria, Colletotrichum, Dothiorella, Lasiodiplodia, Phomopsis, Phytophthora, Pythium, Rhizopus and Mucor, etc., causepost-harvestfruitdecayinconsiderableproportions. The major causal agents of bacterial soft rots are various species of Erwinia, Pseudomonas, Bacillus and Xanthomonas.***

**Keywords:** Diseases, pathogen,post-harvest, *rabi* vegetables

## Introduction

The importance of horticultural crops, especially fruits and vegetables, in improving the nutritional status and economy needs no emphasis. Vegetables are important source of dietary fibers, minerals, antioxidants and vitamins. Shifting from a non-vegetarian diet to vegetarian, global recognition of the importance of vegetables for human health and their medicinal and nutritional value have contributed to a steady upward trend in vegetable production system.China is ranked first in the world and India is the second largest producer of vegetables after China. Vegetable crops in India occupy an area of 10.26 million hectares with a total production of 184.40 million tonnes and productivity of 17.97 million tonnes (Annon., 2018). More than 40 kinds of vegetables belonging to different groups are grown in India in tropical, sub-tropical and temperate regions. Important vegetable crops grown in the country are potato, tomato, onion, brinjal, cabbage, cauliflower, peas, okra, chillies, beans, melons, etc.

Losses caused by various post-harvest diseases, which may occur at any time during post-harvest handling, from harvest to consumption are very high because the value of fresh fruits and vegetables increases many fold while passing from the field to the consumer. Most of the developing countries are situated in tropical regions where high temperature, water shortage and humidity create many problems. (Eckert & Sommer, 1967; Droby, 2006). In the former case, pre-harvest infections remain quiescent until the fruit becomes senescent shortly after harvest or during prolonged storage. Conversely, vast majority of post-harvest infections happen through wounds caused during harvest and subsequent handling. The disease which develop on harvested parts of the plants like seeds, fruits and also on vegetables are the post-harvest diseases. The plant products may get infected by microorganisms and cause rotting or decaying partially or totally. Many of the important fungal pathogen that causes post-harvest diseases include *Penicillium Aspergillus*, *Geotrichum*, *Botrytis*, *Fusarium*, *Alternaria*, *Colletotrichum*, *Dothiorella*, *Lasiodiplodia*, *Phomopsis*, *Phytophthora*, *Pythium*, *Rhizopus* and *Mucor*. The major causal agents of bacterial soft rots are various species of *Erwinia*, *Pseudomonas*, *Bacillus* and *Xanthomonas*. Bacterial soft rots are very important post-harvest diseases of many vegetables. Losses due to various post-harvest diseases are affected by factors like commodity type, cultivar susceptibility to post-harvest disease, the post-harvest environment (temperature, relative humidity, atmosphere composition, etc.), produce maturity and ripeness stage, treatments used for disease control,

produce handling methods and post-harvest hygiene etc. Post-harvest may cause economic losses in fields because of added costs in harvesting transportation and storage. Post-harvest diseases are often classified according to how infection is initiated. Post-harvest diseases destroy 10-30% of the total yield of crops and in some perishable crops especially in developing countries, they destroy more than 30% 0f the crop yield (Agrios, 2005; Kader, 2002). As per the study by the Central Institute for Post-Harvest Engineering & Technology, Ludhiana (published in 2010) post-harvest losses of major agricultural products including fruits and vegetables at National level were estimated to the tune of about Rs. 44,000 crores per annum (Mahant, 2012). The government has stated that nearly 35-40% of the vegetables produced in the country are wasted. But as per the Indian Council on Agricultural Research (ICAR), the maximum loss in vegetables ranges between 12.4 to 18% (post-harvest)**.**Post-harvest diseases of fruits and vegetables are characterized by latent infections that are asymptomatic throughout the growing season and only develop on mature fruit, after harvest and during storage (Mantyka, 2010). Post-harvest deterioration of vegetables limits the period of storage, compromises marketing and consumer's acceptability, and causes great losses. Gray mold, soft rot, Fusarium rot, and Sclerotium rot are the common post-harvest pathogens of vegetables, roots, and tubers (Snowdown, 1990). Ahmed *et al.* (2021) conducted a preliminary study about post-harvest diseases and presence pathogens in some of the common *rabi* vegetables in Jorhat district of Assam and confirmed association of Alternaria sp. (tomato), *Cladosporium* sp. (cauliflower), *Erwinia* sp. (capsicum), *Geotrichum* sp. (carrot), *Sclerotinia* sp. (pea), *Sclerotinia* sp. (bean) and *Phomopsis* sp. (brinjal).

**Post-Harvest Diseases of Some Important *Rabi* Vegetables**

**Tomato**

Tomato (*Lycopersicon esculentum* Mill), has very high nutritive values, delicious taste and is one of the most popular and widely grown vegetables in the world. Tomato is one of the most important vegetable crops in India, accounting for about 10.72 per cent of the total vegetable production in the country. Tremendous progress has been made in tomato production during the past four and half decades (Annon., 2018). Tomato is commercially important for both fresh fruit and processed fruit industries. Fresh tomato fruits contain a high level of vitamins A and C, best known source of lycopene and beta-carotene, the antioxidants that promote good health. It is also rich in medicinal properties which keep human stomach and intestine in biologically active state. The nutrient values of the fresh fruit include carbohydrates (3.6 g) protein (1.9 g), fat (0.1 g), vitamin-A (320 IU), Vitamin-C (31 mg), thiamine (0.07 mg), riboflavin (0.01 mg), nicotinic acid (0.40 mg), minerals (0.06 g), sodium (45.80 mg), magnesium (15 mg), phosphorus (36 mg), potassium (114 mg), copper (0.19 mg), sulphur (24 mg), iron (1.80 mg), chlorine (38 mg) per 100 g fresh fruit (Tiwari and Chaudhary, 1993). Large quantities of fruits are used to produce jam, jelly, juice, sauce, puree, paste, powder and pickles.

Alternaria rot of tomato caused by *Alternaria alternata* (Fr.) Keissler is one of the most common disease of tomato fruits and causes heavy losses and make tomato fruits unfit for consumption. The disease was reported by Douglas (1922) from California. Samuel (1932) in his report mentioned that *A. solani* was mainly responsible for the deterioration of tomato. Barkai and Fauchs (1980) and Hassan (1996) have reported that *Alternaria* is main decay causing organism of post-harvest tomato fruits while responsible for black rot lesions on tomato fruits. Amongst most important post-harvest diseases of tomato, gray mold and soft rot are common. A survey of fresh market tomato fruit was conducted by Ahmed *et al.*, 2017 in Oahu to determine which fungal and bacterial pathogens were most commonly associated with post-harvest disease and found *Alternaria*, *Botrytis*, *Colletotrichum*, *Fusarium*, *Geotrichum*, *Mucor*, *Stemphyllium*, *Rhizopus*, *Penicillium*, *Acetobacter*, *Gluconobacter*, *Klebsiella*, *Leuconostoc* and *Pectobacterium* as common pathogen.

**Cauliflower**

Cauliflower (*Brassica oleracea*) is one of several vegetables in the species *Brassica oleracea* in the genus *Brassica*, which is in the family Brassicaceae. The current production of cauliflowerin the

country is being done over 4.53 lakh hectares of land with an annual production of 86.68 lakh tonnes (Annon., 2018).It has high quality of proteins and peculiar in stability of vitamin C after cooking. It is rich in minerals such as potassium, sodium, iron, phosphorus, calcium, magnesium, vitamin A (Nath, 1976). Food value per 100 g of cauliflower is 92.7 per cent water, edible ascorbic acid 70 mg, thiamine 0.2 mg, riboflavin 0.1 mg and niacin 0.57 mg.

Cauliflower heads suffer from many fungal and bacterial diseases in fields and storage. Alternaria leaf spot (*A. brassicae*), doweny mildew (*Pernospora parasitica*), head rot (*Rhizoctonia soloni*), black rot (*X. campestris*pv. *campestris*) and bacterial leaf spot (*Pseudomonas maculicola*) are reported which affect production and marketability of heads of cabbage and cauliflower. *Cladosporium* rot has been reported in cabbage and cauliflower by Laemmlen (1986). Gray mould (*Botrytis cinerea*), rhizopus soft rot (*Rhizopus stolonifer*), watery soft rot (*Sclerotinia sclerotirum*) and Bacterial soft rot (*Erwinia carotovora*) are diseases which occasionally cause loss in the field but important in the later stage of distribution and storage of the heads. Harbola and Khulbe (1994) havereported the association of many pathogens namely *Alternaria tenuissima*, *Aspergillus niger*, *Cordanamusae* and *Fusarium moniliforme*with curd rot of cauliflower.

**Capsicum**

The current production of capsicum (*Capsicum annuum*) in the country is being done over 24,000 hectares of land with an annual production of 3.26 lakh tonnes (Annon, 2018). With the increasing demand for different varieties of capsicum in the market, it is expected that there would be a scope for expanding the area under production of these fruits. India ranks fourth in the production of capsicum. The plant is extensively cultivated in the states of Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu and Himachal Pradesh. The export market for capsicum is also very high and it demands fruits with good size, longer shelf life, attractive color, etc. *Capsicum* the *pepper*, is a genus of flowering plants *in* the nightshade family Solanaceae. The *capsicum* plant is a perennial plant, which is being cultivated *all* round the *world*. It is rich in Vitamin A (8493 IU), Vitamin C (283 mg) and minerals like Calcium (13.4 mg), Magnesium (14.9 mg) Phosphorus (28.3 mg) Potassium, (263.7 mg) per 100 g fresh weight.

Capsicum is susceptible to various post-harvest diseases, which ultimately lower its quality and as a result, financial returns and may pose health hazards to consumers (Freeman *et al.* 1998). Anthracnose disease caused by *Colletotrichum capsici* is one of a major post-harvest disease of capsicum, which causes great economic losses. In general, the fungal spores infect immature fruits in the field but symptoms on the fruits peel appeared after ripening (Than *et al.* 2008). Major fruit rot causing pathogens on capsicum fruits *Alternaria capsici-annui*and *A. tenuis, Cercospora capsici*, *Colletotrichum capsici, C. gloeosporioides*and *Fusarium* spp. from farmer's fields of Bangladesh. Among them *Fusarium* rot caused greater reduction in dry weight of fruits and it was maximum at the ripened stage (Basak *et al.*, 1994).Stommel *et al.* (1996) worked on Pepper (*Capsicum annuum*) Soft Rot of capsicum and identified the causal organisms as *E. carotovora* subsp. *atroseptica* based on symptomology, carbohydrate utilization and fatty acid profiles.

**Carrot**

The current production of carrot (*Daucus carota* subsp. *sativus*) in the country is being done over 97 thousand hectares of land with an annual production of 1648 thousand metric tonnes (Annon., 2018). The major carrot growing states in India are Karnataka, Punjab, Uttar Pradesh, Tamil Nadu, and Andhra Pradesh.Carrot is important root crops cultivated throughout the world for its fleshy edible roots. Carrot farming is done in the spring, summer, and autumn in temperate climate countries and during winter in tropical and subtropical regions. Roots of carrot are used as a vegetable for soups & curries; graded roots are used as a salad, tender roots as pickles also Carrot halwa and jam are famous. Carrot juice is a rich source of carotene and is sometimes used for colouring buffer and other food articles. Carrot tops are used for extraction of leaf protein, as fodder and also for the poultry feed. Carrots possess many

medicinal properties and are used in Ayurvedic medicine. Carrots are a rich source of b-carotene and contain appreciable amounts of thiamine and riboflavin.

*Sclerotinia* rot caused by *Sclerotinia sclerotiorum*(Lib.de Bary is an economically important disease of carrots (*Daucus carota* L.) and is characterized by the pre-harvest epidemic occurring in the field and the post-harvest epidemic occurring in storage (Kora *et al.,* 2003). The damage caused by the disease is particularly important in temperate regions where carrots undergo long-term storage. In Canada, sclerotinia rot of carrot (SRC) occurs in carrot producing areas across all provinces reported by Conners, 1967 and losses of up to 30% and 50% have been reported in stored crops (Finlayson *et al.,* 1989).Cavity spot is one of the most important soil borne diseases in carrot grown in temperate regions and is often referred to as a disease complex including several species of *Pythium* in single lesions reported by Hiltunen and White (2002). The pathogen *Geotrichum candidum* has been reported in various carrot-growing countries around the world, including the USA, Korea, Turkey, Thailand and Japan (Horita and Hatta, 2016)

**Pea**

India is the second largest producer of pea (*Pisum sativum*) after China in the world. Pea crop, in India occupy an area of 5.41 Lakh hectares with a total production of 54.22 million tonnes and productivity of 10.03 tonnes (Anon, 2018). Major pea growing states in India are Bihar, Haryana, Punjab, Himachal Pradesh, Orissa and Karnataka. Uttarakhand is also emerging as vegetable pea growing state as farmers are taking three crops in a year.It is a rich source of protein (25%), amino acids, sugars (12%), carbohydrate, vitamins A and C, calcium and phosphorus, apart from having a small quantity of iron. Peas being very rich in proteins are valuable for vegetable purposes. It is used as a vegetable or in soup, canned frozen or dehydrate. It is cooked as a vegetable along or with potatoes. Split grains of pea are widely used for dal. Pea straw is a nutritious fodder. Peas are starchy, but high in fiber, protein, vitamin A, vitamin B6, vitamin C, vitamin K, phosphorus, magnesium, copper, iron, zinc and lutein.Pea is an important cool-season, frost-hardy, nutritious leguminous vegetable that is widely cultivated for its green pods throughout the world. As a cool-season crop, it is extensively grown in temperate zones. It is also referred as garden pea and field pea. Pea is a quick growing, an annual herbaceous vine that requires the trellis to support growth.

Pea crop suffers from many important diseases, which are responsible for its poor quality and low yield like other pulse crops. Diseases caused by Fungi, Bacteria, Viruses and Nematodes are among the notable risk factors of field pea cultivation. A large number of fungal pathogens of pea namely, *Ascochyta*, *Alternaria*, *Fusarium*, *Rhizoctania solani* and *Sclerotinia sclerotiorum* have been reported to be seed borne (Neergard, 1977; Rathour and Paul, 2004). Verma *et al.*, (2012) reported Grey mold caused by *Botrytis cineria*, Pod spot or Pod rot caused by *Phytophthora parasitica*, *Fusarium semitectum*, *Colletotrichum pisi*, *Alternaria brassicae*var. *phaseoli*, and Damping-off caused by *Sclerotium rolfsii* and *Pythium* spp. have been reported to associated with pea.

**Chilli**

India is the largest producer consumer and exporter of Chilli (*Capsicum frutescens*) after china cultivating in the area of 309 thousand hectares with 3592 thousand tonnes production (Annon, 2018) contributing about 40 % of the World's chilli production. In India Andhra Pradesh is the leading state in Chilli production followed by Karnataka, West Bengal and Odisha.Chilli is considered as one of the commercial spice crops. It is the most widely used universal spice, named as wonder spice. Different varieties are cultivated for various uses like vegetable, pickles, spice and condiments. In daily life, chillies are the most important ingredient in many different cuisines around the world as it adds pungency, taste, flavor and color to the dishes. Indian chilli is considered to be world famous for two important commercial qualities namely, its colour and pungency levels. Some varieties are famous for the red colour because of the pigment and other quality parameters in chilli are length, width and skin thickness.

Chilli (*Capsicum annuum L.)*, an important economic crop worldwide, is severely infected by fruit rot which may cause yield losses of up to 50%. The disease has been reported in all the chilli producing regions of the world and has become a serious constraint in chilli production. Different species of Colletotrichum, (*C. capsici, C. gloeosporioides, C. acutatum),Alternaria alternata*and *Fusarium* spp. are known to cause fruit rot in chilli. Khodke and Gahukar (1995) described the disease symptoms of fruit rot of chilli (*Colletotrichum gloeosporioides*) as depressed sunken, discoloured, circular to irregular spots of varying sizes.Lesions of *Alternaria alternata* on chilli fruit were darker in color and covered by moldy growth of fungus with heavy sporulation. Symptoms of Alternaria rot on chilli begin as water soaked, gray lesions on fruit further they become darken and become covered with spores, internal necrosis and mycelia growth occurred on the seeds, placenta and pericarp (Halfon*et al.*, 1983; Wall and Biles, 1993).Prabhavathy and Reddy (1995) isolated fungi causing black rot disease on chilli fruits *viz., Alternaria alternata, Curvulari alunatus, C. pallescens, Pythyium butleri,Botryodiplodiatheobromae, Phomopsis equiseti, Rhizopus stolonifer, Fusarium semitectum* and *Choanephora cucurbitarum*for the first time in Andhra Pradesh. In incidence severity of *Alternaria alternata* on chilli fruits causing fruit rot is also a problem, its pathogenicity was confirmed on chilli fruit (Khodke and Gahukar, 1993).

**Bean**

The current production of Bean (*Phaseolus vulgaris* L.) in the country is being done over 2.28 lakh hectares of land with an annual production of 22.77 lakh tonnes (Annon., 2018). Twenty species of green bean are consumed by humans, with green bean most consumed. Green bean, French bean, common bean, broad bean, and navy bean are other common names of *P. vulgaris* species. Bean is the seed of one of several genera of the flowering plant family Fabaceae, which are used as vegetables for human or animal food.

Many phytopathogenic post-harvest fungi such as *Sclerotinia sclerotiorum*, *Botrytis cinerea*, *Alternaria alternate*, *Rihzctonia solani*,*Pythium aphanidermatum* and *Fusarium solani* cause great losses in quantity and quality of the snap bean pods (Snowdon, 1992). The most serious post-harvest diseases were gray mould (Botrytis cinerea) and white mould (*Sclerotinia sclerotiorum*) (Suslow and Cantwell, 1998). Ahmed (2010) and Fahiem (2010), who found that the seven isolated fungi i.e., *Alternaria* spp., *Botrytis cinerea*, *Fusarium* sp., *Mucor* sp., *Pythium aphanidermatum*, *Rhizoctonia solani* and *Sclerotinia sclerotiorum* from naturally infected snap bean pods.

**Brinjal**

Brinjal is one of the most common tropical vegetables grown in India. It is known by different names like Begun (Bengali), ringna (Guajarati), baingan (Hindi), badane (Kannada), waangum (Kashmiri), vange (Marathi)etc. A large number of cultivars differing in size, shape and colour of fruits are grown in India.

Singh and Shukla in 1986 observed epidemiology of *Alternaria* and fruit rot of Brinjal. He found that the disease was severe and appeared regularly causing heavy losses in fruit yield. The disease appeared in two phases, leaf spot and fruit rot. Atmospheric temp, relative humidity and age of the plant played an important role in disease development.Sundaresan*et al.* in 1986 studied the fruit rot disease of Brinjal of the 11 fungi isolated from rotting aubergine in Srilanka, 5 were responsible for post-harvest decay. *Phoma*spp,*Botryodiplodiatheobromae, Rhizopusspp., Absidia*sp. and *Fusarium* sp. were also isolated from the samples. Datar and Ashtaputre in 1988 discovered that *Phomopsis* fruit rot in eggplant caused by *P.vexans*has reached serious proportions. For inoculation a virulent isolate of *P.vexans*was sprayed on the plants at fruiting stage, and two more inoculums sprays were administered 15 days' interval. Jamir *et al.* (2018) isolated a total of 20 isolates of *P. vexans* from Ri-Bhoi district of Meghalaya. The isolates showed significant variations in colony colour, shape, and consistency in the media.

**Conclusion**

Post-harvest diseases of fruits and vegetables limits the period of storage, compromises marketing and consumers' acceptability, and causes great losses.A wide variety of fungal and bacterial cause post-harvest disease in fruit and vegetables. Some of these infect produce before harvest and then remain quiescent until conditions are more favourable for disease development after harvest. Other pathogens infect produce during and after harvest through surface injuries. In the development of strategies for post-harvest disease control, it is imperative to take a step back and consider the production and post-harvest handling systems totally. Many pre-harvest factors directly and indirectly influence the development of post-harvest disease, even in case of infections initiated after harvest. Traditionally fungicides have played a central role in post-harvest disease control. Harvest, trends towards reduced chemical usage in horticulture are facing the development of new strategies. The use of biocontrol agents, natural compounds, and assorted physical treatments as alternatives to the use of synthetic fungicides are also in practice.Proper study on various post-harvest diseases, their management strategy will help to reduce the losses after harvest.As a result, food and nutritional security will also will be improve to a great extent.

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# Phenotypic Screening of Tomato Cultivars for Bacterial Wilt Resistance

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## Abstract

***Bacterial wilt is one of the important diseases of tomato, caused by Ralstonia solanacearum.Management of the diseaseseems to be difficult due tothe pathogen's wide host range, including solanaceous vegetables, ginger, and banana, andits long survival ability in soil. Different management practices of the disease have been suggested by many workers including use of chemicals, antibiotics, soil amendments, soil solarization, biological control, good agricultural practices, use of resistant or tolerant cultivars etc. Again, applications of chemicals and antibiotics for management of the disease have limitations and farmers do not get satisfactory results by their applications alone. Chemicals also exert serious effects on non-target beneficial organisms and consequently hazardous threat to environment. Under these circumstances, exploration of non-chemical methods, like phenotypic screening of tomato cultivars for bacterial wilt resistance (host plant resistance) to be incorporated inintegrated disease management is very important.***

**Keywords*:*** Bacterial wilt, Pathogen, Phenotypic screening, *Ralstonia solanacearum,* Resistance

## Introduction

Tomato (*Lycopersicon esculentum* Mill) is one of the most popular and widely grown vegetables in the world, with very high nutritive values, delicious taste and contain a high level of vitamins A and C, best known source of lycopene and beta-carotene, the antioxidants that promote good health.Tomato is commercially important for both fresh fruit and processed fruit industries. Fresh tomato fruits contain a high level of vitamins A and C, best known source of lycopene and beta-carotene, the antioxidants that promote good health. It is also richin medicinal properties which keep human stomach and intestine in biologically active state. The nutrient values of the fresh fruit include carbohydrates (3.6 g) protein (1.9 g), fat (0.1 g), vitamin-A (320 IU), vitamin-C (31 mg), thiamine (0.07 mg), riboflavin (0.01 mg), nicotinic acid (0.40 mg), minerals (0.06 g), sodium (45.80 mg), magnesium (15 mg), phosphorus (36 mg), potassium (114 mg), copper (0.19 mg), sulphur (24 mg), iron (1.80 mg), chlorine (38 mg) per 100 g fresh fruit (Tiwari and Chaudhary, 1993). Large quantities of fruits are used to produce jam, jelly, juice, sauce, puree, paste, powder and pickles.

Amongst more than 200 known tomato diseases known, bacterial wilt is one of the most important disease,causing yield loss between 10.8 and 90.6 per cent depending on environmental condition, susceptibility of the host (Kishun, 1987). The pathogen,*R. solanacearum* is a soil borne bacterial plant pathogen of global importance, has been classified into 5 races that altogether can infect more than 450 plant species in 54 botanical families (Allen *et al.*, 2005). The *R. solanacearum* strains that cause disease in the plant family solanaceae, including tomato, is designated as race 1.Among theimportant characteristic symptoms of the disease yellowing of foliage, stunting, wilting, and finally collapse of the whole plant are observed. First wilting of youngest leaves takes place during hot day time. When temperature is cooler during evening hours, the plants may show temporary recovery. After few days sudden and permanent wilting of plants takes place. The vascular system of roots and lower portion of stem shows brown discolouration. For confirmation, ooze test is generally done. Here diseased stems are cut and placed in a test tube or beaker containing water, where bacterial ooze comes out from cut ends as a smoke (Mondal, 2011).

## The Pathogen: *Ralstonia solanacearum*

**Survival of The Pathogen**

The bacterial pathogen can persistin soil for a long period of time. Various scientist reported that it can survive about 16 months in soil being soil borne and soil inhabitant in nature. The pathogen can survive in plant debris and, or without a host plant also, in soil. Weed hosts and non-host plants also play important role in the survival of the pathogenic bacteria in the absence of susceptible tomato crop. Lum (1973) reported that both biovar-3 and biovar-4 found to survive in soil for 20 months during severe drought condition in Malaysia. Shamsuddin *et al*. (1979) reported that *R. solanacearum* can survive up to 2 years in bare or weed soil under temperate conditions.

**Dispersal of The Pathogen**

Kelman and Sequeira (1965) reported that spread of the pathogen from plant to plant and localized spread from root to root occurred in tomato and other host plants. Irrigation water also helps in spread of the diseased pathogen from one field to other. In case of vegetatively propagated crops like potato, banana and ginger, infected planting material plays very important role in dispersal of *R. solanacearum*. Bacterial wilt of banana also disseminated primarily on seed pieces, by root wounding during transplanting or by tools (Sequeira, 1958). Insect dissemination of *R. solanacearum* in banana (Moko disease) has been uniquely important in spread of the disease. Insects carry bacteria mechanically from the ooze issued from diseased banana inflorescences to healthy inflorescences. The pathogen also spreads through various means like infected plants/seedlings, infested soil transported with seedlings, and farm implements, for both short and long distance dispersal.The entry of the pathogen *R. solanacearum* into the host plants usually occurs through root wounds produced in various ways such as cultivation practices, especially if injuries caused during transplanting, injuries by root knot nematode *Meloidogyne* spp. and other nematodes. The study of Huang (1986) revealed that the pathogen also enters at the point of emergence of lateral roots.

**Management of Bacterial Wilt of Tomato**

For management of bacterial wilt disease different practices like use of antibiotics, resistant varieties, organic amendments, Phytosanitary measures, host-plant resistance and biological control etc., were earlier advocated in different crops. Practice of crop rotation with non-host crop like rice, maize, cotton, beans, adoption of clean cultivation, control of root knot nematode, avoid root damage during transplanting are some of the additional management practices are advised to reduce disease incidence and further crop loss. Chemical control through antibiotics like Tetracycline, Streptomycinand fumigation with bactericides (chloroform) enhances severity of wilt caused by *R. solanacearum*. Devnath (2000) found that both streptocycline and Blitox-50 was effective *in vitro* in reduction of *R. solanacearum* growth, while, Dey *et al*. (2001) suggested application of stable bleaching powder @ 12-15 kg/ha along with fertilizers in furrows at the time of planting for effective reduction of bacterial wilt incidence of potato.

Among the potential biological agents used to control bacterial wilt of tomato include antagonistic rhizobacteria such as *Bacillus* sp., *Pseudomonas* spp., antagonistic fungi, *Trichoderma* spp., and vesicular-arbuscular mycorrhizae (VAM), etc. Nath *et al.* (2016) developed a biointensive strategy using *Trichoderma parareesei, Pseudomonas fluorescens, Bacillus subtilis* and *Azotobacter chroococcum,* singly and in combination and recorded highest reduction of bacterial wilt incidence of tomato was in treatment combinations comprising of all the biocontrol agents and plant growth promoting microbes. Trigalet and Trigalet-Demery (1990) used avirulent mutant of *R. solanacearum* as a biocontrol agent against the virulent pathogen. Cultural practices, crop rotation and host resistance could provide limited control of *R. solanacearum*. Persley (1992) suggested that better strategy to control bacterial wilt is breeding for resistance cultivars. In the absence of effective chemical or biological control methods, the best possible approach could be pathogen free seed in pathogen free soil in order to avoid or prevent the occurrence of bacterial wilt.

**Phenotypic Screening o f Tomato Cultivars for Bacterial Wilt Resistance**

High level of resistant have been reported in various tomato lines/ cultivars/ genotypes against bacterial wilt pathogen *R. solanacearum* in different countries of the world, including the Asian Vegetable Research and Development Centre (AVRDC), Taiwan. These cultivars have been found resistant depending upon the temperature and humidity prevailed during cultivation period. The release and growing of such tomato resistant to bacterial wilt have been considered as one of the most effective and eco-friendly measures in controlling the disease. Resistant varieties could either delay the initial infection or slow down the rate of wilting if the initial infection is established.

For conducting the experiment of field screening of tomato cultivars/ genotypes/ germplasms against bacterial wilt disease, the site of the experiment should be a bacterial wilt sick plot where tomato and brinjal crops were grown continuously for three years before testing the cultivars/ genotypes/ germplasms. Artificial inoculation should also need to be done in one month old plants following root inoculation technique with suspension of *R. solanacearum* @ 1 X $10^8$ cfu/ ml. Recommended package of practices should be followed to raise the crop.The disease development can be recorded and evaluated for resistance against wilt by modified disease rating scale of Mew and Ho (1976).

| | |
|---|---|
| HR | 0 per cent plant wilted |
| R | 1 to 10 per cent plant wilted |
| MR | >10 to 20 per cent plant wilted |
| MS | >20 to 30 per cent plant wilted |
| S | >30 to 70 per cent plant wilted |
| HS | >70 per cent plant wilted |

The data can be tabulated and disease incidence (DI %) be calculated by the following formula:

$$\text{Disease Incidence (\%)} = \frac{\text{No. of wilted plant}}{\text{Total no. of plants}} \times 100$$

Henderson and Jenkins (1972) reported the first commercial tomato cultivar Venus and Saturn as resistance to *R. solanacearum*. However, these cultivars were found susceptible under high humid conditions of North Carolina (Ferrer, 1974) and due to presence of virulent strains of the pathogen (Mew and Ho, 1976). Similarly, Rao *et al*. (1975) tested 23 wilt resistant tomato lines from USA and Philippines and found only one line CRA66 SelA as resistant to bacterial wilt against Indian isolate of *P. solanacearum*. Kutty and Peter (1986) in their evaluation of segregating and non-segregating populations of tomato for bacterial wilt resistance found that tomato line LE 79 was moderately resistant, while line Saturn was completely susceptible to bacterial wilt. Similarly, Peter and Joseph (1986) listed the wilt resistant *viz*., BL-1131-0-0-38-40 in Taiwan; PI 126408 in Panama, PI 196298 in Nicaragua, PI 263772 in Peurto Tico, PI 129155 and PI 110597 in UK. Singh (1987) reported Pusa Ruby and Punjab Chuhhara as susceptible genotypes of tomato. Hossain *et al*. (1991) in Bangladesh, found that the tomato cultivars Manik and Asha-4 as highly resistant to natural infection of *P. solanacearum*, but Tusti and Bikash were resistant, while Oxheart, TM 0008, Raton and TM 0003 were moderately resistant. Sreelathakumari and Peter (1992) reported digenic nature of inheritance of resistance to bacterial wilt in the $F_1$ lines developed from *L. pimpinellifolium* LE 218 X *L. esculentum* cv. Lousisiana Pink. Bora *et al.* (1993) screened some brinjal genotypes for resistance against bacterial wilt in Assam and found resistance source in some of the genotypes. Sharma (1996) tested thirty-six genotypes of tomato at Danubase, Nepal and found 12 genotypes resistant to bacterial wilt. Promising genotypes based on phenotypical superiority and bacterial wilt resistant were Hawaii 7998, Hawaii 7997, MT 1 and F7-8—465-10-Pink. Kumar *et al.* (1997) tested 14 tomato varieties and evaluated DPT

38 as resistant and BWR-5 moderately resistant to bacterial wilt (*R. solanacearum*) and of 27 exotic lines tested, 5 were immune and 8 were resistant to the wilt pathogen. Similarly, Monma *et al.* (1997) from Japan, used tomato varieties D-9 and Hawaii 7998 introduced from Malaysia and Hawaii, respectively and evaluated the bacterial wilt resistance based on the date of plant death and found D-9 and Hawaii 7998 were highly resistant against the wilt pathogen and could be used to evolve resistant cultivars. In Orissa Mohanta *et al*. (1998) studied field performance of 23 tomato cultivars over two seasons and found BT-12, BT-14 and Pusa Sheetal free from bacterial wilt.Varietal screening of tomato against bacterial wilt disease under subtropical humid climate of Tripura were studied by Dutta and Rahman (2012) and found cultivar All Rounder as resistant.Nath et al. (2015) conducted an experiment assess bacterial wilt resistance with forty-seven different genotypes of tomato and found Konbilahi (*Lycopersicon pimpinellifolium*) as highly resistantfollowed by Sel-35, sel-19 and Sel-9 as resistant.

## Conclusion

Use of agro-chemicals along with other technologies like improved chemo-responsive hybrids/varieties and irrigation has elevated our country to self-sufficiency in food production. In an eagerness to quickly fight against the hunger and overcome the food shortage, overwhelming uses of agro-chemicals were inculcated, apparently ignoring the ill effects of these chemicals. However, use of chemicals has also a saturation point somewhere, as revealed by recent studies that, extensive use of pesticides in the last 10-15 years has not reduced the losses due to pest damages. So, a stage has now reached to review whether promoting the use of these toxic chemicals is appropriate strategy or not. Tomato genotypes showing resistant to bacterial wilt in field condition can be taken as a source of resistance along with high yielding variety in breeding strategy for development of better performer in terms of reduced bacterial wilt and higher yield. Therefore, the selection of resistant tomato genotypes against bacterial wilt with high yield potentiality can be successfully used for cultivation. Also, genotypes with good tolerance, but low yielder can be successfully used in breeding programme or molecular study for development of bacterial wilt resistant high yielding variety.

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# Climate Change and Its Impact on Plant Diseases

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## Abstract

***The change in global climate is because of expanding grouping of greenhouse gases in the atmosphere that is for the most part brought about by human exercises. These activities are driven by, monetary, segment, social and mechanical changes that significantly affect climate change. The significant components overseeing the spread of plant infections are temperature, moisture, light, and $CO_2$ concentrations. Environmental change causes a critical effect on germination, propagation, sporulation and spore dispersal of pathogenic microorganisms. Environment influences all life phases of the microbe and have and turn into a genuine danger to numerous pathosystems. Expanded $CO_2$ concentration can influence both the host and the microorganism to multiply. New races may be advanced quickly under raised temperature and $CO_2$, as developmental powers follow up on gigantic microbe populace supported by a mix of expanded fertility and disease cycle under positive microclimate inside the amplified shade. Different minor infections showed up as significant ones because of adjustments in climatic boundaries and this manner representing a threat to food security.***

**Keywords:**Climate**,** $CO_2$**,** Fecundity, Sporulation, Temperature

## Introduction

Climate change is a drawn-out shift in the parameters of the weather. Overall environmental change is a significant worry of conversation inside both scientific and political gatherings. The last decade of the 20$^{th}$ century and the beginning of the 21$^{st}$ century years have been the most sweltering range according to accessible records. This adjustment of the earth's climatic structure is generally because of the deceitful exercises of the individual. The progressions in the world's environment are the aftereffect of changes in the cryosphere, biosphere, hydrosphere and other collaborating factors. Greenhouse gases like Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs) and Ozone ($O_3$) present in the world's environment trap the reflected radiation; and thus warm the earth surface (Mahato, 2014). Natural cycles are firmly affected by temperature and water accessibility. Environmental change is influencing every one of the four pillars of food security: accessibility (yield and production), access (costs and capacity to acquire food), use (nutrition and cooking), and stability (disturbances to accessibility).

Numerous natural variables influence plant infection improvement viz., temperature, light and water accessibility, soil fruitfulness, wind speeds, and climatic ozone, methane and $CO_2$ concentrations. Among these, three variables viz., $CO_2$ fixation, temperature, and water accessibility are for the most part changed and influence the climate. Environmental change influences crop irritations and sicknesses helplessness which influences crop wellbeing, and these progressions result in a shift in cultivating rehearses to deal with the impacts of these progressions and to forestall a decrease in usefulness. The famous 'disease triangle' idea in plant pathology underlines the connection of the two microbes and plants with the climate. For infection to happen, a susceptible plant has, a virulent pathogen, and ideal environmental conditions are needed, as an absence of any of these three components lacks in disease development (Agrios, 2005). Variation in any of these three variables brings about non-event of disease and when these elements match for a favourable time frame period, really at that time the infection takes place. Changing climate boundaries can instigate extreme plant disease pandemics. The impact of a natural factor on plants and microorganisms can have positive, nonpartisan or adverse results on plant disease development. The two microorganisms and plants need an ideal ecological condition for their development and proliferation, which is best for disease outbreaks. Barely any works have been done to display the impacts of environmental change on plant illness scourges. Serious plant illness

pestilences can be instigated by evolving climate, which undermines food security if they influence staple harvests (Anderson *et al.*, 2004). There is a model change in nature, time and kind of event of viral and different sicknesses of different green yields because of environmental change.

Cereals, vegetables and fruit crops are more prone to disease because of changing environment boundaries (Das *et al.*, 2016). The occurrence of brown spot of paddy, bacterial blight of paddy, Stripe rust of wheat, citrus canker, downy mildew and powdery mildew of cucurbits, fruit rot and anthracnose of king chilli, banana, Curvularia leaf spot of maize, leaf blotch and spot of turmeric, tomato leaf curl and sigatoka diseases.

**Climate Change and Plant Pathosystems**

Plant diseases play akey role in agriculture development. As a result ofchanging climatic scenarios, many plant diseases considered minor emerged as major ones. Plant pathologists continuously keep an eye onthe environmental effects of plant diseases. The disease triangle focuses on the relationship between plant hosts, pathogens and the environment in causing disease. This global climate changes by various factorsand it influences all the three major elements of the disease triangle, *viz*., host, pathogen and environment.Plant health commonly agonizes under climate fluctuations through various mechanisms like rapid pathogen evolution. In the case of fungal pathogens, moisture is necessary for the germination and initiation of infection by spores as well as for dispersal in many species. In some cases, drought helps in enhancing fungal diseases of plants, especially in forest trees. Synergistic interaction between drought and infection has been shown on tree physiology and the severity of plant diseases.

**Environmental Factors Affecting Plant Diseases**

Many environmental parameters affect plant disease development *viz.*, temperature, light, $CO_2$ concentrations, water availability, soil fertility, wind speeds etc. Among these, three factors are most likely to change and affect the climate – temperature, water availability and $CO_2$ concentrations which are discussed thoroughly in the next sections.

**Effects of Change In Temperatures**

For any plant-pathogen interaction, there is a range of optimal temperature which is needed for the development of diseases. An alterationin temperature may facilitate the evolution of many inactive plant pathogens, which can induce an epidemic. Temperature affects the chain of events in the disease cycle *viz.*, survival, dispersal, penetration, development and reproduction rate of many pathogens. Due to continuously change in temperatures; climate change may affect the growth stage, development rate, physiology and resistance of the host plant (Ladanyi and Horvath, 2010). The effect of elevated temperature on pathogen aggressiveness is both high and low (Table 1). Generally, high moisture and temperature favour the initiation of disease development as well as germination and proliferation of fungal spores of various pathogens. Evidence suggests that temperature affects pathogens due to the accumulation of phytoalexins or protective pigments in host tissue. A temperature rise facilitates spore germination of rust fungus *Puccinia substriata.* Owing to continuously change in temperature, plant pathogenic bacteria like *Ralstonia solanacearum, Acidovorax avenae*and *Burkholderia glumae* have emerged as a serious problem worldwide (Schaad, 2008). Similarly, the incidence of vector-borne diseases will also be changed. Climate can have a significant impact on the development and dispersal of vectors. Climate changes can result in geographical distribution, increases inthe number of generations, overwintering, changes in population growth rates, crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of attack by migratory insects. The rise in temperature with enough soil moisture may increase evapotranspiration which creates humid conditions in the crop which lead to a higher incidence of diseases (Mina and Sinha, 2008).

The temperature has a significant impact on plant disease byaffecting both hostsas well asthe pathogen. Scientists reported that an increase in temperature above $20^0$C can disable temperature-sensitive

resistance genes like *Pg3* and *Pg4* in Oat and some forage species with increased temperature become more resistant to fungi. Likewise, wheat leaf rust resistance genes *viz., Lr2a, Lr210* and *Lr217* are also temperature sensitive. Only *Lr2a* genes show resistance at a temperature beyond $25^0$C (Das *et al.,* 2016). So, a shift in temperature will surely affect the resistance capacity of these genes. Many mathematical models designed for predicting plant disease epidemics are based on increases in pathogenic growth and infection within specified temperature limits.

**Table 1. Influence of elevated temperature on host-pathogen interaction**

| S. No | Crop/Host | Disease/Pathogen | Change in Severity | Reference |
|---|---|---|---|---|
| 1. | Pineapple | *Fusarium subglutinans* | Decrease | Matos *et al.,* 1998 |
| 2. | Wheat | *Puccinia striformis* | Decrease | Yang *et al.,* 1998 |
| 3. | Wheat | *Tilletia controversa* | Increase | Boland *et al.,* 2004 |
| 4. | Wheat | *Puccinia striformis* | Increase | Milus *et al.,* 2006 |
| 5. | Citrus | *Colletotrichum acutatum* | Increase | Jesus Junior, 2007 |
| 6. | Citrus | *Guignardia citricarpa* | Increase | Jesus Junior, 2007 |
| 7. | Potato | *Phytopthora infestans* | Increase | Hannukkala *et al.,* 2007 |
| 8. | Coffee | *Meloidogyne incognita* | Increase | Ghini *et al.,* 2008 |
| 9. | Chilli | *Ralstonia solanacearum*<br>*Xanthomonas campestris* pv. *vesicatoria* | Increase | Shin and Yun, 2010 |
| 10. | Grapevine | *Plasmopara viticola* | Increase | Pugliese *et al.,* 2011 |
| 11. | Wheat | *Blumeria graminis* f. sp. *tritici* | No change | Matic *et al.,* 2018 |

**Effect of Rising $Co_2$ Levels**

The $CO_2$ concentrations in the troposphere are estimated to rise from 360ppm to 710 ppm, by the year 2050. There is an enormous literature on the beneficial effects of elevated $CO_2$ concentrations on biomass production, probably due to increased water use efficiency. Much less is known about $CO_2$, effects on the incidence and severity of biotic diseases of plants. An increase in $CO_2$ concentration has a direct effect on both the host plant and the pathogen. The well-known effects are an increase in leaf area, leaf thickness, tillering, branching, dry weight and stem and root length.An increase in $CO_2$ concentration leads toan increase in canopy size and density resulting in increased high nutritional quality biomass. When this $CO_2$ concentration is combined with increased canopy humidity, it promotes foliar diseases such as rust, powdery mildew, blight and leaf spot.Under increased temperature and $CO_2$, new races may intensify as evolutionary forces act on mass pathogenic populations boosted by a combination of increased fecundity and infection cycles under favourable conditions within an enlarged canopy (Chakraborty, 2013). The increase in crop residues results in better survival conditions for the necrotrophic pathogen. The reduction in the stomatal opening can hinder the stomata-invading pathogens. The shortened growth period and accelerated ripening and senescence can reduce the infection period for biotrophic pathogens and increase the necrotrophic pathogen population. Alternatively, a high level of carbohydrates in the host tissue enhances the growth of biotrophic fungi such as rust, powdery mildew (Chakraborty *et al*., 2002). In general, the density of normal grown plantswill tend to increase leaf surface wetness period and regulate temperature, and hence it makes a chance of infection by foliar pathogens (Dalla Pria *et al*., 2006).Elevated ozone can have similar effects

such as a 3 to 5-fold increase in rust infection on poplar, however, this response is reduced by elevated $CO_2$.

**Table 2. Influence of elevated $CO_2$concentration on host-pathogen interaction**

| S. No | Crop/Host | Disease/Pathogen | Severity level | Reference |
|---|---|---|---|---|
| 1. | Barley | Powdery Mildew (*Erysiphe graminis)* | Decrease | Hibberd *et al.,* 1996 |
| 2. | Wheat | Leaf rust (*Puccinia triticina)* | Increase | Tiedmann and Firstching, 2000 |
| 3. | Tomato | Root rot (*Phytophthora parasitica*) | Decrease | Jwa and Walling, 2001 |
| 4. | Penciflower (*Stylosanthes*) | Anthracnose (*Colletotrichum gloeosporiodes*) | Decrease | Chakraborty *et al.,* 2002 |
| 5. | Aspen (Poplar) | Rust (*Melampsora medusae* f. sp t*remuloidae*) | Increases | Karnosky *et al.,* 2002 |
| 6. | Rice | Sheath Blight (*Rhizoctonia solani*) | Increase | Kobayashi *et al*,2006 |
| 7. | Rice | Blast (*Pyricularia oryzae*) | Increase | Kobayashi *et al.*,2006 |
| 8. | Chilli | Phytophthora blight (*Phytophthora capsici*), Bacterial wilt (*Ralstonia solanacearum*) and Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) | Increase | Shin and Yun, 2010 |
| 9. | Chilli | Anthracnose (*Colletotrichum acutatum*) | Decrease | Shin and Yun, 2010 |
| 10. | Grapevine | Powdery Mildew (*Uncinula necatrix*) | No effect | Pugliese *et al.,* 2010 |
| 11. | Soybean | Downy Mildew (*Peronospora manshurica*) | Decrease | Eastburn *et al.,* 2010 |
| 12. | Soybean | Septoria brown spot (*Septoria glycine*) SDS (Sudden Death Syndrome) | Increase No effect | Eastburn *et al.,* 2010 |
| 13. | Grapevine | Downy Mildew (*Plasmopara viticola*) | Increase | Pugliese *et al.,* 2011 |

| | | | | |
|---|---|---|---|---|
| 14. | Rocket salad | Alternaria leaf spot (*Alternaria japonica*), Basil black spot (*Colletotrichum gloeosporiodes*) | Increase | Pugliese *et al.*, 2012 |
| 15. | Zucchini | Powdery Mildew (*Podosphaera xanthii*) | No effect | Pugliese *et al.*, 2012 |
| 16. | Wheat | Fusarium Head Blight (*Fusarium graminearum*), *Septoria tritici* Blotch | Increase | Vary *et al.*, 2015 |
| 17. | Basil | Downy Mildew (*Peronospora belbahrii*) | Decrease | Gilardi *et al.*, 2016 |
| 18. | Wild Rocket and Radish | Leaf spot (*Fusarium equiseti*) | Increase | Gullino *et al.*, 2017 |
| 19. | Wheat | Powdery Mildew (*Blumeria graminis* f. sp. *tritici*) | No effect | Matic *et al.*, 2018 |

**Effect of Moisture**

Moisture is one of the primeaspects affecting the growth of pathogens. Uneven rainfall patterns for longer spells aids in retaining moisture on leaf surface and RH in the atmosphere for a long periodand thus deliversthe conducive condition for pathogens and diseases such as late blights including powdery mildews and vegetable root diseases. High moisture facilitates foliar diseases and some soil-borne pathogens such *R. solani, Sclerotium rolfsii*, *Pythium* and *Phytophthora*, Moreover, powdery mildew conidia hold their ability to germinate in low moisture and some do so even at 0 % relative humidity (Yarwood, 1978). The conidia of *Erisiphe cichoracearun* germinate at7-32°C with an RH of 60-80% (Khan and Khan, 1992). Spores of *Erysiphe necator* germinate at temperatures from 6-23°C with an RH of 33-90 % (Bendek *et al.*, 2007). Low soil moisture affects the incidence and severity of viruses such as *Maize dwarf mosaic virus (*MDMV*)*and *Beet yellows virus* (BYV) (Clover *et al.*, 1999).

**Conclusion**

Climate change can have positive, negative and impartial effects on individual pathosystems due to the particular idea of the interactions of host and microorganism. Universally, plant microbes obliterate 10-16% of crop losses even with further developed nuisance and illness the board measures. Since both $CO_2$ and temperature are significant variables influencing plants and their microbes, worldwide food supply and disease risk are drawing in extraordinary exploration interest in numerous nations. Various examinations have been done on the impact on plant development under states of raised $CO_2$ and temperature. Specialists presumed that expanded $CO_2$ for the most part delivered bigger plants with more as well as larger organs, while hotter temperatures animated the pace of organ improvement and extension however diminished organ lifetime. Temperature is one of the primary components related to the downpour to decide the frequency and seriousness of the disease, yet the impact could be positive and negative. Environmental raised $CO_2$ and temperature might influence the real, spatial and fleeting spread of infections. Climate change is one the most significant issue in the present century as not in agribusiness in particular; it is presenting a threat to all types of life on earth. So, to confront the problem, there is a need for collaboration of all the disciplines together. The current management strategies should be constantly evaluated and alternative suggestions to be kept well in advance to get prepared against the alarming threat.

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# Cultivation and Identification of Pathogens for Plant Disease Diagnosis

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## Abstract

***Diagnosis of plant pathogens is one of the critical aspects in effective plant disease management. Much of the study of pathogens depends on its ability to grow in the laboratory, and this is possible only if suitable culture media are available for the growth of pathogens. Plant pathogens can be isolated from various sources such as diseased leaves, roots, fruits, stem and soil, water etc., following some standard guidelines and procedures. During isolation, pure culture of the actual pathogen needs to be obtained from a mixed culture, as a diseased plant part may contain many species. By transferring a small sample into a new, sterile growth medium in such a way as to disperse the individual cells across the medium surface leading to thinning effect, the propagules may be separated out, before inoculating the new medium. Most commonly used methods for obtaining pure cultures of fungi are streaking technique, spore suspension dilution technique and single hyphal tip culture. For bacteria, commonly used methods for obtaining pure cultures are streak plate method, pour plate method and spread plate technique. Finally, various approaches need to be conducted for proper and accurate identification of the pathogen associated with any disease, viz., classical approach for identification of microorganisms as well as biochemical, serological and nucleic acid based tests in the aid of identification.***

**Keywords:** Cultivation, disease diagnosis, identification, microorganisms, pathogen

## Introduction

Disease diagnosis requires thorough investigation, following aseries of standard procedures, which start from study of symptom expression in diseased plants. Symptoms, though give vital information on the probable cause of the disease, it cannot be conclusive as many similar symptoms are produced by many different pathogens and abiotic stress. Along with symptoms, signs are also studied which are actual parts of the pathogen visible to naked eye such as spores of fungus, dormant structures such as sclerotia present on host surface or bacterial ooze coming out from host tissues. Further, dissection and observation under compound microscopes for specific spores and fruiting bodies give crucial leads in identification of possible disease agents. Sometimes neither symptoms nor signs and microscopic observation provide enough specific or characteristic information to decide the cause of an infectious plant disease. In such cases, it may be necessary for further laboratory tests to isolate and identify the causal agent.This requires specialized skills for cultivation of pathogens through isolation and pure culture facilitating accurate identification. Furthermore, isolation and pure culture isamandatory step in pathogenicity test for confirming association of a pathogen in case of a new disease, in cases where the organism has not been reported to be a pathogen on that particular host. Furthermore, microbial cultures are fundamental for downstream studies on genetic diversity as well as molecular biology.

## Cultivation of Pathogens/ Microorganisms

Cultivation of plant pathogens by isolation and pure culture, enables study of various morphological, cultural, physiological and biochemical parameters facilitating proper identification of genus and differentiation among closely related species of pathogens. Facultative parasites and facultative saprophytes have the ability to grow in artificial media and can be isolated and maintained in appropriate media for characterization of these pathogens. But obligate parasites such as downy mildew, powdery mildew and rust fungi and viruses, viroids, phytoplasmacannot be cultured in artificial media and have to maintained in live hosts plants by adopting different transmission methods.

## Culture Media

When microorganisms are cultivated in the laboratory, a growth environment called a medium is used. A typical culture medium must contain all the essential nutrients and growth factors necessary for proper growth and development of microorganisms. A culture media can be solid, semi solid or liquid (broth). For solidifying any media, a jellifying material generally agar-agar, a complex polysaccharide derived from red algae, is added into it. Agar has a unique physical property as it acts as inert material in media which melts at 96°C and remains liquid until cooled to 40-45°C, the temperature at which it solidifies. In a semi-solid media agar is added at a concentration of 0.5% which is generally used for micro aerophillic bacteria. Due to great variation in nutrient requirement of different pathogens, the composition of the media used for their cultivation also varies. Media rich in carbohydrates and slightly acidic in nature (pH 6-6.5) favour the growth of fungi, whereas bacteria prefer neutral or slightly alkaline pH. A media must be sterilized prior to inoculation with microorganisms.

**Types of Media Based on Chemical Composition**

On the basis of their composition, there are three main types of culture media: (i) natural or empirical culture media; (ii) semi-synthetic media; and (iii) synthetic or chemically defined culture media. The exact chemical composition of anatural medium is not known. The natural culture media include milk, vegetable juices, meat extracts, rice grain and infusions. Those media whose chemical composition is partially known are called semi-synthetic media. Potato dextrose agar (PDA), Nutrient agar (NA), CzapekDox agar, Oat meal agar, Beef peptone agar are some of the semi-synthetic media. Semi-synthetic media are routinely used in laboratory. Synthetic or a chemically defined mediumis one whose chemical composition is precisely known such as Mineral glucose media, Richard's solution, Raulin's medium, Martin's rose Bengal medium etc. Synthetic media are costly and take more time to prepare than semi-synthetic and natural media. The choice of the media depends on purpose and requirements of the experiment.

**Types of Media Based on Application or Function**

Based on specific function of obtaining pure culture, media may be of mainly two types: (i) Selective media (ii) Differential media.

The selective media are those which permit the growth of some specific group or type of organisms while preventing or retarding or inhibiting the growth of others, thus facilitating microbial isolation.This selectivity is achieved in several ways. For example, organisms that have the ability to utilize a given sugar are screened easily by making that particular sugar the only carbon source in the medium for the growth of the microorganism. Like-wise, the selective inhibition of some types of microorganisms can be studied by adding certain dyes, antibiotics, salts or specific inhibitors that will affect the metabolism or enzymatic systems of the organisms. For example, media containing potassium tellurite, sodium azide or thallium acetate at different concentrations of 0.1 - 0.5 g/l will inhibit the growth of all Gram-negative bacteria. Also, media added with crystal violet dye becomes selectively bacteriostatic for Gram-positive bacteria. Eg. Phenylethyl alcohol agar, Mannitol salt agar and Hektoen enteric agar.

A **differential medium** is that which will cause certain colonies to develop differentially from other closely related organisms present by producing characteristic change in the bacterial growth or the medium surrounding the colonies. These media are used for distinguishing among morphologically and biochemically related groups of microorganisms.Certain dyes or chemicals (such as phenol red, eosin or methylene blue) are added in the media due to which the organisms will produce characteristic changes or growth patterns that are used for identification or differentiation.Unlike selective media, differential media does not kill organisms but it gives an indicationif the target organism is present.

**Isolation of Plant Pathogens**

Plant pathogens can be isolated from various sources such as diseased leaves, roots, fruits, stem and soil, water etc. In general,attempt to isolate the plant pathogen is done from the margins of the diseased tissue where the pathogen in active form is more abundant or active, whereas in recently killed tissue

saprophytes are more numerous.The infected tissue may contain many saprophytesin the necrotic areasand these saprophytes may outgrow the plant pathogen on the culture medium, thwarting accurate identification of the pathogen. To avoid this, plant tissues are surface sterilized with 10% Clorex or1% Sodium hypochlorite solution or 70% ethyl alcohol for 30 seconds to 2 minutesfollowed by thorough washing with sterilized distilled water. The tissue sections are blotted in sterile paper towel to remove any traces of surface sterilant. Thereafter, surface sterilized tissue sections are placed on various nutrient media and the organism that grows out of this tissue in the medium, is then isolated and subsequently pure cultured.Bacteria are often isolated by chopping up surface sterilized infected tissue in a small amount of sterile waterallowingbacteria to ooze out or byimmersion of cut ends of stem of wilted plants in a beaker containing distilled water. This water:bacteria suspension is then streaked onto 3-4 petri plates containing bacteriological medium such as nutrient agar with the help of sterilized inoculating loop without recharging the loop. In cases where a specific plant pathogen is suspected, a medium selective for the pathogen may be used. For example, TTC media for *Ralstonia solanacearum*, King's B agar media for *Pseudomonas spp.* These plates are incubated at 25 - 30°C for 4 to 10 days.

In case of fungal pathogen, the pathogen grows out of the host tissue and a small segment of this culture is further transferred to a fresh sterilized culture plate of nutrient medium and incubated for 7 days for further purification. In case of bacteria, colonies are developed in nutrient media which are to be picked up and purified.

**Purification of Plant Pathogens**

Microorganisms isolated from diseased plant tissues under controlled condition in a medium may contain the pathogen in association with other microbes such as secondary saprophytes. Also, microorganisms isolated from various sources such as soil, water, food, sewage etc. may contain billions of individuals. From the isolated mixed culture, it is essential to obtain a culture containing only one kind of microorganism called pure culture. Pure culture**,** in microbiology, is a laboratory culture containing a singlespeciesof organism. A pure culture is usually obtained from a mixed culture,comprising of many species, by transferring a small sample into a new growth medium so as to disperse the individual cells across the medium surface, which leads to thinning of the sample many fold before inoculating the new medium. Both methods separate the individual cells so that, when they multiply, each will form a discrete colony, which may then be used to inoculate more medium, as a result only one type of organism will be present in that media. Isolation of a pure culture may be improved by providing a mixed inoculum with a medium favouring the growth of one organism in comparison to the others. A pure culture may originate from a single cell or single organism, in which case the cells are genetic clones of one another. Pure cultures are essential in order to study the biochemical characteristics, morphology, staining, immunological and genetic properties. A culture which contains more than one kind of microorganism is called a mixed culture and if it contains only two kinds of microorganisms that are deliberately maintained in association with one another, it is called two-member culture or dual culture.

**Most Commonly Used Methods for Obtaining Pure Cultures of Fungi Are**

**Streaking Technique**

This technique involves purification of fungus cultures by taking a small portion of fungus on a loop and streaking it over an agar surface in a petri dish. As streak dissipates, the spores become more and more separated until eventually individual colonies are obtained arising from single spores or clumps of spores. Streaking out a suspension of spores in sterile water can improve the prospects of obtaining single spore colonies.

**Spore Suspension Dilution Technique**

Spore inoculum is placed in a tube of 10 ml of sterile water, from which a clean sterile pipette is used to transfer an aliquot (e.g. 1ml) of this to a tube with 9 ml sterile water. A fresh sterile pipette is used to

mix this and transfer 1 ml of this to another tube containing 9 ml sterile water. This is continued for as many dilutions as required and 0.1 ml is plated out each dilution separately in petri dishes by spread plate or pour plate technique.

**Single Hyphal Tip Culture**

In this method, the growth of spore is allowed on a plain agar surface in a petri dish for 24- 48 hours and hyphal tip coming out from the single spore or single cell of multiseptae spore are marked and transferred.

**Most Commonly Used Methods for Obtaining Pure Cultures of Bacteria Are**

**Streak Plate Method**

Loopful of bacterial suspension is streaked over the surface of nutrient agar medium in plates by to and fro motion of inoculating loop. Two more plates are streaked without recharging the loop with bacterial suspension. Plates are labelled and incubated in an inverted position at 25°C. Most bacteria develop colonies within 4 to 5 days, but some of them may take as long as 10 days. Single colonies are usually obtained in second and third plate.

**Pour Plate Method**

In this technique, successive dilutions of the inoculums (serially diluting the original specimen) are added into sterile Petri plates to which is poured melted and cooled (42-45°C) agar medium and thoroughly mixed by rotating the plates which is then allowed to solidify. After incubation, the plates are examined for the presence of individual colonies growing throughout the medium. The pure colonies which are of different size, shape and colour may be isolated/ transferred into test tube culture media for making pure cultures.

**Spread Plate Technique**

The spread plate technique is used for the separation of a dilute, mixed population of microorganisms so that individual colonies can be isolated. In this technique microorganisms are spread over the solidified agar medium with a sterile L-shaped glass rod. Alternatively, sterile glass beads may be used for uniform spreading of the cells. Some of the cells will be separated from each other by a distance sufficient to allow the colonies that develop to be free from each other.

After incubation in steak plate, pour plate or spread plate techniques, appearance of the discrete, well separated colonies would be observed. Sometimes, more than one type of colony may develop and in such case the colonies which are more abundant and constantly found in several suspensions from affected tissues are selected. Also, colonies which come up slowly are likely to be pathogenic. For confirmation, it is desirable to select two or three types of colonies, streaked on nutrient agar medium and tested for pathogenicity.(Vishunavat and Kolte, 2005)

The next step is to subculture the colonies to separate agar-slants with a sterilized needle or loop. Sub-culturing is the procedure of transferring of microbes from their parent culture to a fresh one or from one medium to another. Live cultures on a culture medium can be successfully stored in refrigerators or cold rooms maintained at 4°C, where the metabolic activities of microorganisms will be greatly slowed down at this temperature but not low enough to stop metabolism completely. Hence, regular sub-culturing is required at an interval of 2-3 weeks in bacteria and 3-4 months in fungi.

**Identification of Microorganisms / Pathogens**

Upon successful isolation of amicroorganism from a infected plant tissue, the organism must be identified. There are estimated some 1.6 million fungal species most of which are non- infectious. Many fungi and bacteria have never been isolated and identified. The characteristics upon which their identification is based are often complex. Diagnosticians with experience are often able to identify the most commonly isolated organisms. The fact that scientists can identify so many kinds of organisms

including microbes with scientific names is because they have been described and ordered by a system of classification and nomenclature that is internationally accepted. This science devoted to identifying, naming and classifying organisms is called taxonomy.In case of fungus and bacteria, when an unknown organism is isolated in the laboratory in the pure form, it is usually identified by a combination of information from microscopic observation of morphology, cultural characteristics, biochemical tests, serological reactions and genetic relationship.

**Classical Approach for Identification of Microorganisms**

**Identification of Bacteria**

The classical approach for bacterial identification involves a series of studies such as morphology and arrangement of cells, cultural characteristics on agar and in broth, gram staining and other staining reactions, the absence or presence of motility and endospores, biochemical and molecular tests etc.Bergey'sManual of Determinative Bacteriology serves as a practical guide for identification of bacteria which contains key and tables describing additional criteria for identification of genus and species of bacterium. Morphological studies such as shape, arrangement, differential staining reactions, and cultural characteristics such as form, margin, elevation, density provides vital keys (Arneja, 2012). The identification and characterization of bacterial isolates based on its expression of the "chemical identity" through testing their biochemical and physiological properties are fairly stable and reliable techniques of bacterial differentiation. The ability of a bacterium to utilize C or N sources such as Levan production, carbohydrate fermentation test, hydrogen sulphide, indole production or to produce various enzymes and gases such as catalase test, casein hydrolysis test are determined which serves as the basis for bacterial differentiation. Additional tests may include analysis of fatty acids, carbohydrate utilization (*i.e.* BIOLOG test), and enzyme activity testing (*i.e.* pectinase, isozyme patterns) helps in bacterial identification (Borah *et al*., 2015).

**Identification of Fungi**

Identification of fungus, as soon as it is isolated in a pure form, is often made by recognition of characteristic structures seen in culture which includes colonial morphology: waxy, leathery, velvety, fluffy; hyphal characters: coenocytic or septate; asexual spores: zoospers, sporangiospores, conidia, blastospores; sexual spores: ascospores, basidiospores, oospores or zygospores; reproductive bodies: ascocarp, basidiocarp, pycidia, acervuli and arrangement of conidia: solitary, masses, chains (acropetal and basipetal). Also, dimensions of various structures *i.e.* hyphae, spores, reproductive bodies is calibrated using ocular micrometer. After recording the microscopic details of a culture it is identified up to generic/ specific level consulting various taxonomic books and monographs available on various groups of fungi. Further, the field of chemotaxonomy including isozyme analysis and fatty acid profile provides a reliable tool for species identification (Arneja, 2012)

**Identification of Biotic Causal Agents**

A major problem in identification of biotic causal agents is the inability of some infectious pathogens to grow on artificial media. Viruses, as well as some fungi (e.g. powdery and downy mildew causing agents) and some prokaryotes (e.g. phytoplasmas), require a living host in order to grow. In cases where the plant pathogen is difficult or impossible to grow on artificial media, other methods may be used for their detection, such as the use of serological tests for viruses. Viral identification is often accomplished utilizing ELISA (enzyme-linked immunosorbent assay) which is based on the binding of an antibody produced to a specific virus with the virus in the infected plant material. More tests are currently being developed using the polymerase chain reaction (PCR) for detection of specific organisms. These types of reactions take specialized equipment and reagents, and the tests are not commonly done outside diagnostic and research laboratories. Other techniques used for the identification of viruses include negative staining and electron microscopy to view the viral particles in plant tissue or suspensions. PCR and ELISA tests, as well as other serological and nucleic acid based laboratory tests, may be used for organisms that grows on artificial media as a confirmatory tool (Riley *et al*., 2012).

### Serological Tests in the Aid Of Identification

These test forms an important step in microbial identification. Serological tests, involving the reactions of microorganisms with specific antibodies, are useful in determining the identity of strains and species, as well as relationships among organisms. Slide agglutination, ELISA, and Western blotting are examples of serological tests. It usually involves detection of antigens by enzyme or fluorescence immunoassays. Serology is also used to confirm identification obtained by other methods.

### Nucleic Acid Based Tests in The Aid Of Identification

Among the tools available for pathogen detection, nucleic acid (NA)-based techniques are widely recognized as some of the most powerful. NA-based detection techniques, particularly those that rely on the polymerase chain reaction (PCR), typically are rapid, specific, and highly sensitive. Other (NA)-based techniques such as Restriction fragment length polymorphisms (RFLP) of DNA representing selected genes can be used to identify pathogen species. Amplified fragment length polymorphism (AFLP), a modification of the RFLP technique, has been used for species identification and more commonly to examine genotypic diversity within a population. For fungus and bacteria, ribosomal RNA genes and intervening sequences are common targets for PCR amplification. The internal transcribed spacer (ITS) regions of ribosomal genes are especially useful targets for species-specific primers for fungal identification (Vincelli and Tisserat, 2008). Similarly, the 16S rRNA gene consists of highly conserved nucleotide sequences, interspersed with variable regions provides targets for genus- or species-specific primers for bacterial identification. PCR primers targeting the conserved regions of rRNA can amplify variable sequences of the rRNA gene enabling bacterial identification by analysis of the PCR product followed by comparison of sequences with known sequences stored in a database (Jenkins *et al*., 2012).

### Conclusion

Accurate and timely diagnosis of plant diseases can help to formulate disease management strategies in the right direction, whereas improper identification of the disease and the disease-causing agent, management practices adopted can be a waste of time and money and can lead to further disease spread. Therefore, for proper diagnosis of any plant disease, very good observation skills, sound training and education is very much important. Various diagnostic kits available, identification of causal organism(s) associated with the disease(s) by adopting various conventional and advanced techniques at laboratory and field level along with Artificial Intelligence (AI) technology is going to help further in early detection and prompt action on disease management.

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# Fall armyworm and its Managementin Indian subcontinent

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## Abstract

***Spodoptera frugiperdais a new insect that cause huge damages to grassy crops. It is a native of tropical and subtropical areas of the America and during 2018 it was introduced to India and recorded in maize crop of South Karnataka in the India and found more damage to the crops.This silent army is becoming a major danger to the maize production by its behaviour of migration, presence of multiple generations, potential to throw on a maximum range of host plants and lack of diapause mechanisms. Fall armyworm food preferences, larva can wreak havoc on a wide range of agricultural crops. The efficacy of pest control in maize shows the major significance. The pest has economic significance and damaging characters, biology and number of generations, nature of damage, grain and fodder yield loss and prioritized decreasing activities to curb pest.***

**Keywords: India, maize, management, *Spodoptera frugiperda, Metarrhi ziumrileyi***

## Introduction

Fromthree years, at least four species of insect pests have invaded India affecting agricultural production. Therecent invasive insect pests reported in India were Western Flower Thrips, *Franlcliniella accidentalis* (Pergande)(KaomudTyagi and Vikas Kumar, 2015).

Study showed that about 1300 species of invasive pests and pathogens introduced into 124 countries (Paini *et al.*, 2016).

The pest is a dangerous insect with high potentiality of migration from one region to another, maximum feeding crops and high reproduction capacity for establishment which cause more damage to important crops such as sorghum, maize and other grassy crops.

## Origin and Spread

Pest, which belongs to the American tropical and subtropical region, is apolyphagous, retaining huge damage in many agricultural and horticultural crops they arecotton, corn, jowar and beans (Abrahams *et al*., 2017; Day *et al*., 2017). The pest was occurred on September 2018, high or low the full regions of sub-Saharan Africa (44 countries) were invaded by this pest(Rwomushana *et al*., 2018) showing high dissemination of the pest in the African region, causing food shortagefor millions of people.

This insect pest was reported to have remarkable dispersal ability, high fecundity, the absence of resting stage, it can spread to entire country and further to other neighbouring countries. Hence, there is urgency for nationwide coordinated efforts to contain the pest (Sharanabasappa *et al*., 2018b).

## Host range, Nature of Damage and economic loss

The pest which cause damage to higher than 80 plant species, considering maize, sorghum, millet, sugarcane, and vegetable crops (Prasanna *et al*., 2018); but corn is the main crop damaged in Africa. Montezano *et al.* (2018) concluded that 353 species of host crops based on a thorough review of literature, and surveillances in Brazil, from 76 crop families, which are Poaceae, Asteraceae and Fabaceae. Matti and Patil (2019b) reported theoccurence of *S.frugiperda*on sugarcane crop along with maize and sorghum in Karnataka. On ratoon sugarcane as well as older crop less damage was recorded and more incidence was observed on maize + sugarcane intercropping and in intercropping of Rabi crops which contains as sugarcane and corn.

1st stage neonatelarvae scratches leaves and cut hole damagingsymptoms resemble the stem borer small holes. In the later vegetative stages, the constant feeding results in skeletonized leaves and heavily windowed whorls(Goergen*et al*., 2016).

## Taxonomy

It is not clear whether both the strains are introduced to India, haplotype analysis is required for further confirmation (Sharanabasappa *et al*., 2018b).

**Morphology of the pest**

The eggs are dorso-ventrally flattened, initially light green on one day and turned to gold yellowish colour andbefore hatching attains to blackish colour(Sharanabasappa *et al.,* 2018a).On the egg mass female moth coveredgreyish scaleslayer and this shows mildew arrivals(Capinera, 2014).

**Biology**

Gravid females of *S. Frugiperda*t end to lay eggs in groups on above or belowlayer of the leaf,crop bed and in whorls (Sharanabasappa *et al.,* 2018a). Eggs are found on the bottomof leafeven if at maximuminhabitantmasses, nearly any surface will be used (CABI, 2017). Duration of eggs hatching ranged from 2-3 days with a mean of 2.50 days (Sharanabasappa *et al.,* 2018a).Thereafter hatching neonate larvae move to seek a good preferable feeding place on crop, eggs were placed (Pannuti *et al.,* 2015). The neonate larvae and second instars feed together on tender leaves and on the edible crop growing tips. Larvae willshow cannibalistic at maximum larval population when there is a shortage of host plant material to feed on (Andow *et al.,* 2015). Thereafter 7days of growth of third instar caterpillars migratefrom each other and show continuation to feed. Each larva passed through six distinct instars over a period of 14 -19 days. The head capsule width of the five moults were 0.34±0.01, 0.48±0.01, 0.81±0.02, 1.22±0.05 and 1.96±0.06 mm, respectively. (Sharanabasappa *et al.,* 2018a). Similarly, varied larval duration was recorded when the pest was reared on different food source*viz*., sugarcane, maize and artificial diet (Sharanabasappa *et al.,* 2018a; Matti and Patil, 2019a and Uma Maheshwari and Ramya Sri, 2018).

Debora *et al.* (2017) noticed that the duration of pupation of *S. frugiperda* on corn was 8.54 days (Sharanabasappa *et al.*, 2018a).

**Integrated Pest Management**

Fall armywormdensities are maximum on a crop, developed caterpillars rarely go to treproductin stages of corn, decreasinggrade of grain yield at crop harvest(FAO, 2018).The insecticides are considered as highly powerful and enormously adapted weapons to manage insects.Afterdependency on pesticides have caused many bad consequences they are build up of pest rebellious to insecticide, emergence of minor pests, hazardous to useful biological organisms, Therefore, judicious use of insecticides and use of insecticides with selective action are recommended in insect control practices.

**Cultural and Mechanical control**

Midega *et al.,* (2018) evaluateddecrease of 82.7% in thecaterpillar'spopulationper plantwhereas 86.7% ininjury per plot in weather-accepted push-pull compared to corn monocrop plots. Similarly, maize grain yields in the climate-adapted push-pull plots are 2.7 times those in single crop.Electing egg masses and larvae showed anaccessible method for fall armyworm(FAO 2018).Some farmers are trying out for innovative fall armyworm control techniques including application of clay, wood coal, slag, soaps, kerosene andlubricant. Herb originated products were employed in suppression of fall armyworm viz.,*Capsicum frutescens*, *Azadirachta indica*,Wild indigo,Mexican sunflower, *Lantana camara* and *Allium sativum*( FAO, 2018).

**Biological control**

The fall armyworm has a various types of predatory and parasitic insects which have the capacity to supress the fall armyworm populations efficiently. The significant natural enemies are dermopterans, coccinellid beetles and anthocorids(FAO, 2018)..Matti*et al*., 2018 discussed hymenopteran parasitoid, *Campoletis spp*. found parasitizing the *S. frugiperda*in maize at Belgaum district of Karnataka, India

The various entomopathogens includes moulds, *Bacillus thuringiensis*, and roundworms, which cause lethal infections (FAO, 2018).Nucleopolyhedro virus infecting fall armyworm, *S. frugiperda* was identified at location 'Kanisa', Anand district, Gujarat (Raghunandan *et al*., 2019). Mallapur*et al.*, 2018b reported that NPV is safe biopesticide and it could be an important component for integrated management of fall army worm.Entomopathogenic fungus, *N. rileyi* application is one of the potential tool to combat the *S. frugiperda*. This pathogenic fungus being compatible with other ecofriendly control actions, it is self-multipling and highly cost efficient under favourable environment conditions.

**Chemical control**

The farmers reported the success in the fall armyworm management at early vegetative crop stagesby usage of the improvised entomopathogens like *Metarrhiziumrileyi* @ 1.0 g, *Metarrhiziumanisophliae* @ 2.0 gm/l insecticides *viz*., Proclaim 5 SC @ 0.2 ml,Tracer 45 SC @ 0.2 ml, Coragen18.5% SC @ 0.2 ml/ l (Patil*et al.,* 2018).Use of fermented toxicbadgeralong spreading inside corn whorls,in the sunset hours gavebest result to decrease the damage.

**Conclusion**

The fall armyworm is numerous reproduction,potential to dispersal,capacityto eat on a various crops and absence of resting stagemakes fall Army worm most dangerousinsect to supress in tropical Asia. Fall armywormis a new alarm to crops in the mainland. Speed and correlation action, huge consciousness creation and national, regionaland international collaboration arerequiredtotacklethemenhanceofcaterpillarstohindrance of adversityforsmallholders. Employmentofsuccessful IPM tools, gives viable to grant potentially test hazardof fall armyworm.

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