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Management of Fruit Rot of Chilli caused by *Colletotrichum capsici*

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A B S T R A C T

Chilli (*Capsicum annuum* L.) is a major spice crop in India. The production of chilli is constrained mainly by fruit rot (anthracnose) caused by *Colletotrichum capsici* and other species. Use of chemical fungicides is the common practice for control of anthracnose. However, continuous use of chemical fungicides leads to negative effects on environment, soil and human health. Therefore, in view of exploring the alternatives to control *Colletotrichum capsici* and management of fruit rot, the updated literature on characteristics of *Colletotrichum capsici*, fruit yield losses, symptoms and management practices like mechanical, chemical, biological and integrated measures are discussed herewith.

Introduction

India is "The Home of Spices" and Indian spices are world famous for their medicinal values. Chilli is one of the major spice crops in India and India stands 3rd in production of chillies (Saxena *et al.*, 2016). *Capsicum annuum* is the widely cultivated species. Green chilli provides vitamin-C while, the red chilli provides vitamin-A (Martin *et al.*, 2004) in addition to iron, potassium and magnesium. The alkaloid (Capsicinoid) present in chilli is responsible for pungency (Perez-Galvez *et al.*, 2003). Hottest pungent varieties reported are "Carolina Reaper" and "Naga Jalokia". The area and production of green chillies in India is 0.316 m.ha and 3.63 m.t respectively during the year, 2016-17 (Anon., 2017). Although India stands 3rd in production, the productivity is much lower than many countries. One of the important constraints for low productivity of chilli are the biotic stresses caused by fungi, bacteria and viruses, major being the fungal diseases (Berke *et al.*, 2005; Than*et al.*, 2008; Kumar and Venkateswarlu, 2011).

The chilli crop suffers from more than 40 fungal species, of these *C. capsici* is one of the most destructive species (Rangaswami, 1979) causing seedling rot or damping off at seedling stage/ nursery, leaf spot or die back at different stages of crop growth and fruit rot or anthracnose at fruiting stage leading to reduced fruit yield and marketability (Pandey and Pandey, 2003; Pakdeevaraporn *et al.,* 2005; Rahman *et al.,* 2011). To control this fungus, many contact and systemic fungicides have been recommended (Phansawan *et al.,* 2015). However, continuous use of chemical fungicides has negative effects on biodiversity, environment and human health (Knight *et al.,* 1997; Avinash and Hosmani, 2012). In addition, development of resistance by new strains to the chemicals is another problem (Staub, 1991; Compant *et al.,* 2005). Further, in view of export of chillies, the fruits should be free from fungal toxins and synthetic fungicide application is not advised. In light of these, positive effect of botanicals, organics and bio-fungicides like *Trichoderma viridae*, *Pseudomonas fluorescens* etc. to enhance the seedling vigour and yield of chilli with a decreased fruit rot have been reported (Jeyalakshmi *et al.,* 1998; Compant *et al.,* 2005; Sharma *et al.,* 2005; Srinivas *et al.,* 2005; Intana *et al.,* 2007; Tiwari*et al.,* 2008; Anand and Bhaskaran, 2009, Priya Reddy *et al.,* 2017a; Priya Reddy *et al.,* 2017b). Therefore, efforts were made to compile complete and up to date information on different management practices for control of *Colletotrichum capsici* and management practices to reduce the fruit rot of chilli to achieve higher fruit yields.

Colletotrichum

More than 40 fungal species known to affect the crop growth and fruit yield of chilli, more common species of *Colletotrichum* those cause the anthracnose are *C. capsici, C. gloeosporioides, C. acutatum, C. coccodes, C. dematium, C. siamense* added with *C. karstii* (Saini *et al.,* 2016) and *C. scovillei* (Oo *et al.,* 2017). Of these, mainly the *Colletotrichum capsici* is reported to be most virulent in causing higher fruit rot of chilli (Amusa *et al.,* 2004; Than *et al.,* 2008; Ratanacherdchai *et al.,* 2010; Akhtar *et al.,* 2017) and the virulence do not differ significantly with geographical regions (Sharma *et al.,* 2005). *Colletotrichum capsici* can be identified on the basis of colony colour, growth pattern and pattern of acervuli formation on PDA medium (Smith and Black, 1990). The *C. capsici* will be fairly white to light grey colour with circular fluffy mycelia and; black coloured acervuli scattered all over the colony (Gupta *et al.,* 2017). *Colletotrichum capsici* is reported to be seed and debris borne (Richardson, 1990) and also air borne (Asalmol *et al.,* 2001). *Colletotrichum capsici* spread by water splashes in the form of conidia and as cospores in the air (Nicholson and Moraes, 1980; Asalmol *et al.,* 2001). Dev *et al.,* (2012) reported a strong and negative correlation between *Colletotrichum capsici* and seed germination (r=0.90**) suggests that, seed infection is main source for spread of pathogen (Akhtar *et al.,* 2017).

The optimum temperature for growth of *Colletotrichum capsici* is 28 to 32^{o}C. However, Sawle (2016) reported that temperature more than 30^{o}C would inhibit the growth of *Colletotrichum capsici*. *Colletotrichum* colonization leads to disintegration of parenchymatous layers of seed coat and depletion of food material in endosperm and embryo (Chitkara *et al.,* 1990). *Colletotrichum capsici*isa broad range pathogen, affect not only the chilli but also several other crops like cowpea (Freeman *et al.,* 1998; Mark and Channya, 2016; Thio *et al.,* 2016). *Colletotrichum* cause disease on all parts of the plant and at different stages of plant growth (Kim *et al.,* 1989; Sangchote *et al.,* 1998). The *C. capsici* cause pre and post emergence damping off, leaf spot, premature fruit drop, mummification of unripen green fruits and fruit rot of chilli and also in other crops like cowpea (Summerfield and Robert, 1985; Agrios, 2005). Fruit rot of chilli and other vegetable and fruit crops caused by different species of *Colletotrichum* lead to extensive fruit losses especially in hot and humid climates (Park *et al.,* 2012).Therefore, studies on *Colletotrichum capsici* and crop management would be more relevant.

Yield losses due to anthracnose

In India, pre and post-harvest losses of chilli are more than 50% (Pakdeevaraporn *et al.,* 2005). Fruit rot caused by *C. capsici* reported to reduce the marketable yield from 2.5 to 11.6 depending on the variety (Rahman*et al.,* 2011). Fruit rot alone reduces the fruit yield by more than 50 % in different parts of India (Lakshmesha *et al.,* 2005; Ramachandran *et al.,* 2007). A wide range from 10 % to 80 % reduction in fruit yield has also been reported (Than *et al.,* 2008). The disease incidence varies from 44 to 51 % (Yadav and Singh, 2016). Recently, Yadav *et al.,* (2017) have shown a decreased fruit yield from 50.3 to 58.6 % in untreated control as compared to the fungicide seed treatment (1 %) + NSKE spray (5 %). The yield losses extend even up to 100 % (Amusa *et al.,* 2004) and reduce the marketability. Hence, management of *C. capsici* is very important in chilli cultivation.

Symptoms of anthracnose

The pathogen is seed, soil and air borne. The disease is prevalent in almost all major chilli growing areas of India (Rathore, 2006). On the leaves, initially small-circular spots appear and the severely infected leaves fall off leading to defoliation of plant. The infection starts from growing tips (necrosis of apical branch, dieback) followed by leaves and branches and then fruits (Kumar and Bhaskaran, 2007; Rahman *et al.,* 2011). Among the plant parts, most susceptible stage is ripe fruit stage (Rahman *et al.,* 2011). Symptoms on matured fruit appear as sunken necrotic lesions with concentric rings which produce conidial masses in pink to orange colour. Under severe conditions, lesions fuse and conidial masses may form concentric rings on lesions (Gupta *et al.,* 2017).

Approaches for anthracnose management

Management of fruit rot (anthracnose) is a major issue among chilli growing farmers. Generally, chemical fungicides are commonly used as control measure. However, combination of strategies like mechanical, chemical, biological and intrinsic resistance would be appropriate for management of anthracnose (Agrios, 2005).

Mechanical/ cultural approach

*Colletotrichum capsici*is capable of remaining in soil and plant debris hence, soil must be deeply ploughed before planting (Agrios, 2005). Disease free seeds are to be used to reduce the infection. Crop rotation may be followed with non Solanaceous crops (Roberts *et al.,* 2001).Appropriate spacing shall be maintained to reduce the crop canopy density thus to reduce relative humidity. Nutrient status of plant could be one of the factors which alter the physiology and metabolism of plant cell. The chilli varieties tolerant to *C. capsici* found to have higher minerals compared to the susceptible varieties, as *C. capsici* compete for the nutrients with the plant in susceptible varieties (Bashair *et al.,* 2016). Use of resistant varieties is primarily economical and eco-friendly in the changing climate scenario. Use of resistant varieties/ hybrids not only reduces crop losses but also saves costs on chemicals and labour as chilli is labour intensive crop (Agrios, 2005). Resistance to *Colletotrichum capsici* is controlled by a single dominant gene (Lin *et al.,* 2002); however, control of anthracnose in other species like *Capsicum chinense* was shown to be controlled by single recessive gene (Pakdeevaraporn *et al.,* 2005, Kim *et al.,* 2008). Further, Kim *et al.,* (2008) have suggested that additional dominant minor genes may be inherited for *Colletotrichum capsici*. It was also observed that, different set of genes are expressed at different stages of fruit maturity like green or red ripe stage (Taylor *et al.*, 2007). Developing resistance would be most relevant and sustainable approach for management of anthracnose and; varieties *viz*., Arka Harita, Classica-152 and Madhurima-148 have been identified as resistant having less than 3.75 % disease incidence (Gupta *et al.*, 2018). However, development of resistance through breeding strategies would be difficult as the anthracnose is also caused by other species of *Colletotrichum*. Therefore, chemical methods became vogue as an easy and effective method.

Chemical approach

Traditionally, chemical control has been sought most effective. Among the several chemical fungicides, carbendazim is commonly used chemical to control the *C. capsici* of chilli (Phansawan *et al.*, 2015; Priya Reddy, 2017a). The other fungicides advocated are copper containing compounds like, dithiocarbamates, benzimidazole and triazole compounds. Chemical control of mycoflora on chilli has been well established and the time of application is also very important for effective control of anthracnose (Shetty *et al.*, 1998). Seed treatment with bavistinplus thiram found effective in eliminating *Colletotrichum capsici* infection from chilli seeds (Kumudkumar *et al.*, 2004).Seed treatment with propiconazole or difenconazole (200 ppm) effectively inhibited the mycelia growth of *Colletotrichum capsici* by 94 %, whereas *Trichoderma* species inhibited the mycelia growth by 78.5 % (Arvindkumar, 2016). Further, Linuand Jisha (2017) reported that the chemical fungicides, carbendazim, mancozeb and azoxystrobin (0.05 to 0.2 %) inhibited the mycelia growth of *Colletotrichum capsici* from 62.2 to 73.5 %. Tricyclazole and propyconazole found more effective with no radial growth of *Colletotrichum capsici*, while carbendazim showed 25.4 % radial growth as compared to control at 7 days after inoculation on PDA (Sawle, 2016).

Hydrogen peroxide (1 %) is one of the chemical which acts as antifungal chemical that increases the seed germination of chilli from 60.4 % (control) to 84.8 % by inhibiting the mycelia growth of *C. capsici* by 64.8 % or more at higher concentrations. However, higher concentration (above 1 % hydrogen peroxide) drastically decreases the seed germination and seedling vigour (Nandi *et al.*, 2017). Seed treatment with carbendazim (0.2 %) plus FYM (3 kg m^{-2}) found effective with only 17.5 % dieback in nursery (Arvindkumar, 2016). Seed treatment with chemical fungicides, thiram (0.2%) or carbendazim (0.2 %) found effective in reducing fruit rot incidence to 34.1 and 37.1 % respectively as against 51.1 % fruit rot in control (Ali *et al.*, 2017). Further, Ali *et al.*, (2017) also reported that foliar spray of mancozeb 50 EC (0.3%), COC 50 WP (0.1%), carbendazim 50 WP (0.1%), difenoconazole 25 EC (0.03%) or propinpconazole 25 EC (0.15 %) thrice at pre-flowering, the fruit set and fruit maturity showed only 20.3 % or less fruit rot incidence as compared to the control (48.9 % fruit rot) and the fruit rot incidence could be further reduced with additional seed treatment. The fruit rot of highly pungent, Naga chilli was only 9.2 % when seeds are treated with 0.1 % bavistin (Ngullie *et al.*, 2010).

Recently, mancozeb (0.2 %) found to inhibit fruit rot by 73.47 %, while carbendazim (0.05%) gave 64.12 % control as compared to control (Linuand Jisha, 2017). Arvindkumar (2016) reported that foliar spray of fungicide, propiconazole (0.1 %) at pre-flowering, fruit set and fruit maturation resulted in fruit yield of 15.3 q ha^{-1} as against control (9.6 q ha^{-1}) and *Trichoderma harzianum* spray (10.7 q ha^{-1}). Off all these advantages, remnant toxic residues are problem for human consumption and also for export of chilli. In addition, development of host plant resistance in long run is also a problem with application of chemical fungicide (Sariah, 1989). Therefore, alternatives like biological methods need to be developed.

Biological approach

Indiscriminate use of chemicals leads to development of disease resistance, soil pollution and food poisoning. To overcome these undesirable effects, one of the approaches could be the use of plant based biological products or antagonistic bio-fungicides to control fruit rot of chilli. Biological control has been developed as an alternative to synthetic chemical fungicides and considerable success has been achieved in this direction.

Use of botanicals

Use of botanicals (plant extracts) is reported to be safe due to its easy decomposition, non-residual activity and non-phytotoxic properties. Development of new alternative strategies for management of fungal diseases is very essential in the changing climate scenario. In this regard, plant products appear to be in-exhaustive source of potential fungicidal activity to serve as harmless pesticides (Chutia *et al.,* 2009; Kambar *et al.,* 2014).

Most studies have evaluated the leaf extracts of various plants to control *C. capsici*.Leaf extracts of neem, *Datura, Ocimum, Polyalthia*, *Vincarosea* were found fungi-toxic against *C. capsici* (Shivapuri *et al.,* 1997). Sundaramoorthy *et al.,* (2014) have reported that the use of leaf extract (in water) of *Alliumsativum* (20 %), *Allium cepa* (60 %) and seeds of neem (60 %) inhibited the mycelia growth of *C. capsici* by 100 % which was comparable to that of carbendazim. Such a reduction was due to inhibition of cellulolytic and pectinolytic enzymes of *C. capsici* and reduced fruit rot. The differences in inhibition of *C. capsici* growth by different plant products could be due to differences in accumulation of antifungal content among the plant species. Nduagu *et al.,* (2008) reported that infusion of dried plant material of neem root or bark @ 5.0 % w/v for 72 hours was effective in reducing colony diameter of *C. capsici* due to presence of alkaloids. The bark extract was more effective than the root extract of neem. Harsha *et al.,* (2014) reported that colony diameter (mycelia growth) of *C. capsici* was inhibited by more than 50 per cent, when the media was poisoned with 1 mg leaf extract/ ml of media (dried extract from *Citrus reticulata* leaf incubated in methanol). Leaf extracts (10 %) of *Abrusprecatoruius* and *Aeglemarmelos* found effective in reducing the colony diameter of *Colletotrichum capsici* (Anand and Bhaskaran, 2009). Rajput (2011) demonstrated that, among several botanicals, *Ocimum* leaf extract was effective in inhibiting the mycelia growth of *Colletotrichum capsici* by 68 % in culture media. Among neem based formulations, Neem gold (300 ppm), Neem fighter (10,000 ppm) and Achook (1500 ppm) inhibits the mycelia growth of *Colletotrichum capsici* by 100 per cent in culture media. Ngullie *et al.,* (2010) reported that the mycelia growth of *C. gloeosporoioides* causing anthracnose of Naga chilli fruit rot was inhibited by garlic extract and neem leaf extract (10 % w/v) to the extent of 54.8 and 42.2 % respectively as compared to the higher inhibition (83.4 %) with bavistin (0.1 %). The garlic and neem leaf extracts did not differ significantly. Further, the garlic bulb extract (3 %) found to inhibit the growth of *C. capsici* completely and also the spore germination (Singh *et al.,* 1997). Even flower extract of *Datura* found to inhibit the fungal growth (Chitra and Kannabiran, 2000).

Choudhury *et al.,* (2017) reported that the chloroform extracts (20 EC) of ginger, *Clerodendrum* and *Polyalthia* found more effective than carbendazim at 20 ug/l in inhibition of radial growth of *Colletotrichum capsici* and the inhibition was higher (57.8 %) at 4000 ppm (0.4%) and this concentration of leaf extracts was non-phytotoxic. Hence, the plant extracts can be effectively used as compared to the carbendazim/ chemical fungicides. Although, higher concentrations of bio-fungicides are required for reduction in fungal biomass production and inhibition of spore germination of *Colletotrichum capsici* it would be safe as compared to the chemical fungicides. The fungicidal activity of these plant extracts may be attributed to variations in the chemical constituents (Nduagu *et al.,* 2008). The antifungal activities of the plant extracts could be due to the presence of secondary plant metabolites like terpinoides, phenols, flavonoides, alkaloids (Vijayan, 1989; Mohamed and EI-Hadidy, 2008). Foliar spray of *Clerodendrom* leaf extract using chloroform was more effective with 23.8 % fruits infected as compared to 56.5 % infected fruits with carbendazim (0.1%) and the lesion diameter was similar between plant extracts and carbendazim (Choudhury *et al.,* 2017).

Plant oils also found effective as control measures for *C. capsici*. In this regard, Mark and Channya (2016) reported that application of 1.0 ml of garlic oil to 20 ml of PDA containing *C. capsici* resulted in 65.7 % reduction in colony diameter of *C. capsici* i.e., from 32.0 cm in control to 12.76 cm, and the lower doses of garlic oil were less effective. Priya Reddy *et al.,* (2017a) demonstrated that the seed mycoflora (*C. capsici*, *Cercospora sp*., *Alternaria sp*., *Penicillium sp*., *Aspergillus sp*.) incidence was least with neem oil (5 ml kg^{-1} seed) and the decrease in incidence was 70 per cent as compared to the untreated seed. This treatment resulted in significantly higher seed germination, seedling vigour index and disease control. Therefore, the neem oil @ 5 ml kg^{-1} seed can be used as an alternative to carbendazim for seed treatment to control the *C. capsici* and related diseases (Priya Reddy *et al.,* 2017b). The other oils like neem oil, palmorosa also reduced the fungal growth (Jeyalakshmi *et al.,* 1998).

Asma*et al.,* (2012) reported that the selected strains of lactic acid bacteria (LAB) isolates from different fruits and vegetables were shown to inhibit the growth of *Colletotrichum capsici* by inhibiting the spore germination and mycelia growth on culture media and increased the seed germination and seedling growth of chilli. Even the commercial formulations like Nimbicide treatment found to inhibit the growth of *C. capsici* (Hegde *et al.,* 2002). Seed treatment with bulb extract of garlic (20 %) resulted in superior seed germination of chilli which was comparable to that of carbendazim (0.1%) seed treatment (Sundaramoorthy *et al.,* 2014).Further, they showed that foliar application of garlic extract at 115 and 130 days after planting increased the fruit length and fruit weight by 43.5 and 36.2 % respectively over the control and; was effective to that of carbendazim (0.1) foliar spray (Sundaramoorthy *et al.,* 2014). Therefore, it would be apt for deriving the compounds from plants which can be used against anthracnose of chilli.

Use of bio-fungicides

Substances which are living in nature and control the fungal diseases are called bio-fungicides. Amongst the antagonists, fungal isolates of *Trichoderma viridae* and bacterial isolate *Pseudomonas fluorescens* found effective in inhibiting the growth of *Colletotrichum capsici* (Anand and Bhaskaran, 2009). These are safe bio-control measures in addition to positive influence on plant growth promotion. *Trichoderma* spp. is soil borne fungi having antagonistic potential against wide range of phytopathogenic fungi (Elad *et al.,* 1982) and saprophytic in nature. The action of antagonistic fungus involves mycoprasitism, antibiosis, competition for nutrients and space with ability to induce systemic resistance against pathogens in plants. The antagonists also secrete extracellular enzymes like glucanase, chitinase etc. to degrade the mycelia of pathogen and to reduce the colonization of pathogen (Singh *et al.,* 2012). There are several species of *Trichoderma*, of which the major ones are *Trichoderma asperellum*, *T. viridae*, *T. harzianum* and *T. longibrachiatum*. Isolates of *T. longibrachiatum* found to inhibit the mycelia growth of *Colletotrichum capsici* upto 66 % due to volatile compounds released by *Trichoderma (*Mishra *et al.,* 2017).

Priya Reddy *et al.,* (2017a) reported that seed dressing with *Trichoderma viride* (10 g kg^{-1} seed) or *Trichoderma viride* (5 g kg^{-1} seed) + *Pseudomonas fluorescens* (5 g kg^{-1} seed) decreased the mycoflora incidence by 81.8 per cent compared to untreated seed and; is comparable to that of carbendazim (0.2 %) treatment. Hence, *T. viride* can be effectively used to control seed mycoflora (*C. capsici*, *Cercospora*, *Alternaria*, *Penicillium*, *Aspergillus)* in place of carbendazim. Similarly, Rajput (2011) demonstrated that, *T. viridae* was more effective in inhibiting the growth of *Colletotrichum capsici* on culture media as compared to the *Pseudomonas fluorescens*. In contrast, Ngullie *et al.,* (2010) reported that the mycelia growth of *C. gloeosporoioides* causing anthracnose of Naga chilli fruit rot was inhibited by *Pseudomonas fluorescens* and *T. viridae* to the extent of 67.4 and 63.3 % respectively as against the bavistin (83.4%). However, *P. fluorescens* found to inhibit the mycelia growth of *C. capsici* effectively (Ramamoorthy and Samiyappan, 2001). In an another study, Shilpa and Gokulapalan (2015) have shown that *T. viridae* cause 55% inhibition of mycelia growth of *C. capsici*, while *P. fluorescens* inhibited 90 % mycelia growth.

The *C. capsici* infected chilli seeds when treated with *T. viridae* showed significantly higher seed germination (94.7 %) followed by *P. fluorescens* treatment (92.7 %) as compared to the carbendazim (92.0 %) seed treatment. However, the seedling length and seedling vigour with *T. viridae* treated seeds found on par to the carbendazim treatment (Priya Reddy, 2017b). Such improvement in seed germination and other seedling parameters with bio-antagonists could be through inhibition of growth of *C. capsici* (Raj *et al.,* 2008; Yadav, 2008). Therefore, the use of *T. viridae* and *P. fluorescens* or their combinations are suggested in place of carbendazim against *C. capsici* for better seed quality parameters in chilli (Priya Reddy, 2017b).

Fruit rot can be controlled by foliar application of *P. fluorescens* (1 %) at 40 day old crop (Ekbote, 2005).Foliar application of *Trichoderma viridae* (2.0%) or *Pseudomonas fluorescens* (2.0 %) at fruit set stage and 20 days after decreased the disease index by 61.4 and 58.1 % respectively over the control and; the fruit yield was comparable to that of carbendazim (0.25 %) spray (Ngullie *et al.,* 2010). Rahman *et al.,* (2018) reported that seed treatment with either *Colletotrichum capsici* (4 x 10^5 spores/ml) or *Trichoderma harzianum* (4 x 10^5 spores/ml) and when the same suspensions (50 ml per pot) were added individually and in combinations, the results show that chilli fruit yield was 83.6 % higher with *Trichoderma harzianum* as compared to the *Colletotrichum capsici* treated control. Even in the same family of Solanaceae, tomato fruits treated with *P. fluorescens* and or *T. viridae* showed reduced fruit rot due to higher polyphenol oxidase (PPO) activity

(Shiva *et al.,* 2013). It was opined that PPO oxidises phenols to form quinone compounds or helps in synthesis of lipids to form physical barrier for entry of pathogen or PPO oxidise phenols to release free radical creating unfavourable conditions for pathogen (Ngadze *et al.,* 2012). Further, the bio-fungicides found more effective than plant extracts (Ngullie *et al.,* 2010), hence it would be apt to recommend and practice the use of bio-fungicides *viz.,* *T. viridae* or *P. fluorescens*.

Use of other biologicalcompounds

Use of yeast strains as antagonist to *C. capsici* is another biological approach to prevent / reduce the fruit rot of chilli caused by *C. capsici*. Yeasts strains isolated from rhizosphere found antagonistic effect on *C. capsici* by inhibiting the mycelia growth of *C. capsici* to the extent of 40.6 to 43.1% which intern found to control the anthracnose to the tune of 60 % (Chaisemsaeng *et al.,* 2013).

Treating post-harvest chilli fruits with an epiphytic yeast strain, *Pichiaguilliermandii* isolated from fruits and vegetables exhibited a remarkable decrease in post-harvest fruit decay by 93.3 % with a lesion diameter of 6.7 mm as against 15.4 mm in control (Chanchaichaovivat *et al.,* 2007). Use of yeast has an advantage of production easily and rapidly through fermentation process, therefore, development of yeast strains may be exploited to control fruit rot of chilli as pre or post-harvest.

Yet another technique could be application of biological substances in the form of nanoparticles. In this direction, oligochitosan from shrimp shells irradiated with Co-60 combined with nano-silicon (10-30 nm), sprayed three times before fruiting as 60 mg L^{-1} each found effective in controlling the anthracnose infection to the tune of only 22.2 % as against the control with 90 % anthracnose infection (Dzung *et al.,* 2017). Another approach could be the acquired resistance, which is eco-friendly concept through host plant derived signal molecules. One such organic compound is cerebroside, foliar application of cerebroside found to stimulate early hydrogen peroxide accumulation and subsequent production of defense related enzymes like phenylalanime amino lyase, peroxidase, polyphenol oxidase and lypoxygenase and capscidiol (a phytoalexin) to protect the chilli against anthracnose (Naveen *et al.,* 2013). Even salicylic acid (10mM) inhibits the conidial germination of *Colletotrichum capsici* (Rajeswari, 2009).

Integrated approach

Agrochemicals in combination with biological methods would reduce the requirement of agrochemicals and associated pollution. Zahida and Masud (2002) reported that although synthetic fungicides are generally recommended for disease control, it enters to food chain contamination. Therefore, integrated management practice would be a better option for eco-safety.

Seed treatment with propiconazole (0.1 %) found more effective than tebuconazole (0.1 %) and carbendazim (0.1 %) for anthracnose disease control in chilli. Seed treatment with fungicides and additional foliar spray of NSKE (5.0%) at 15 days interval (65 and 80 DAT), after the inoculation of pathogen resulted in 8.10 to 8.23 q ha^{-1} dry chillies as against 3.41 q ha^{-1} in control (Yadav *et al.,* 2017).Seed treatment with thiram (0.2 %) or carbendazim (0.2 %) found effective to control dieback disease caused by *Colletotrichum capsici* in nursery, the dieback was only 31 %. Addition of FYM or vermi-compost to nursery further reduced the dieback to only 26-27% as against 41 %

dieback in control treatment (Ali *et al.,* 2017). In addition to seed treatment, foliar application of fungicide (0.1 to 0.3 %) at pre-flowering, fruit set and fruit maturity resulted in 80 to 84.4 q ha^{-1} as against 59.3 q ha^{-1} of green chillies in control (Ali *et al.,* 2017).Foliar application of carbendazim (0.2 %) at the appearance of disease symptoms and subsequently twice at 15 day interval resulted in fruit yield of 103.8 q ha^{-1}. Addition of FYM to soil and foliar spray of *Pseudomonas fluorescens* (2.0 %) resulted in 95.8 q ha^{-1}. Further, root dipping in *Pseudomonas fluorescens* at the time of transplanting + foliar spray of *Pseudomonas fluorescens* produced 92.5 q ha^{-1} (Pooja and Simon, 2018). Seed treatment with chemical fungicides, captan (0.25%) or mancozeb (0.25%) or *Trichoderma harzianum* (5 g /kg seed) or *Pseudomonas fluorescens* (5 g /kg seed) followed by foliar sprays at 20, 30 and 50 days after planting showed that as compared to the control treatment, fungicide spray possess only 18.9 % infected fruits, against 24 to 25 % with antagonists (*Trichoderma harzianum* or *Pseudomonas fluorescens*). However, combination of captan and *Trichoderma harzianum* showed only 9.3 % infected fruits (Vivekanand *et al.,* 2018).

Root dipping in *Pseudomonas fluorescens* (0.1 %) at the time of planting followed by spraying of carbendazim (1.0 %) or hexaconazole (0.1 %) or Iprobenphos (0.1 %) or *Pseudomonas fluorescens* (1.0 %) at the onset of disease and 15 days after showed that, chemical fungicide spray resulted in dry fruit yield of 2.83 to 3.06 q ha^{-1} with a decreased dieback and fruit rot, while, *Pseudomonas fluorescens* spray yielded 1.75 q ha^{-1} as against 1.31 q ha^{-1} in control (Ekbote, 2005). Foliar spray of ridomil or botanicals at 21 days after planting and 15 days after showed that, ridomil (0.2 %) spray gave dry fruit yield of 1.56 t ha^{-1}, while application of plant extract spray in combination (neem leaf extract + mahagony seed + garlic extract or neem leaf extract +mahagony seed +*Crassia carandus* fruit, 1:10 ratio) resulted in higher yield of 1.65 t ha^{-1} (Rashid *et al.,* 2015).

Rajput (2011) demonstrated that, seed treatment with neem oil was the best for inhibition of mycelia growth of *Colletotrichum capsici* by 36 % as compared to seed treatment with panchagavya, biodigestor, cow urine, butter milk, jeevamrutha or vermi-wash. However, combination of neem oil with organics, the mycelia growth was inhibited to a minimum of 43 %. Combination of these organics increased the seed germination and seedling vigour of chilli. Rajput (2011) also demonstrated that, in addition to seed treatment, seedling dip in cow dung slurry (10 %) + sulphur spray at 15 day interval (0.2%) + *Trichoderma viridae* or *Pseudomonas fluorescens* (10 ml/L) doubled the fruit yield of chilli as compared to the control (vermi-compost and FYM equivalent of recommended dose of nitrogen).

Handiso and Alemu (2017) reported that the foliar application in combination of antagonists (*Trichoderma* sp. 10%) + plant extract (10 %) + chemical (ridomil, 0.2%) at 21 days after planting resulted in lower fruit infection (17.5 %) as compared to chemical alone (23.6 %) and thus, higher dry fruit yield in combined application (8.03 to 8.63 g pl^{-1}) as compared to chemical application (7.7 g pl^{-1}). Therefore, eco-friendly measure of integrated management would be ideal (Anand and Bhaskaran, 2009). The combination of antagonists and plant extracts would be more ideal in view of safe environment (Handiso and Alemu, 2017).

Method of treatment

Most widely used treatment methods against fungal or any other diseases are either seed dressing or foliar application. Ali *et al.,*

(2017) reported that chilli fruit yield can be increased by foliar spray of propiconazole (0.1%) by 23.3 % and additional seed treatment could enhance the fruit yield up to 29.7 %, suggesting that foliar application is more effective than seed treatment. However, quantity of chemical required for spraying would be high which has major concern with respect to environmental safely. Therefore, alternate eco measures like botanicals or bio-fungicides shall be preferred for seed treatment and more specifically for foliar application.

Conclusion of the study are as follows:

i) Although many cultural practices are being followed for control of anthracnose, it would be apt to derive resistant varieties/ hybrids as an eco-friendly option.

ii) Although fungicides like propiconazole, carbendazim, thirametc. (0.1 to 0.3 %) are highly effective in control of anthracnose remnant toxic residue, export of chilli and host plant resistance are the major drawbacks, hence, identification of chemical fungicides which are readily degradable without carcinogenic effect is indeed essential. In addition, indiscriminate use of chemical fungicides shall be avoided.

iii) Leaf extracts of several plants like neem, *Clerodendron* etc. and bulb extract of garlic found to inhibit the growth of *Colletotrichum capsici* effectively and comparable to that of chemical fungicides. The bio-fungicides like *Trichoderma* and *Pseudomonas* species found more effective than plant extracts in addition to growth promoting effect. However, the limitation is availability of the product and their use by the farmers, which needs greater attention. In other words, market availability of formulations of these extracts or bio-fungicides in combinations would be appropriate.

iv) Non traditional approaches like endophyticfungi, nano-particles and organic compounds may be exploited for control of anthracnose.

v) Although fungicide performed better in controlling anthracnose and fruit yield, a few combinations of plant extracts out yielded the fungicides. Therefore, integrated approach would be apt for immediate purpose and in long run the combinations of plant extracts and antagonistic bio-fungicides could be identified.

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