FRUIT ROT OF CHILLI : ITS DIVERSITY, CHARACTERIZATION, EPIDEMIOLOGY AND INTEGRATED MANAGEMENT

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CERTIFICATE

This is to certify that the thesis entitled "FRUIT ROT OF CHILLI : ITS DIVERSITY, CHARACTERIZATION, EPIDEMIOLOGY AND INTEGRATED MANAGEMENT" submitted by Mr. SANTOSHREDDY MACHENAHALLI, for the degree of DOCTOR OF PHILOSOPHY in PLANT PATHOLOGY, to the University of Agricultural Sciences, Dharwad is a record of research work done by him during the period of his study in this university under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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"A smile happens in a flash, but its memory can last a lifetime."

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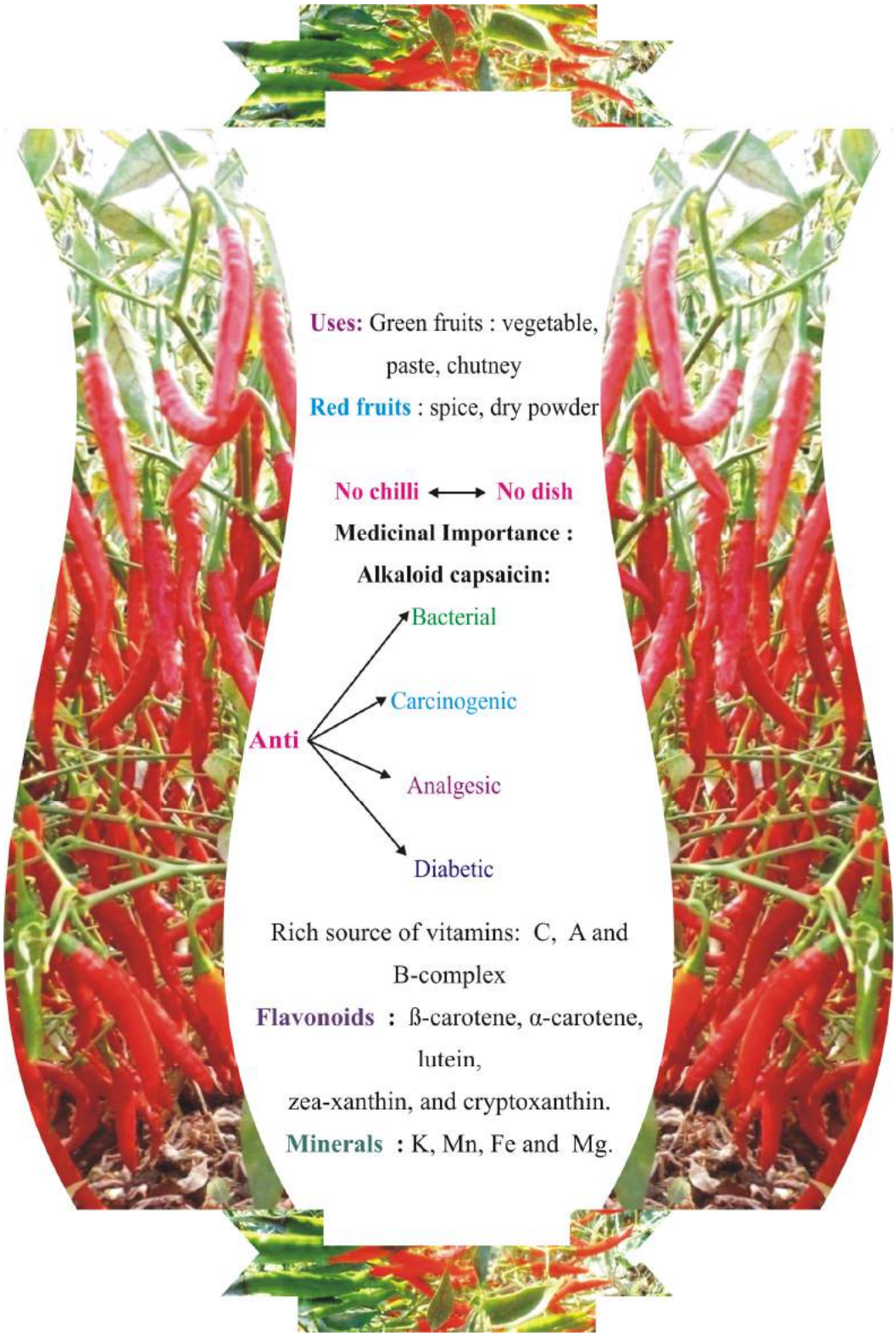
1. INTRODUCTION

Chilli (*Capsicum annuum L.*) despite of its fiery hotness, is one of the very popular spice and vegetable crop grown worldwide. It is also known for its medicinal and health benefiting properties. The fruit of *Capsicum* has a variety of names, such as 'chilli', 'chilli pepper' or 'pepper' depending on place and type of fruits. The chilli is actually a fruit pod from the plant belonging to the family of solanaceae. Several cultivars of chilli are grown all around the world. The chilli plant is native to Central American region where it was used as the chief spice ingredients in Mexican cuisine for centuries. It was introduced to the rest of the world by Spanish and Portuguese explorers during 16^{th} and 17^{th} centuries and now grown widely in many parts of the world as an important commercial crop. India is the largest producer of chilli, grown over an area of 0.79 m. ha with an annual production of 0.13 m. tons with the productivity of 1.6 m tons /ha (Anon., 2014).

Fruits are variable in size, shape, color, and pungency. The hotness of chilli is measured in "Scoville heat units" (SHU). Chilli contains an impressive list of plant derived chemical compounds that are known to have disease preventing and health promoting properties. It contains health benefiting alkaloid capsaicin, which gives strong spicy pungent character. It has anti-bacterial, anti-carcinogenic, analgesic and anti-diabetic properties. Chilli is also good in other antioxidants like vitamin A, flavonoids like ß-carotene, α-carotene, lutein, zea-xanthin, and cryptoxanthin. It is also good in vitamin C and B-complex group of vitamins such as niacin, pyridoxine (vitamin B-6), riboflavin and thiamin (vitamin B-1). Chilli is also source of minerals like potassium, manganese, iron, and magnesium (Bosland and Votava, 2003) (Plate 1).

Chilli is suffering from several economically important diseases like damping off, die back, fruit rot, leaf spots, leaf curl, wilt etc. which are posing a serious threat to the successful large-scale cultivation. The fruit rot disease caused by fungi *Colletotrichum* spp. (*C. capsici*, *C. gloeosporioides* and *C. acutatum*), also *Alternaria alternata* and *Fusarium* spp. is major yield limiting factor. It has been observed to occur in three phases *viz.* (i) seedling blight or damping off stage, prevalent in the nursery, (ii) die back stage which is initiated at different stages of growth and (iii) fruit rot stage in which


Uses: Green fruits : vegetable, paste, chutney
Red fruits : spice, dry powder
No chilli ⟷ No dish
Medicinal Importance :
Alkaloid capsaicin:
Anti
Bacterial
Carcinogenic
Analgesic
Diabetic
Rich source of vitamins: C, A and B-complex
Flavonoids : ß-carotene, α-carotene, lutein,
zea-xanthin, and cryptoxanthin.
Minerals : K, Mn, Fe and Mg.

the ripe fruits are infected. The last phase causes extensive damage to the fruits since the lesions on the fruits considerably reduce the market value of the produce. The infected seeds, plant debris and fruits act as primary source of inoculum (Siddique *et al.,* 1977).

The disease is more severe in India because of its complex nature. Symptoms vary in different stages of crop. In the present situation of climate change, there is a need to investigate the disease in depth, as epidemics vary in different regions giving scope for understanding the extent of variability in pathogen population. Hence, collection of isolates from different regions and their characterization by morphological studies is quite relevant. Further, their variation at the molecular level using ITS rDNA, a more reliable technique can give a logical conclusion regarding the genetic variability existing among isolates. Hence, it is proposed to sequence ITS rDNA region.

Epidemiological study helps to know about survival ability of pathogen/s and favorable environmental conditions for disease spread. It also helps in forecasting system to delink the infection chain at appropriate time in order to manage the disease effectively. It is essential to manage the disease in an integrated manner in which fungicides, botanicals and bio-agents, resistant genotype/s, optimum date of planting play an integral part and becoming more relevant in the present day disease management scenario. Therefore evaluations of bio-intensive, adoptive and chemical modules are of utmost concern to identify best module for management of disease with maximum cost benefit ratio which will help the farming community to a greater extent.

The present studies were therefore directed to throw some light on different aspects of the disease and pathogens which have a bearing on the facts discussed in the preceding paragraphs. Hence, the investigation was taken up to unravel the complexes involved in the fruit rot complex disease of chilli and issues are addressed through following objectives.

Objectives of investigation

- Survey, isolation and identification of pathogen/s to study the distribution in different geographical regions of South India.
- Morphological characterization and molecular variability of major pathogen/s.
- Epidemiology of disease in relation to climatic factors.
- Development of IDM strategies for disease.

2. REVIEW OF LITERATURE

Fruit rot complex disease of chilli is caused by *Colletotrichum capsici, C. gleosporioides, C. acutatum, Alternaria alternata, Fusarium oxysporum* and *F. sporotrichoides* which are carried along with seed to cause deterioration of seed in storage, pre and post emergence damping off and later dieback leading to heavy loss. Large numbers of reports are available in literature regarding this disease which has been reviewed in the chapter. The review pertains to survey, isolation, and identification of pathogens, epidemiology, morphological, molecular variability, seed health management and integrated management of chilli fruit rot.

2.1 History and Economic Importance

2.1.1 Fruit rot

Chilli fruit rot disease is one of the most economically important diseases was reported for the first time in India by Sydow from Coimbatore of Madras presidency in 1913. *Colletotrichum* species including *C. acutatum* (Simmonds), *C. capsici* (Syd.) Butler and Bisby, *C. gloeosporioides* (Penz.) Penz. and Sacc. and *C. coccodes* (Wallr.) S. Hughes (Simmonds, 1965; Johnston and Jones, 1997; Kim *et al.,* 1999; Nirenberg *et al.,* 2002; Voorrips *et al.,* 2004; Sharma *et al.,* 2005; Pakdeevaraporn *et al,.* 2005; Than *et al.,* 2008b) reduced marketable yield from 10% to 80% of the crop production m(Poonpolgul and Kumphai, 2007). Fruit rot is mainly a problem on mature fruits, causing severe losses due to both pre and post harvest fruit decay (Hadden and Black, 1989; Bosland and Votava, 2003).

Many post-harvest diseases of fruits exhibit the phenomenon of quiescence in which symptoms do not develop until the fruit ripens. Fruit rot causes extensive pre and post harvest damage to chilli fruits causing anthracnose lesions. Even small anthracnose lesions on chilli fruits reduce their marketable value (Manandhar *et al.,* 1995).

Colletotrichum species are the most important pathogens that cause latent infection (Jeffries *et al.,* 1990). Appressoria are known to form adhesive disks that adhere to plant surfaces and remain latent until physiological changes occur in fruits

(Bailey and Jeger, 1992). Appressoria that formed on immature fruits may remain quiescent until ontogenic changes occur in the fruits (Prusky and Plumbley, 1992).

Loss due to fruit rot and die-back of chilli in different locations of the world

Symptom	Place	Loss (%)	Reference
Fruit rot	Assam	12 - 30	Choudhury (1957)
Fruit rot	Punjab and Haryana	10 - 60	Bansal and Grover (1969)
Fruit rot	Korea	15	Kim and Park (1988)
Fruit rot	United States	30	Howard *et al.* (1992)
Fruit rot	Malaysia	50	Sariah (1994)
Fruit rot	India	10 - 15	Datar, (1995)
Seedling rot, dieback and fruit rot	Madhya Pradesh	15 - 20	Bhale *et al.* (1999a)
Fruit rot	Sri Lanka	21- 47	Rajapakse and Ranasinghe (2002)
Fruit rot	Udaipur	10 - 15	Bagri *et al.* (2004)
Dieback and fruit rot	Uttaranchal	12 - 25	Akhtar (2007)
Fruit rot	China	15 - 60	Deyong *et al.* (2007)
Fruit rot	Indonasia.	10 - 80	Widodo (2007)
Dieback and fruit rot	Northern Karnataka and Andhra Pradesh	15 - 20	Santoshreddy *et al.* (2012)

2.1.2 Symptomatology

The appearance of a small black circular spot, sharply defined but at time diffused. The disease spread was more in the direction of long axis of the fruit, so that original circular spot becomes elliptical. As the infection progress the spot gets either

diffused black, greenish black or dirty gray in colour, markedly delimited by a thick sharp black outline enclosing a dark lighten black or straw coloured area. Two or more spots coalesced to form bigger spots. Diseased fruits lost their normal red color and turned straw colored or in some cases white. When diseased fruit was cut open the lower surface of the skin was found to be covered with minute, black, spherical elevations. In advanced cases, seeds were covered by a mat of mycelium (Choudhury, 1957).

Siddique *et al.* (1977) and Isaac, (1992) observed the disease symptoms in three phases *viz.,* i) seedling blight or damping off, prevalent in the nursery, ii) leaf spotting and dieback which is initiated at different stages of the growth. Die back infection starts from the growing point of secondary branches gradually advance downwards and invades the entire branch and iii) fruit spotting and rotting in which mostly the ripened fruits were infected.

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 mycelial growth occured on the seeds, placenta and pericarp (Halfon *et al.,* 1983 ; Wall and Biles, 1993).

Symptoms appear mostly on the ripened fruits but the highest infection occurs on stored fruits. The dry rot symptom comprising of brown circular to irregular lesions which were increased and coalesced damaging the fruit partly or completely however soft rot showing water soaked lesions appeared on the fruits and then turned to brownish, soft rot set in and the fruit was completely rotted (Datar, 1995).

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. Oh *et al.* (1998) observed that initial anthracnose symptoms were detected on some green fruits at two days after inoculation resulting in typical sunken necrosis within five days after inoculation.

Lesions of *Alternaria alternata* on chilli fruit were darker in color and covered by moldy growth of fungus with heavy sporulation (Shivakumara, 2006).

Typical fruit symptoms are circular or angular, depressed sunken lesions, with concentric rings of acervuli that are often wet and produce pink to orange conidial masses. Under severe disease pressure, lesions may coalesce. Conidial masses may also occur scattered or in concentric rings on the lesions (Shivakumara, 2006; Than *et al.,* 2008a; Akhtar, *et al*., 2009).

2.1.3 Causal agent

Generally, anthracnose symptom of fruit rot disease is caused by *Colletotrichum* species which belongs to the Kingdom Fungi; Phylum Ascomycota, Class Sordariomycetes; Order Phyllachorales; and Family Phyllachoraceae. The anamorphs are *Glomerella* species. Anthracnose of chilli was first reported from New Jersey, USA, by Halsted (1890) in 1890 who described the causal agents as *Gloeopsorium piperatum* and *Colletotrichum nigrum*. These taxa were then considered as synonyms of C. *gloeosporioides* by Von Arx (1957).

The fungus, *C. capsici* was reported for the first time in India by Sydow on chilli from Coimbatore of Madras presidency in 1913. Since then it has been reported and described from several parts of the world (Butler, 1918; Dastur, 1921; Seaver *et al.* 1932; Marchionatto, 1935; Ling and Lin, 1944; Bansal and Grover, 1969; Thind and Jhooty, 1985; Mridha and Siddique, 1989; Hegde and Kulkarni, 2001a; Meenugupta and Garg, 2002). Von Arx (1957) noted *C. capsici* as a synonym of *C. dematium* (Pres. Ex. Fr.) Groove.

Oh *et al.* (1998) reported that *C. gloeosporioides* (*Glomerella cingulata*) is a common pathogenic fungus in many plants. When the isolate of *Glomerella cingulata* was inoculated on both green and red fruits, conidial germination, appressoria and infection hyphae were observed on both fruits within 24 hours after inoculation.

Than *et al.* (2008b) revealed that in the *Colletotrichum* patho-system, different species can be associated with anthracnose of chilli have been reported from different countries and regions of world. Although these species have been the subject of numerous investigations, there remain many gaps in the knowledge of the disease process and understanding of the complex relationships between the species involved.

Chilli fruit rot pathogens identified in different locations of the world

Causal organism/s	Country	Reference
C. capsici	India	Sydow (1913); Ramakrishna (1954); Maiti and Sen (1979); Paul and Behl, (1990); Verma and Sharma (1999)
Gloeosporium piperatum E. and E., *C. nigrum* E. and Hals	Myanmar (Burma)	Dastur (1920)
Alternaria alternata	Mexico	Leyendecker (1950)
Colletotrichum acutatum, *C. atramentarium*, *C. dematium*, *C. gloeosporioides* var. *minor*, *C. gloeosporioides* var. *gloeosporioides*	Australia	Simmonds (1965)
Colletotrichum dematium, C. graminicola and *C. atramentarium*	India	Verma (1973)
C. acutatum, *Glomerella cingulata*	UK	Adikaram *et al.*(1983)
C. capsici, *C. gloeosporioides*	Papua New Guinea	Pearson *et al.* (1984)
C. acutatum, *C. gloeosporioides*, *C. coccodes*, *C. dematium*	Korea	Park and Kim (1992)
Fusarium spp. and *Alternaria* spp.	Bangladesh	Basak *et al.* (1994)
Alternaria alternata , Aspergillus niger, Fusarium moniliforme, F. solani, Drecheslera australiensis and *Colletotrichum capsici*	India	Datar (1995)

Contd…..

Causal organism/s	State	Reference
C. acutatum, *C. capsici*, *C. Gloeosporioides*	Taiwan	Manandhar *et al.* (1995)
C. coccodes	New Zealand	Johnston and Jones (1997)
C. capsici C. gloeosporioides	Sri Lanka	Rajapakse (1998)
C. acutatum	USA	Roberts *et al.* (2001)
C. acutatum, *C. capsici*, *C. gloeosporioides*	Indonesia	Voorrips *et al.*(2004)
Colletotrichum dematium, Glomerella cingulata, C. gloeosproides, C.coccodes, C. acutatum	Korea	Byung-Soo (2007)
C. acutatum, *C. capsici*, *C. gloeosporioides*, *C. Nigrum*	Vietnam	Don *et al.* (2007)
C.capsici C. gloeosporioides C. acutatum	India	Ramachandran *et al.* (2007) ; Lydia and Zachariah (2012),
Colletotrichum acutatum, C.boninense C. gloeosporioides and *C.capsici*	Taiwan.	Sheu *et al.* (2007)
C. capsici, C. acutatum, C. gleosporioides	Thailand	Taylor *et al.* (2007)
C. acutatum, *C. capsici*, *C. gloeosporioides*	Thailand	Than *et al.* (2008b)
C.capsici C. gloeosporioides C. acutatum	Malaysia	Yun *et al.* (2009)
From Indian regions		
C. capsici	Coimbatore	Sydow (1913)
Colletotrichum, Choanephora, Alternaria, Phomopsis, Pythium , Rhizopus, Fusarium spp.	Punjab	Thind and Jhooty (1985)
Alternaria alternata, *Curvularia lunata*, *C. pallescens*	Andhra Pradesh	Prabhavathy and Reddy (1995)
C. capsici, Alternaria and *Fusarium* spp.	Karnataka	Mesta (1996)

Causal organism/s	State	Reference
Alternaria alternata	Madhya Pradesh	Bhale *et al.* (1999a)
C. capsici	Karnataka	Hegde and Kulkarni (2001a); Ekbote (2002a); Rajput (2011);
C.capsici C. gloeosporioides, Alternaria alternate, Rhizopus, Fusarium spp., *Aspergillus,* and *Curvularia*	Karnataka	Shivakumara (2006)
C. dematium, C. gloeosporioides, C. graminicola and *C. atramentarium*	Arunachal Pradesh	Selvakumar (2007)
C. capsici, C. acutatum, C. gleosporioides	Karnataka	Chowdappa (2010)
C. capsici, C. acutatum, C. gleosporioides and *Alternaria alternata*	Tamil Nadu	Madhvan *et al.* (2010)
C. gleosporioides	Nagaland	Ngullie *et al.* (2010)
Alternaria alternata	Udaipur	Bagri *et al.* (2011)
Fusarium oxysporum	Udaipur	Bagri *et al.* (2012)
C. capsici, C. acutatum, C. gleosporioides, Alternaria alternata and *Fusarium* spp.	Karnataka and Andhra Pradesh	Santoshreddy *et al.* (2012)
C.capsici , *Fusarium moniliforme. F. pallidoroseum, F. oxysporum, Alternaria alternata* and *Aspergillus flavus*	Jammu and Kashmir	Parey *et al.* (2013)

2.2 Survey, isolation and identification of pathogen/s to study the distribution in different geographical regions of South India

2.2.1 Survey

Thind and Jhooty (1985) reported that *Colletotrichum capsici* as a predominant fungus in causing fruit rot of chilli. The incidence varied between 66-84%. Mathew *et al.* (1995) made a survey during 1989-91 in Vellanikkara, Trichur, Kerala and reported that dieback and fruit rot were serious problems during rainy season.

Ekbote (2002a) conducted a survey during 1998-99 and 1999-2000 *kharif* in Haveri district. Among five taluks surveyed, the fruit rot of chilli incidence was more in Savanur taluka (42%) followed by Siggaon taluka (41%).

Shivakumara (2006) conducted a roving survey in North Eastern districts of Karnataka *viz.,* Raichur, Gulbarga and Bellary during 2005 and 2006 which revealed that mean per cent disease incidence ranged from 13.96 to 20.55. Maximum per cent disease index (11.56 PDI) was recorded in Gulbarga district followed by Raichur (11.17 PDI) district.

Akhtar *et al.* (2008) reported that chilli growing areas in Tarai belt of Uttaranchal (Sitarganj, Pantnagar and Bilaspur) showed anthracnose symptoms, particularly dieback and fruit rot which caused heavy loss in transit and storage.

Rajput (2011) conducted roving survey in Dharwad, Gadag and Haveri districts of northern Karnataka and revealed that disease severity ranged from 24.13 to 46.35 per cent. The highest severity of fruit rot was noticed in Nalvadi and Sanshi villages of Dharwad district.

2.2.2 Isolation and identification of pathogen/s

Ramakrishna (1954) reported the pathogenicity of two isolates of *C. capsici* obtained from chilli fruits. Kenchaiah (1975) proved the pathogenicity of the two isolates using both ripe and unripe fruits of *C. annum* and *C. fruitescens* and were pathogenic to their respective hosts and also cross inoculable. Singh *et al.* (1977)

isolated *C. capsici* from a severely infected chilli fruit and confirmed its pathogenicity experimentally.

Thind and Jhooty (1985) reported that, the chilli fruits were affected by *Colletotrichum, Choanephora, Alternaria, Phomopsis, Pythium, Rhizopus, Fusarium* spp. of fungi. Raut *et al.* (1990) isolated eleven fungi from apparently healthy, green, semiripe and ripe capsicum fruits. *Alternaria tenuis, Cladosporium oxysporum, Colletotrichum dematium, Curvularia lunata, Drechslera tetramera, Exserohilum rostratum* and *Machrophomina phaseolina* were the major ones. The sclerotial stage of *Macrophomina phaseolina* was isolated from the pedicel, pericarp, placenta and seeds of infected fruits. Pathogenicity was confirmed in green, semiripe and ripe chilli fruits. Datar (1995) reported that six fungi, viz., *Alternaria alternata , Aspergillus niger, Fusarium moniliforme, F. solani, Drecheslera australiensis* and *Colletotrichum capsici* were associated with chilli fruit rot.

Major fruit rot causing pathogens on capsicum fruits *Alternaria capsici-annui* and *A. tenuis, Cercospora capsici*, *Colletotrichum capsici, C. gloeosporioides, Fusarium* spp. and *Periconia byssoides* 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).

Prabhavathy and Reddy (1995) isolated fungi causing black rot disease on chilli fruits *viz., Alternaria alternata*, *Curvularia lunatus, C*. *pallescens, Pythyium butleri, Botryodiplodia theobromae, Phomopsis equiseti, Rhizopus stolonifer, Fusarium semitectum* and *Choanephora cucurbitarum* for the first time in Andhra Pradesh. Incidence and 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). *Phoma sorghina* was reported from *Capsicum annuum* (Khare *et al.,* 1995).

Khodke and Gahukar (1995) isolated *C. gloeosporioides* (*Glomerella cingulata*) from ripe chilli fruits (*Capsicum annuum*) in pure culture and its pathogenicity was confirmed. This was considered to be the first record of this species occurring on chilli in Maharashtra, India. Amusa and Alabi (1996) isolated *C. gloeosporioides* from infected pepper.

Paul and Behl (1990) reported that, chilli suffers considerable losses due to fruit rot/dieback/anthracnose caused by *C. capsici* in tropical and subtropical areas.

Khaleeque and Khan (1991) proved pathogenicity of *C. capsici* in chilli fruits. Thind and Jhooty (1990) conducted the pathogenecity test on chilli by detached fruit method and proved pathogenecity of *C. capsici*.

Bhale *et al.* (1999a) revealed that, *A. alternata* was found responsible for severe seed rot, seedling decay, tender twig tip drying and fruit rot. Wall and Biles (1993) reported that, fruit rot of New Mexican type of chilli is caused by *A. alternata.*

Verma and Sharma (1999) reported that, fruit rot of chilli caused by *C. capsici* was an important disease in field, transit, transport and storage.

Shivakumara (2006) found maximum frequency (25.0%) of *Colletotrichum* followed by *Alternaria* (21.0%) and others, *viz.*, *Aspergillus, Fusarium, Curvularia, Rhizopus* and mixed infections in chilli fruit rot samples collected from northern Karnataka.

Suthinraj and John (2009) isolated pathogen from infected chilli fruits collected from the Chidambaram. The fungus was purified and identified as *C. capsici.*

Byung-Soo, (2007) reported that *C. dematium, Glomerella cingulata, C. gloeosproides, C.coccodes, C. acutatum* causes fruit rot. Among them *C. gloeosprioides* and *C. acutatum* were dominant in Korea.

Singh *et al.* (2007) collected plant part showing anthracnose symptoms, particularly dieback and fruit rot which were subjected to microscopic examination which showed *C. capsici* spores. Further purified cultures of *C. capsici* used for *in vitro* pathogenicity on detached fruits of chilli cultivar Kandhari which revealed that sunken anthracnose symptoms on fruits.

Ramachandran *et al.* (2007) conducted survey and collected 92 isolates from different chilli growing areas of India. Among them 53 were identified as *C.capsici* 38 as *C. gloeosporioides* and one was found to be *C. acutatum*.

Than *et al.* (2008b) reported that several species of *Colletotrichum viz*., *C. capsici* (Butler Bisby), *C. gloeosporioides* (Penz.), *C. acutatum* (Simmonds), *C. atramentarium* (Berk and Broome), *C. dematium* (Pers.) and *C. coccodes* (Wallr.), *Glomerella cingulata* (Stoneman) along with *A. alternata* (Keissler) were causal agents of chilli fruit rot worldwide .

Roat *et al.* (2009) collected the infected chilli fruits and isolated the *C.capsici*. Fresh chilli fruit samples were surface sterilized and anthracnose symptoms were observed after seven days of incubation.

The isolates were used in the inoculation of chilli seedlings and fruits by the detached leaf assay procedure. (i) Conidial suspension (1 x 10^6conidia per ml) of twelve day old PDA grown cultures was sprayed on one-month-old chilli plants. (ii) The inoculated plants were covered with plastic bags for two days to maintain humidity. (iii) The plants were assayed for disease seven days after inoculation and continued to be so for up to 20 days; (iv) The presence of the pathogen was further confirmed by incubating the leaves in moist chambers for 5-7 days at 22 ± 1ºC and observed for the development of fungal growth.(Chandra Nayak *et al.,* 2009)

Madhvan *et al.* (2010) reported that out of the 16 chilli fruit samples collected from Tamil Nadu, *C. capsici* was the most commonly isolated (69%) followed by *C. gloeosporioides* (19%). *Alternaria alternata* was isolated from Poothapadi of Salem district and *Gibberella* sp. Othakadai of Madurai district.

2.3 Morphological characterization and molecular variability of pathogen/s

2.3.1 Morphological characterization

Hegde, (1998) reported that colony of *C. capsici* on potato dextrose agar was dark grey to blackish with a smooth margin. Whitish aerial mycelial growth and concentric rings of growth were visible along with light rose colored spore masses. Conidia were single celled curved with smooth margin and hyaline with central oil globule.

Among the five *C. capsici* isolates, isolate II had the largest conidia (22.9 x 394 µm), with an average of 53.8 setae on each acervuli and 4.2-6.4 septa and showed highest growth rate on PDA and PDB at pH 6.5. Thermal death point of its conidia was 47^{o} C and isolate was most virulent, as determined by fruit rot incidence and infectivity (Jeyalakshmi and Seetharaman, 1999 ; Rohana *et al.,* 2005).

Wharton and Uribeonodo (2004) reported that *C. acutatum* conidia were single septate and fusiform.

Shivakumara (2006) revealed that morphologically *C. gloeosporioides* was distinct from *C. capsici* showing fast, fluffy, dull white mycelium and within the isolates also found distinct characteristics with respect to growth, colour of mycelia and sporulation. *A. alternata* isolates showed ash colour to dark coloured mycelium with medium to fast growth and moderate to excellent sporulation.

Venkataravanappa and Nargund (2007) revealed that conidia size of six isolates of *C. gloeosporioides* varied between 10.9-20.6 µm in length and 4.39 – 6.65 µm in width.

Five isolates of *C. capsici* from Uttaranchal showed variation in colony color (white grey to blackish grey), growth (smooth to wavy margin) and sickle shaped conidia with size varied from 25.27 to 25.15 µm length, 3.17 to 3.66 µm width (Akhtar and Singh 2007).

Than *et al.* (2008a) reported that mycelium of *C. gloeosporioides* varied from light orange colony colour with delicate and thin to pale grey to black zonated colonies with abundant orange conidial masses near the centre. Conidia were cylindrical in shape and measured about 13.5 X 4.5 µm. *C. acutatum* white to olive grey colour colony with very thick cottony mycelium to orange-coloured colony, conidia were fusiform in shape and measured about 13 – 14 X 3.5 µm.

Zivkovic *et al.* (2010) reported that conidia of *C. acutatum were* elliptic-fusiform in shape and conidia size varied between 8-16 x 2.5 – 4 µm.

Sangdee *et al.* (2011) recorded variation of six isolates of *C. capsici* in Thailand based on colony color, growth, sporulation, spore size and shape.

Four isolates of *Alterneria alternata* variation was recorded based on colony color, growth, sporulation and spore size (Amit Kumar *et al.,* 2012).

Biju *et al.* (2012) revealed that *C. gloeosporioides* obtained from different location were analyzed for diversity employing macro and micro morphological features. The isolates were further grouped based on colour of the colony into five groups Viz., grey, white, grayish white, grayish olive and pale pink. Further, they also reported that sporogenic microsclerotia produced by *C. gloeosporioides* act as a potential source of inoculum for anthracnose of black pepper.

Chandramani (2012) reported that cultures of *C. gloeosporioides* on PDA produced white to grayish of dark orange on upper surface, while the lower side of colonies were of white, yellowish orange to black. Conidia were straight, one celled, hyaline, oblong, or cylindrical, slightly curved with translate base and rounded apex and measured 11.57 – 15.50 X 3.38 – 7.52 µm.

Christopher *et al.* (2013) collected twenty isolates of *C. capsici* from different growing regions of Tamil Nadu and characterized morphologically based on colony color, growth, sporulation and spore size.

Masoodi *et al.* (2013) revealed that twenty isolates of *C. capsici* from different growing regions of Kashmir valley which showed variation in culture color from white to grey, growth between 32.0-67.5mm with cottony to fluffy and regular to irregular margin, conidial size varied between 2.23 – 33.6 µm.

2.3.2 Molecular variability of pathogen/s

Morphology and pathogenecity are not enough to distinguish between *Colletotrichum* spp. diversity. Studies include internal transcribed spacer (ITS) regions (Freeman *et al.,* 2001; Moriwaki *et al.,* 2002; Sanders and Korsten*,* 2003; Lee *et al.,* 2007) as well as restriction fragment length polymorphism (RFLP) (Balardin *et al.,* 1999; Martin and Garcia-Figueres, 1999; Saha *et al.,* 2002 ; Weir *et al.,* 2012; Patil and Nargund 2013)

Shivakumara (2006) studied strainal variations among the species of *C. capsici* and *C. gloeosporioides* by RAPD profile.

ITS-RFLP technique is an efficient method for rapid diagnosis of *Colletotrichum* species from pepper. A total of 412 Taiwan isolates collected from pepper production areas were analyzed through ITS-RFLP fingerprinting. Among them, 245 *C. acutatum*, 34 *C. boninense*, 52 *C. capsici* and 69 *C. gleosporioides* were identified. Other *Colletotrichum* isolates (3%) were not distinguishable, which inferred to the various inter- and intra-species variations in *Colletotrichum* members (Sheu *et al.,* 2007).

Patil and Nargund (2013) collected 68 fungal pathogen isolates causing onion twister disease from onion growing regions of Karnataka and identified by PCR-based molecular method using specific primers as 19 *C. gloeosporioides,* 24 *C. acutatum* and 25 *F. oxysporum* isolates. Further these isolates were analyzed through RFLP fingerprinting by digestion with *HaeIII* which resulted in a characteristic pattern of three fragments and showed variability between the species as four clusters of *C. gloeosporioides,* six clusters of *C. acutatum* and five clusters of *F. oxysporum*.

Fungal isolates from chilli (*Capsicum* spp.) fruits in Thailand that showed typical anthracnose symptoms were identified as *Colletotrichum acutatum, C. capsici* and *C. gloeosporioides.* Phylogenetic analyses from DNA sequence data of ITS rDNA and β-tubulin (*tub*2) gene regions revealed three major clusters representing these three species. (Than *et al.,* 2008a)

Chowdappa and Chethana (2012) reported that 28 isolates of *C. gloeosporioides* from Sikkim causing anthracnose of orchids species specific PCR using primer CgINT and ITS4 amplified at 450bp.

Imjit *et al.* (2013) reported that PCR- based molecular method provided improved early detection and diagnosis system of fruit rot disease of chilli.

Pongpisutta *et al.* (2013) reported that effects of environmental manipulation on the morphological stability makes identification between *Colletotrichum* species difficult. ITS RFLP and ITS sequence analysis are considered to be essential tools to solve the problems of species differentiation and specific identification of the chilli anthracnose causal agents.

Sharma and Shenoy (2013) reported that 52 isolates of *C. gloeosporioides* of chilli fruit rot in southern India which showed affinity with *C. siamense* and *C. fructicola* within *C. gloeosporioides* species complex based on ITS / 5.8S rRNA and glyceraldehyde-3-phosphate dehydrogenase (gapdh) genes.

Santoshreddy *et al.* (2013) detected *C. capsici C. gloeosporioides, C. acutatum, A. alternata* and *Fusarium* spp. from seeds, fruits and die-back infected twigs of chilli plants by PCR-based molecular method using specific primers.

2.4 Epidemiology of disease in relation to climatic factors.

2.4.1 Survival ability of pathogens

C. capsici causing fruit rot of chilli survived in the field in plant debris atleast for six months (Choudhary, 1957; Rai and Chohan, 1966). *C. piperratum* and *C.capsici* were found to be capable of surviving in both internal and external tissues of dry pepper seeds for nine months (Smith and Crosson, 1958).

Ahmed (1982) found that, *Colletotrichum capsici* causing fruit rot of chilli survived up to eight months in both seed and culture.

Manandhar *et al.* (1995) reported that, *Colletotrichum* species were generally able to survive in or on seeds and one of the ways that anthracnose was introduced to the chilli field is through infected transplants.

Sanathkumar, (1999) observed that, the *C.capsici* could survive upto 225 days on infected seeds stored under room conditions where as on pedicel and fruit rind it survived for 195 days.

Kulkarni and Benagi, (2012) reported that, *Colletotrichum truncatum* survivived 360 days in greengram debris under 4^0 - 5^0C, 90 days under field condition and in seed up to 12 months.

2.4.2 Host range

Sundararaman, (1927) found that *C. capsici* infected soybean pods, tomato fruits, brinjal fruits by artificial inoculation. Pring *et al.* (1995) revealed that *C. capsici*

can overwinter on alternative hosts such as solanaceous vegetables and legume crops, plant debris and rotten fruits in the field. Hegde, (1998) revealed that *C. capsici* which causes fruit rot of chilli also infected tomato, potato, and brinjal.

Pandey, (2006) reported that *C. capsici* from chilli caused fruit rot, seed and seedling mortality in tomato based on pathogenecity test by pin prick method and also by molecular characterization with species specific primer (CcINT) which amplified at 450 bp from both chilli and tomato.

Mehetre and Joshi *et al.* (2010) revealed that *Colletotrichum capsici,* isolated from Yam anthracnose could infect chilli, turmeric and mango.

2.4.3 Aerobiology

Thakur and Khare (1991) reported that, maximum trapping of spores (*C. lindemuthianum* and *C. dematium*) in greengram was recorded when there was moderate temperature between 26 to 29˚C, relative humidity between 91 to 96 per cent, rainfall from 0 to 21.6 mm and wind velocity from 6 to 10 km per ha. Highest spore trap coincided with these conditions prevalent on July 30.

The maximum growth and sporulation of *C. capsici* observed at 25˚-30˚C (Ekbote, 1994; Angadi, 1999).

Roberts *et al.* (2001) reported that fruit rot of chilli infection occurs during warm, wet weather. Temperatures around 27°C and high humidity (80%) were optimum.

The aerobiological studies on effect of weather factors on the development of spore load of *C.truncatum* indicated that more conidial counts were observed during last week of July and first week of August, which coincided with the critical stages of infection in green gram (Kulkarni, 2009).

Patil *et al.* (2013a) revealed that cumulative rainfall contributed maximum (R^2 = 0.97) to development of onion twister disease severity caused by *C. gleosporioides, C. acutatum* and *F. oxysporum.*

2.5 Development of IDM strategies for disease

2.5.1 Evaluation of genotypes

Mesta (1996) studied the reaction of 217 chilli genotypes to *Colletotrichum capsici* in Dharwad and the results revealed that none of the genotypes were found to be immune to fruit rot either in field or in laboratory. Out of 217 chilli genotypes 11 genotypes were found to be resistant and 24 were moderately resistant in both field and laboratory conditions. Further he observed that, among different seed treating chemicals captan and thiram at 0.3 per cent were effective in controlling seedling infection.

Basak (1997) screened ten chilli cultivars against three major fruit rot fungi, *Colletotrichum capsici, C. gloeosporioides* and *Fusarium semitectum*. None of the cultivars were found to be immune however, except few remaining were rated as moderately resistant. Cultivars C-011 and C-045 were susceptible to *C. gloeosporioides*, *C. capsici*, C-123 to *C. capsici* and Chittagong local and Bogra local were susceptible to *F. semitectum* and highly susceptible to *Colletotrichum* spp.

Of fifty chilli cultivars/lines tested under artificial inoculation, five (Pusa Sada Bahar, 91-2, DC-9, DC-27 and Achar) were free from infection whereas six (86-5, Aparna, Kalyanpur Red, Sabour Anil, BG-1, Lorai and Perennial) were resistant and four (Pant C-1, DC-18, Suryamani and PS-1) were moderately resistant to *C. capsici* (Singh *et al.,* 1997).

Bhale *et al.* (1999b) reported that pinprick method was found to be most effective method for the pathogenicity of *Colletotrichum dematium*, on semiripe and fully ripe detached fruits in five and six days after inoculation respectively

Hegde and Anahosur (2001b) evaluated fifty two chilli genotypes against fruit rot fungus, *C. capsici* under natural condition. LCA-301, LCA-324, K-1 and Byadagi Kaddi were found resistant. Whereas, KDSC-210-10 and S-32 were found highly susceptible. Resistant genotypes contained higher capsaicin, ascorbic acid and lower amount of total sugars than susceptible ones.

Fifty one chilli cultivars were screened for field resistance to fruit rot fungus *C. capsici*. Of the cultivars tested, none were immune, one was resistant, three were

moderately resistant, five were moderately susceptible, seven were susceptible and nine were highly susceptible to the disease (Ekbote *et al.,* 2002a).

Naik and Rawal (2002) used pinprick method of inoculation under laboratory condition to identify the resistant source against aflatoxin fungus and anthracnose pathogen.

The observation on incidence of fruit rot was recorded at each picking. None of the cultivars was found to be immune to the disease. However, cultuivars namely Jwala, Phule Suryamukhi, Arka Lohit, KAC-86-25, Agni Rekha, AKC-BC-89-11, Parbhani tall, X-235, AKC-BC-89-8, G-4 and Surkta were found to be moderately resistant and seven genotypes were susceptible to disease (Patil *et al.,* 2002).

Angadi *et al.* (2003) screened 37 genotypes against anthracnose disease of chilli using pinprick method of inaculation in which six of the genotypes *viz*., KDSC-110-10, CO-1, PC-1, LCA-301, IHR-3023 and H-232 were resistant, seventeen were susceptible and four were highly susceptible.

Das *et al.* (2004) tested chilli genotypes against leaf spot and anthracnose (dieback and ripe fruit rot) disease under field condition. Among them, none of the entries were free from both the disease. However, cultivar KS3 (31.52%), CA 219 (34.07%), KS1 (35.41%) were tolerant to dieback disease. In case of ripe fruit rot, lowest rotting was observed in KS1 (33.41%) and KS3 (40.45%).

Malathi (2004) evaluated twelve hybrids with seven parents for yield and anthracnose resistance in three different seasons during 2002-03. The disease resistance in the parent S1 showed its superiority followed by S 2, Arka Lohit and CC-4. Among the hybrids, the least PDI of 3.02 per cent was recorded in the S hybrid S 1 x Ujwala followed by CC-4 x S 2 (3.27 %) and PDI of the top two best hybrids, Ujwala x 1 and S 1 x CC-4 were 9.06 and 11.60 per cent respectively.

Shivakumara (2006) screened the sixty one chilli genotypes against *C. gloeosporioides* and *A. alternata* under *in vitro* condition, among them P-14 showed resistant reaction for both pathogens. The popular cultivars Byadagi Dabbi and Byadagi Kaddi showed highly susceptible reaction to both pathogens.

Pugalendhi (2010) reported that, the genotypes Arka Lohit, Pepper Hot, CA 97, KDC 1, CC 4, CA 95, CA 115 and CA 59 were found to be moderately resistant to anthracnose and identified a high yielding moderately resistant to fruit rot disease chilli hybrid CCH1(Sln 1 x CA 97).

Susheela (2012) reported that, spray inoculation method in field is ideal screening method for anthracnose disease in chilli compared to fruit puncture method in laboratory.

2.5.2 Seed health management

2.5.2.1 Seed mycoflora

Basak (1994) identified seventeen fungi (11 genera) from chilli seeds which included *A. solani*, *C. gloeosporioides*, *Phomopsis capsici*, *Bipolaris* spp. and *Verticillium* sp. The different species of *Fusarium* were isolated by blotter method in chilli seed samples and also observed the seedling mortality after 30 days (Liang, 1990).

Basak *et al.* (1996b) screened different grades of infected seeds obtained from different types of fruit rot diseases of chilli. The highest percentage of diseased seeds was recorded in seeds infected by *Fusarium* spp. followed by *C. capsici*, *C. gloeosporioides*, *Alternaria* spp. and *Cercospora capsici*. The highest percentage of seed borne *Fusarium* infection was found in the seed coat (75%) (Basak *et al.,* 1996a). A positive correlation between fruit infection and seed infection was established (Mridha and Siddique, 1989).

Among the sixteen fungi, *C. dematium* and *A. alternata* associated with chilli seeds were found responsible for severe seed rot and seedling decay. Standard blotter method was better than agar plate method for their detection. Pre and post emergence mortality was also recorded due to fungi (Bhale *et al.,* 1999a; Hemannavar, 2008).

Solanke *et al.* (2001) reported the presence of *C. capsic*i, *F. moniliformae*, *A. alternata* from chilli seed samples.

Shivakumara, (2006) recorded that 97.73 per cent seed mycoflora on seeds collected from fruit rot infected chilli, 83.66 per cent and 38.24 per cent seed mycoflora on partially and apparently healthy seeds respectively after 120 hr of incubation.

Hemannavar *et al.* (2009) conducted seed health test of different fruit rot affected chilli seed samples collected from different parts of northern Karnataka revealed the dominance of *C. capsici* (71.24%) followed by *Cercospora* sp. (14.37%) and *Alternaria* sp. (3.28%). Other saprophytic fungi included species of *Penicillium* and *Aspergillus*.

Chauhan *et al.* (2010b) reported that toxic metabolites of *C. capsici and C. gloeosporioides* reduced seed germination, seedling vigour and seedling mortality.

Jayalakshmi *et al.* (2013) found that active metabolites released by *C. gloeosporioides* were toxic to seed germination of sorghum and growth of tomato seedlings.

Pandey *et al.* (2012) reported that 16.5 to 28.4% of chilli seeds were infected by *A. alternata* which cause seed rot, seedling decay, leaf spot, fruit rot and tender tip drying at different stages of crop growth

2.5.2.2 Seed treatment

Hegde and Kulkarni, (2001b) recorded the observations on control of damping off of chilli by treating the seeds with bioagents and chemicals. Among them the least per cent mortality (10.13) was observed in captan treated seeds, which was on par with *Pseudomonas fluorescens* (11.12) and thiram (12.34).

Shivakumara, (2006) evaluated six fungicides as seed treatment, among them prochloraz at 0.1 per cent concentration recorded highest seed germination per cent and also lowest seed mycoflora from the infected seed samples.

Srinivas *et al.* (2006) reported that *P. fluorescens* was more effective followed by *T. harzianum* in management seed and seedling rot of chilli caused by *C. capsici*

Hemannavar, (2008) revealed that, seed treatment with carboxin + thiram at 0.2 per cent concentration along with *P. fluorescens* at 0.6 per cent concentration followed by hexaconazole foliar spray showed least per cent disease index, maximum yield and maximum benefit cost ratio.

Deshmukh *et al.* (2012) revealed that seed inoculation with *Trichoderma harzianum* recorded least damping off incidence (18.90%) followed by *T.viride* (19.30%) and *Pseudomonas fluorescence* (19.70%) compared to untreated control (54.70%) in chilli.

Santoshreddy *et al.* (2013) reported that seed treatment of carboxin 37.5 + thiram 37.5 WS (2g/kg) and consortium of *T. harzianum* and *P. fluorescens* managed seed and seedling health of chilli under nursery condition.

2.5.3 Integrated disease management

Sharma *et al.* (2004) evaluated three chilli anthracnose management modules biological, chemical and IPM. Among them IPM module was found superior to biological and chemical modules with lower incidence for die-back and fruit rot compared to control with higher yield.

Lydia and Zachariah (2012) evaluated three chilli anthracnose management modules biological, chemical and IDM. Among them IDM module is superior to biological and chemical modules with lower incidence and greater disease control with higher yield.

Patil and Nargund (2013) evaluated five management modules for onion twister disease among them combination of adoptive and nutrient module found superior to alone chemical, biological, nutrient modules with least disease severity and high yield and C:B ratio.

Evaluation of fungicides, bioagents, against fruit rot causing pathogens of chilli are summerised in the following table

In vitro Colletotrichum capsici, C. gleosporioides* and *C. acutatum			
Fungicide	**Concentration (%)**	**Remarks**	**Reference**
Blitox	0.1, 0.2, 0.3	Complete inhibition of mycelial growth	Naik and Hiremath (1986)
Captofal, mancozeb, copper oxy chloride and carbendazim	0.1, 0.2 and 0.3	Inhibited the conidial germination	Patel and Joshi, (2002); Abhishek and Verma (2007); Patel (2009); Watve *et al.* (2009); Vinod *et al.* (2009)
Chlorothalonil	0.2, 0.3	Effective	Bernard and Schrader (1984); Patil *et al.* (2013b)
Carbendazim + mancozeb	0.2	Highest per cent inhibition of mycelial growth (89.23%)	Prashanth *et al.* (2008) ; Patel (2009) ; Jayalakshmi (2010) ; Praveena *et al.* (2011)
Difenconazole, Propiconazole	0.1	90.78% inhibition of mycelial growth	Patel and Joshi, (2002); Prashanth *et al.* (2008); Gud and Raut (2008) ; Patel (2009); Watve *et al.* (2009); Patil *et al.* (2013b); Nargund *et al.* (2013a)
Hexaconazole	0.10, 0.15, 0.20 and 0.40	Completely inhibited the mycelial growth	Patel and Joshi, (2002); Patil *et al.* (2013b)
Propicinazole and iprobenfos	0.1 0.15	Very effective in inhibiting the mycelial growth of the fungus	Nargund *et al.* (2013a) ; Patil *et al.* (2013b)
Propineb	0.2	87.78% inhibition of mycelial growth	Prashanth *et al.* (2008)
Thiophanate methyl	0.1, 0.2	Highly effective	Patel and Joshi, (2002); Abhishek and Verma (2007)

Tricyclazole	0.1	Very effective	Venkataravanappa and Nargund (2002); Patel and Joshi, (2002); Patel (2009); Patil *et al.* (2013b)
In vivo /Field			
Captafol seed treatment with per cent blitox foliar spray	0.3	Effectively managed dieback of chilli	Arunkmar and Vyas (2003)
Copper hydroxide	0.25	Effectively managed fruit rot of chilli	Ekbote (2002b) ; Nargund *et al.* (2012)
Copper oxy chloride	0.1	Pre-flowering followed by monthly application from fruit set onwards for effective in control of mango anthracnose.	Lonsdale (1992), Sanders and Korsten, (2003)
Carbendazim	0.1	Effectively managed fruit rot of chilli	Hegde and Anahosur (2001a)
Carbendazim + Mancozeb and propiconazole	0.3, 0.1	Effectively managed anthracnose of pomegranate	Hegde *et al.* (2002b) ; Nargund *et al.* (2012) ; Biju *et al.* (2011)
Difenconazole 25 EC Prochloraz 45 EC	0.1	Effective in reducing the anthracnose of pomegranate	Jamadar and Patil (2007); Benagi *et al.* (2009)*;* Nargund *et al.* (2012)
Hexaconazole	0.1	Effectively managed fruit rot of chilli	Hegde and Anahosur (2001a) ; Hegde *et al.* (2002b); Yenjerappa *et al.* (2002); Hemannavar (2008)
Kitazin	0.15	Effectively managed fruit rot of chilli	Nagaraja *et al.* (2004)

Bio agents			
Bio agents	**Pathogens/ disease**	**Remarks**	**Reference**
Aspergillus niger	*C.gloeosporioides*	Effective in inhibiting the growth	Patel and Joshi, (2002); Santha Kumari (2002)
Bacillus subtilis (isolate Tp-Tu 311), *Pseudomonas fluorescens* (isolate Tn-S 221) and *Pichia ohmeri* (isolate Y 24-8)	*C. gloeosporioides*	Inhibited the mycelial growth	Chuang and Ann (1997)
Combination of *T. viride, T. harzianum* and *Gliocladium virens*	*C. gloeosporioides, C. capsici*	Effective antagonistic	Gud and Raut (2008); Jadav *et al.* (2008); Vinod *et al.* (2009) ; Chauhan *et al.* (2010a) ; Rahaman *et al.* (2011)
RB50 (Rhizobacterial strain)	*C. gloeosporioides*	Effective antagonistic inhibition	Mallesh *et al.* (2009)
T. harzianum	*A. alternata*	Effective	Gohel and Solanky (2011)
Soil solarization and *T. harzianum* @ 5.0 g/kg with farmyard manure @ 0.2kg/m^2	Damping – off of chilli, tomato and brinjal	Effective	Akhtar *et al.*(2012)
Trichoderma sp.	*C. gloeosporioides*	Inhibited the mycelial growth	Bhuvaneswari and Rao (2001)
T. viride and plant growth promoting rhizobacteria	*C. gloeosporioides*	Effective antagonistic	Babu *et al.* (2008)
T. viride, T. harazianum, Pseudomonas fluorescence, Bacillus subtillis	*C. gloeosporioides C.capsici*	Effective antagonistic	Patel and Joshi, (2002); Hegde *et al.* (2002a); Raheja and Thakore (2002); Santha Kumari (2002); Prashanth *et al.* (2008) Hemannavar (2008) ; Watve *et al.* (2009) ; Ngullie *et al.* (2010) ; Jayalakshmi *et al.* (2012) ; Patil *et al.* (2013b)
T. viride, T. virens and *Bacillus subtillis*	*C. graminicola, C. gloeosporioides, C. capsici*	Effective antagonistic	Akhtar and Dwivedi (2006) Basha *et al.,* (2010)

Bio agents	Pathogens/ disease	Remarks	Reference
Bacillus subtilis	*Colletotrichum capsici*	Peroxidase, Polyphenol oxidase, Phenylalanine ammonia lyase and total phenols	Ramanujam *et al.* (2011)
Bacillus thermophillus	Pomegranate leaf spot and purple blotch of onion	Restrict the fungal growth and invasion in host plant	Mandhare and Suryawanshi (2003)
Fruit dip of *Bacillus licheniformis* (isolate B 250 and B 251)	Anthracnose	Gave good control of anthracnose and stem end rot	Korsten *et al.* (1993)
Propiconazole(0.05 %) + *P. fluorescens* (0.2%)	*Colletotrichum capsici*	Effectively inhibits the production of cellulase and pectinase enzymes	Chandramani *et al.* (2013)
Pseudomonas fluorescens	Effectively manage the chilli dieback and fruit rot	Beneficial yield	Ekbote (2005)
Pseudomonas fluorescens amended with chitin	Effectively manage the chilli dieback and fruit rot	Higher yield	Sarvanan (2012)
P. fluorescens and *T. viride* seedling dip and three spray	Effectively manage the chilli dieback and fruit rot	Higher yield	Keshgond *et al.* (2013)
Trichoderma harzianum	*Alternaria* fruit rot of chilli	Effective	Begum *et al.* (2010)

Fusarium* spp. *In vitro			
Fungicide	**Concentration (%)**	**Remarks**	**Reference**
Hexaconozole, carbendazim, mancozeb	0.1 and 0.3	Significantly inhibited the mycelial growth	Musmade *et al.* (2009),Taskeen *et al.* (2011)
Propiconazole	0.1	Effective in inhibiting mycelial the growth	Patil *et al.* (2013b)
Mancozeb 63% + carbendazim 12% trifloxystrobin 25% + tebuconazole 59%	0.2 and 0.3	Effective in inhibiting mycelial the growth	Anupama *et al.* (2012)

Bio agents			
Bio agents	**Pathogens**	**Remarks**	**Reference**
T.harzianum and *Pseudomonas* sp. Pf 12	*F. oxysporum*.f. sp. *Cepae*	Inhibited the growth	Malathi and Mohan (2011)
T.harzianum, T. virens, T.koningii and *T. viride*	*F. oxysporum*.f. sp. *Cepae*	Inhibited the growth	Mishra *et al.* (2010) Anupama *et al.* (2012), Patil *et al.* (2013b)

3. MATERIAL AND METHODS

The research activities were carried out during 2012 and 2013 in the Department of Plant Pathology, Main Agriculture Research Station, University of Agricultural Sciences, Dharwad. Laboratory experiments were carried out in the Department of Plant Pathology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka. Dharwad is situated in northern transitional zone (Zone 8) of Karnataka state at $15^0$15' N latitude, $75^0$7' N longitude and at an altitude of 774.0 m above mean sea level. The physical and chemical properties of soil of experimental field were mentioned in Apendix I. The mean maximum and minimum temperatures, relative humidity of morning and evening along with rainfall data have been collected from Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad for 2012 and 2013 (Table19 and 20). The details of the materials used and the methodology adopted during the course of investigations are presented in this chapter.

3.1 Survey, isolation and identification of pathogen/s to study the distribution in different geographical regions of South India

3.1.1 Survey

An intensive roving survey was carried out during 2012-13 and 2013-14 (*kharif and rabi/ summer*) in major chilli growing states of South India *viz*., Andhra Pradesh, Maharashtra, Karnataka to know the incidence and severity of fruit rot disease.

During 2012-13, totally 56 villages belonging to 15 taluks of 7 districts of Karnataka state, four taluks belonging to Kurnool district of Andhra Pradesh and three villages of Solapur district of Maharashtra state were surveyed. In each field, 10 plants were selected in zig zag manner starting from one end of field and noted the disease incidence and graded according to the scale and calculated disease severity. Similarly in 2013-14, totally 57 villages belonging to 15 taluks of seven districts of Karnataka, 20 villages belonging to six taluks of two districts of Andhra Pradesh were surveyed.

Fruit rot severity was recorded by referring the following 0-9 scale given by Mayee and Datar (1986) (Plate 2).

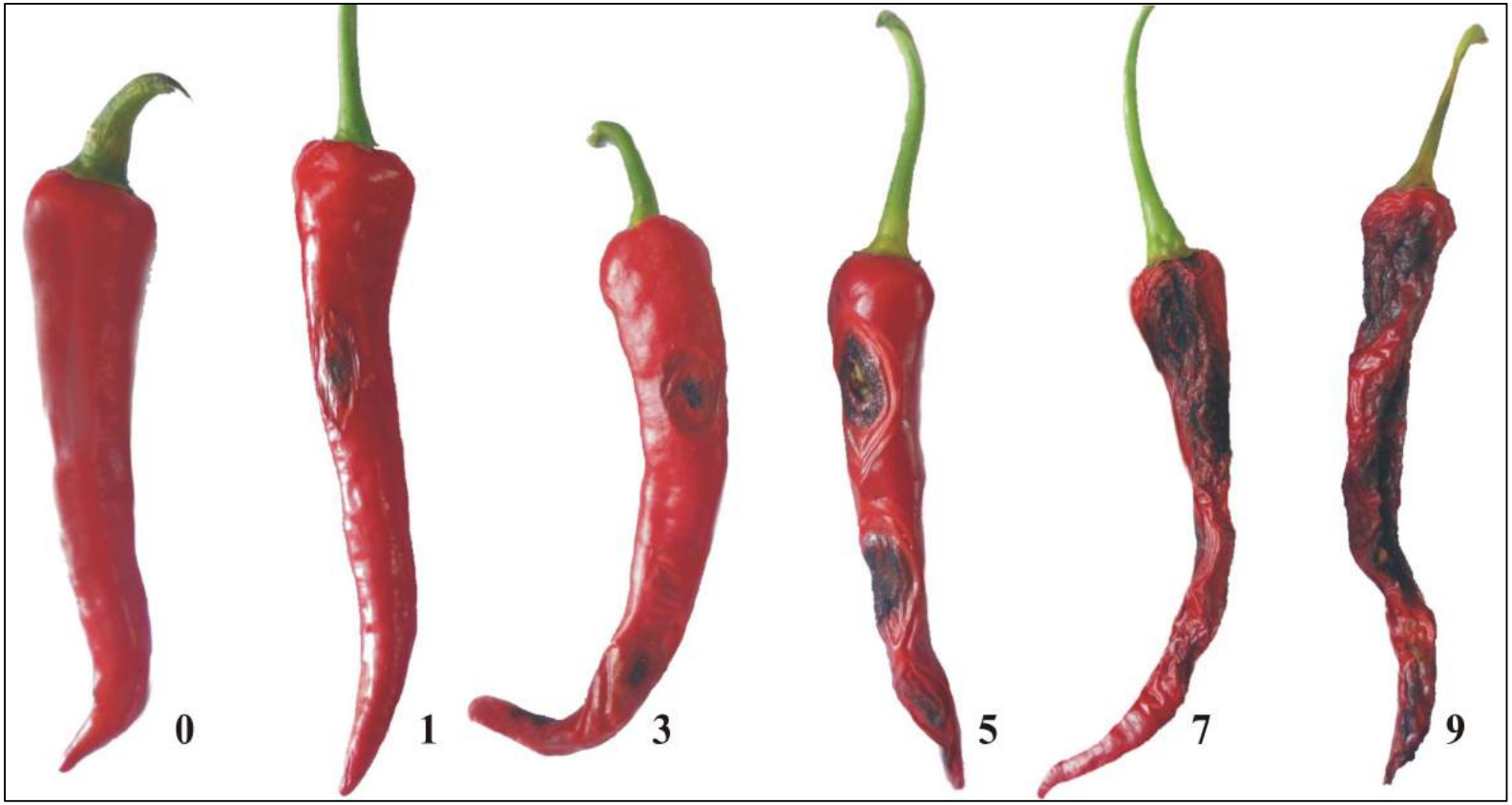


Plate 2 Disease scale of chilli fruit rot (0-9)

Grade	Per cent fruit area infection	Reaction
0	0	Immune
1	1-10	Resistant
3	11 – 25	Moderately resistant
5	26 – 50	Moderately susceptible
7	51 – 75	Susceptible
9	> 75	Highly susceptible

Die-back severity was recorded by referring the following 0-9 scale (Fig.1) based on per cent branches infected in each plant as given below

Grade	Branches infected per plant (%)
0	0
1	1-10
3	11 – 25
5	26 – 50
7	51 - 75
9	> 75

Per cent disease incidence of fruit rot was calculated by

$$\text{Per cent disease incidence} = \frac{\text{Number of fruits infected}}{\text{Total number of fruits examined}} \times 100$$

Per cent Disease Index was calculated to estimate the disease severity of fruit rot disease as per the formula given by Wheeler (1969).

$$\text{Fruit rot PDI} = \frac{\text{Sum of numerical disease rating}}{\text{Total no. of samples x Maximum of disease rating scale}} \times 100$$

Per cent disease incidence of die-back was calculated by

$$\text{Per cent disease incidence} = \frac{\text{Number of plants infected}}{\text{Total number of plants examined}} \times 100$$

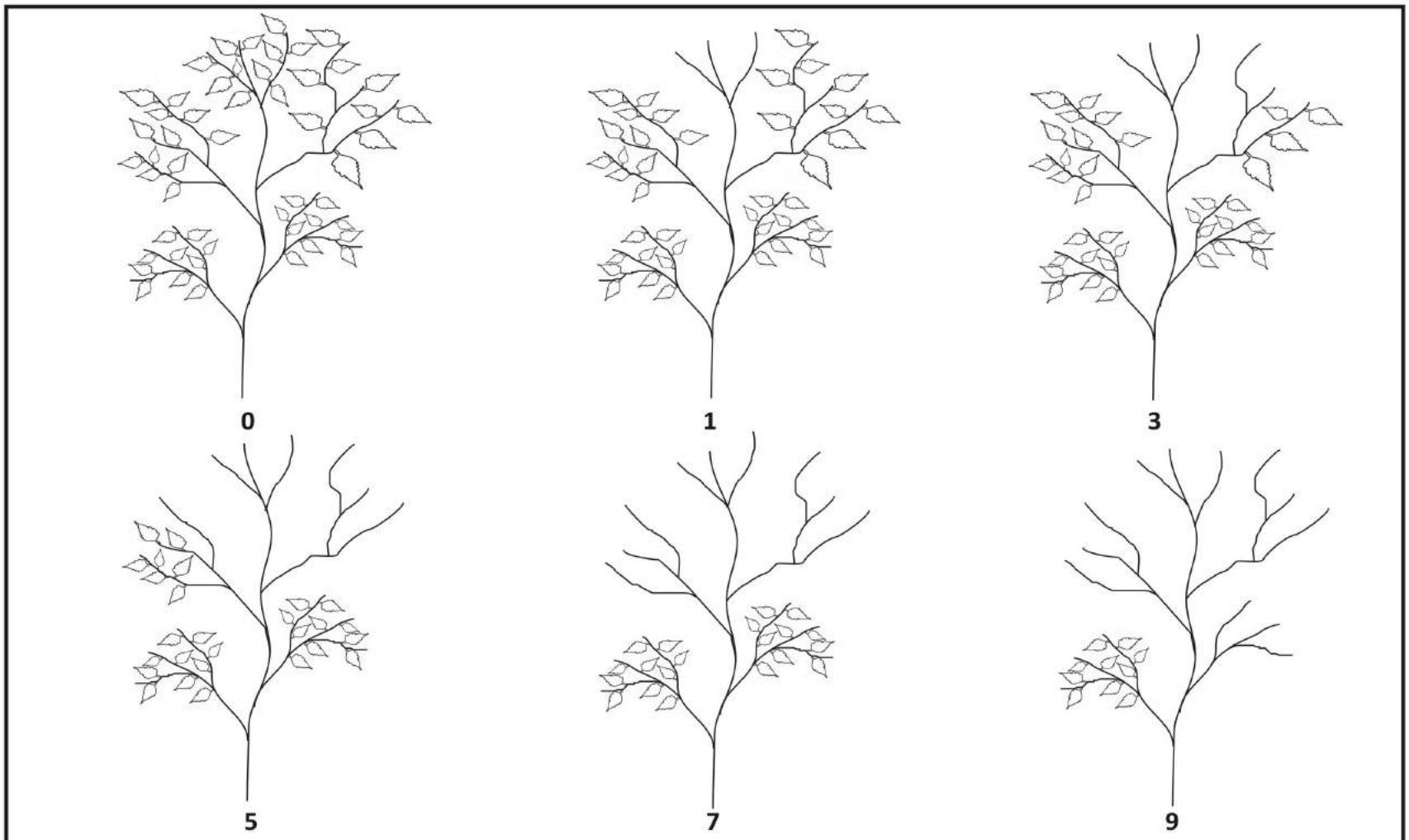


Fig. : Chilli dieback disease rating scale

Die-back severity was estimated as per the formula

$$\text{Die-back PDI} = \frac{\text{Sum of numerical disease rating}}{\text{Total no. of plants x Maximum of disease rating scale}} \times 100$$

3.1.2.1 Isolation and identification of pathogen/s

The pathogen/s were isolated from chilli plant samples collected during survey which showed the typical fruit rot and dieback symptom. The infected parts like fruit, twigs and fruit pedicel were cut into small bits and surface sterilized with one per cent sodium hypochlorite solution for two to three minutes and three times repeatedly washed in sterilized distilled water. Then the infected bits were transferred on to Petri dishes (1-2 bits per Petri dish) containing Potato Dextrose Agar (PDA) with the help of a sterile forceps and incubated at 25± 1°C for seven days. Further based on culture morphology and conidia pathogens were identified.

3.1.2.2 The frequencies of associated organisms in the infected chilli fruits

The frequencies of fungi and their dominance were also recorded by keeping the infected chilli fruits in a moist chamber for four days. Then the spores from the infected tissue were observed under microscope (400X). Based on morphology of spores fungi were identified. Frequencies of fungi were worked out for each sample which was collected from different geographical regions.

3.1.2.3 Single spore isolation

Ten ml of clear filtered two per cent water agar solution was poured into sterile petriplates and allowed to solidify. The dilute spore suspensions were prepared in sterile distilled water from ten days old culture. Two ml of spore suspension was spread uniformly on water agar plates. The excess suspension was aseptically drained off. After four hours of incubation at 25^{o} $\pm 1^{o}$C, the plates were examined to locate the germinated conidia. Single isolated germinated conidium was marked with ink on the lower glass surface of the Petriplate, which was cut and transferred to PDA slants in such a way that the conidium bearing surface was in contact with PDA surface and

incubated at 25^{o} ± 1^{o}C. The pure culture obtained was preserved in refrigerator and subcultured once in a month.

3.1.2.4 Maintenance of the cultures

The fungus was subcultured on PDA slants and allowed to grow at 28^{o} ±1^{o}C for 12 days. Such slants were preserved in refrigerator at 5^{o} C and maintained. Subculturing was done once in a month. Such cultures were used throughout the study.

3.1.2.5 Pathogenicity test

Pinprick method of inoculation

For inoculation, pinprick method on chilli fruit developed by Naik and Rawal (2002) was followed. Ten days old cultures were used for artificial inoculation. Chilli fruits harvested at red ripened stage were surface sterilized with one per cent sodium hypochlorite solution and then washed in two changes of sterile water. Thereafter, the fruits were pricked with pin bundles specially designed for pricking. The pinpricked fruits were then dipped in spore suspension having 1 X 10^{6} spores /ml for one minute. This procedure is followed for all *Colletotrichum* spp., *Fusarium* spp. and *A. alternata*. Further these fruits were kept for incubation on a perforated tray under humid chamber. The humid chamber was prepared by keeping water in the tray, which was placed below the perforated tray kept with inoculated fruits. Three wet cotton pieces were placed on the tray. The tray was covered with polythene sheet to maintain the relative humidity of over 90 per cent and then incubated at 25^{o} ±1^{o}C for eight days.

After the development of symptom on the chilli fruits, reisolation of the fungus was made from the affected portion of the fruit as per the method described earlier and Koch's postulates were proved.

3.2 Morphological characterization and molecular variability of pathogen/s by ITS markers

3.2.1 Morphological characterization

The pathogens were isolated from chilli plant samples collected during survey which showed the typical fruit rot and dieback symptom and also from Aurangabad and

Coimbatore as explained in 3.1.2.1. Further purification and sub culturing were done on PDA slants and Petridishes. These isolates were characterized based on diagnostic characters like colony color, spore shape and size and asexual fruiting body after ten days of incubation.

3.2.2 Molecular variability of pathogen/s

3.2.2.1 Isolation and purification of genomic DNA

Isolation of total DNA from *Colletotrichum* spp.*, Fusarium* sp. and *Alternaria* sp. was done as given below

- Fungal mat (2-3g) grown on potato dextrose broth was taken and homogenized using pestle and mortar by using liquid nitrogen.
- To the above solution 1 ml of lysis buffer was added and incubated for 60 minutes in hot water broth.
- The suspension in pestle and mortar was extracted with equal volume of phenol: chloroform: isoamyl alcohol (1:1 W/V) in centrifugation tube, centrifuged at 10,000 rpm for 20 minutes at 4^{o}C.
- Supernatant was taken in fresh centrifuge tube and 2.5µl RNase and 2.5µl protienase-K were added and incubated at room temperature for 30 minutes.
- Cool isopropanol of about 1/3rd volume (300-400 µl) was added and centrifuged @ 10, 000 rpm for 15 minutes at 4^{o}C.
- Wash buffer 500µl was added and centrifuged at 10, 000rpm for 5 min at 4^{o}C.
- Pellet was washed with 70 per cent ethanol, air dried and resuspended in 500µl of $T_{10}E_1$ buffer.
- DNA obtained was further quantified by agarose gel electrophoresis.

3.2.2.2 Standardization of template DNA, primer and dNTPs concentration

Two concentrations of the template DNA (40 ng, 80 ng) and primer (2 pmol, 5 pmol and 10 pmol) were checked for good amplification and 40 ng of template and 5

pmol of primer concentration were selected for further standardization of dNTPs concentration. Three concentrations of dNTPs (100 150 and 200 □l) were used. Based on the preliminary results, 150 □l of dNTPs concentration was selected.

3.2.2.3 Polymerase chain reaction

The primers for amplification were custom synthesized at Bangalore Genie Pvt. Ltd. Bangalore and supplied as lyophilized products of desalted oligos. Primer sequences used are given below.

Organism	Sequence	
Universal fungal ITS	ITS-1 - f	5'-TCCGTAGGTGAACCTGCG-3'
	ITS-4 - r	5'-TCCTCCGCTTATTGATATGC-3'
C. capsici	C.cap-f	5'-GTAGGCGTCCCCTAAAAAGG-3'
	C.cap-r	5'-CCCAATGCGAGACGAAATG-3'
C. gloeosporioides	CgInt -f	5-´GGCCTCCCGCCTCCGGGCGG-3'
	ITS-4 - r	5´- TCCTCCGCTTATTGATATGC-3'
C. acutatum	CaInt-2 - f	5´- GGGGAAGCCTCTCGCGG -3'
	ITS-4 - r	5-´TCCTCCGCTTATTGATATGC-3'
Alternaria alternata	AAF2	5'-TGCAATCAGCGTCAGTAACAAAT-3'
	AAR3	5'-ATGGATGCTAGACCTTTGCTGAT-3'
Fusarium spp.	Tef-Fu3f	5'-GGTATCGACAAGCGAACCAT-3'
	Tef-Fu3r	5'-TAGTAGCGGGGAGTCTCGAA-3'

3.3.2.4 PCR reaction mixture

Reaction mixture	Quantity (□l)
Template DNA (40 ng)	1
Primer (5pm)	1
dNTP's (2 mM)	2
Taq buffer A (10X)	2
Taq DNA polymerase (3U/µl)	0.3
Sterile water	13.7
Total	20

3.2.2.5 PCR condition for ITS region, *Colletotrichum capsici C. gloeosporioides C. acutatum, Alternaeria alternata* and *Fusarium* spp. amplification

	Universal ITS		***C. capsici***		***C. gloeosporioides***		***C. acutatum***		***A.alternata***		***Fusarium* spp.**	
Step	Temp (°C)	**Duration (min)**	**Temp (°C)**	**Duration (min)**	**Temp (°C)**	**Duration (min)**	**Temp (°C)**	**Duration (min)**	**Temp (°C)**	**Duration (min)**	**Temp (°C)**	**Duration (min)**
Initial denaturation	94	5	95	3	95	5	95	5	94	2	95	5
Denaturation	94	1	95	1	94	1	94	1	94	0.5	58	1
Annealing	54	1	52	0.5	62	1	62	1	55	0.5	94	1
Extension	72	2	72	1	7	1	72	1	72	0.5	72	2
Final extension	72	10	72	10	72	7	72	7	72	5	72	8
Hold	4	20	4	20	4	20	4	20	4	20	4	20
No. of cycles Denaturation Annealing Extension	35		30		30		30		30		30	

3.2.2.6 Separation of amplified products by agarose gel electrophoresis

Agarose of 1.2g was added to a conical flask containing 100 ml of 1 x TAE buffer. The agarose was melted by heating the solution in an electric oven and the solution was stirred to ensure even mixing and complete dissolution of agarose. The solution was then cooled to about 40-45^{o}C. Two to three drops of ethidium bromide (0.5 µg ml^{-1}) was added. The solution was mixed and poured into the gel casting platform after inserting the comb in the trough. While pouring sufficient care was taken for not allowing the air bubbles to trap in the gel. The gel was allowed to solidify and the comb was removed after placing the solidified gel into the electrophoretic apparatus containing sufficient buffer (1xTAE) so as to cover the wells completely. The amplified products (20µl) to be analysed were carefully loaded into the sample wells, after adding bromophenol blue with the help of micropipette. Electrophoresis was carried out at 75 volts, until the tracking dye migrated to the end of the gel. Ethidium bromide stained DNA bands were viewed under UV transilluminator and photographed for documentation.

3.2.2.7 Sequencing of ITS region

The ITS region was sequenced based on morphological variability in three *Colletotrichum* isolates, two *Fusarium* isolates and one *Alternaria* isolates belonging to five different geographical regions to confirm organism at nucleotide sequence level.

3.2.2.8 Sequencing and *in silico* analysis

The PCR product was sequenced using forward and reverse primers at Chromos Biotech Ltd., Bangalore. Homology search was done using BLAST algorithm available at http://www.ncbi.nlm.nih.gov.

3.2.2.9 Specific amplification of *Colletotrichum capsici, C.gloeosporioides, C. acutatum, Alternaeria alternata* and *Fusarium* spp.

DNA of 83 isolates were further subjected for specific amplification with species specific primers (mentioned in 3.3.2.3) of *Colletotrichum capsici, C. gloeosporioides, C. acutatum*, *A. alternata* and genera specific primers of *Fusarium* spp.

3.2.2.10 Analysis of the genetic variability among the *Colletotrichum capsici C. gloeosporioides*, *C. acutatum, Alternaeria alternata* and *Fusarium* spp. by using PCR-RFLP

Amplified PCR product was digested with four restriction enzymes namely *EcoR I, Taq I, Hae III* and *Hind III*. Enzyme treatments were made by taking a 4 µl aliquot of the PCR reaction and incubating it with 0.5µl of the 1U respective enzyme for 4 hour at 37°C using the 1µl digestion buffer specified by the manufacturer. The restriction fragments generated were analyzed by electrophoresis in 3 per cent agarose gels in TAE buffer as explained in 3.3.2.6.

3.2.2.11 Quick detection of fruit rot fungal pathogens from host tissue.

For quick detection, infected parts (seed, fruit, pedicel, die-back affected stem) were macerated into fine powder in liquid nitrogen using a mortar and pestle. Genomic DNA is extracted by CTAB method as explained in 3.3.2.1. Further species specific primers of *Colletotrichum capsici, C. gloeosporioides*, *C. acutatum, Alternaeria alternata* and *Fusarium* genera specific primers were used to perform PCR amplification in Eppendorf master cycler as described earlier. The amplification was quantified by electrophoresis in 1.2 per cnet agarose gels in TAE buffer as explained in 3.3.2.6

3.3 Epidemiology of disease in relation to climatic factors.

3.3.1 Survival ability of *Colletotrichum* spp. *A. alternata* and *F. oxysporum* in plant debris

The infected fruit and twig samples collected from field during survey (2012-13) were used for the study. The infected samples (100g) were kept under three different conditions. a) On soil surface of pot under natural condition b) in soil at 10 cm depth and c) laboratory condition in brown paper bag. The infected samples kept in different environmental conditions were subjected for isolation at 15 days interval on PDA using standard tissue isolation and incubated at 25±1^{o}C for seven days. Similar procedure was repeatedly followed at 15 days interval until the pathogens (*Colletotrichum* spp., *A. alternata* and *Fusarium oxysporum*) could not

be recovered from the infected parts (fruits, pedicel, and twig) preserved under different environmental conditions.

3.3.2 Host range of *C. capsici*

Host range studies were made in order to find out the capacity of the *C. capsici* to infect any host other than chilli, solanaceous vegetables like brinjal, tomato and legume crops *viz.,* moth bean, black gram, green gram, cowpea, soybean, chickpea and pea. Five seeds of these plants were sown in earthern pots of 30cm diameter (2kg soil), one month old plants were inoculated with spore suspension of *C. capsici,* by spray inoculation technique. Plants were kept in moist chamber for 24 h before and after inoculation. Chilli plants inoculated with spore suspension served as control. Symptoms were recorded at every 24 h after inoculation up to 10 days.

3.3.3 Cross inoculation and pathogen interaction

To know the cross inoculation nature of *C. capsici* which causes seed rot, seedling rot, die-back and fruit rot, different disease affected parts (seed, twigs, pedicel, fruits) were collected and subjected for isolation on PDA using standard tissue isolation and incubated at 25±1^{o}C for seven days. Pathogen from infected seed, twig and pedicel were inoculated to fruits and vice-versa, development of symptoms were recorded after ten days of incubation in glasshouse condition.

Interaction of the *Colletotrichum* spp. alone also with *F. oxysporum* and *A. alternata* in combination were studied. Byadgi Dabbi chilli fruits were collected and surface sterilized by sodium hypochlorite solution (1%). Further pin prick method was used for injury and inoculation of spore suspension (1X10^{6}/ml) of pathogens. These fruits were incubated in moist chamber for five days, development of symptoms were recorded.

3.3.4 Aerobiology

Aerobiological studies were carried out to trap the spores of *Colletotrichum* spp. present in the air current during *kharif* 2012 and 2013. For this, aeroscope exposure of stationary slide was done by mounting it on a wind vane and placed inside chilli cv. Byadgi Dabbi field at MARS, Dharwad. A slide of 150 sq. cm

smeared with a thin layer of vaseline was used for trapping spores, by keeping smeared slide in the slot inside the box. The slide was removed every day at 08.30 hr. Average number of conidia per microscopic field was recorded under low power (100X) taking count of ten microscopic fields on a slide after staining with cotton blue. Incidence of fruit rot disease on chilli crop in the aeroscope installed field was also recorded. The weather data *viz.,* maximum and minimum temperature, morning and evening relative humidity and rainfall received during the period of aerobiological studies were recorded from MARS Dharwad (Appendix I and II). The information obtained from these observations were studied in relation to weather factors *viz.,* minimum and maximum temperature, rainfall and relative humidity (morning and evening) prevailed during the crop period by following standard statistical methods. The multiple regression equation was developed for estimation of spore load and fruit rot incidence by taking weather parameters as input variables.

3.3.6 Effect of date of planting on fruit rot and die-back disease incidence and severity

An experiment was conducted to see the effect of various dates of planting on incidence and severity of chilli fruit rot and die-back disease. Seedlings of one month old were transplanted in the main field. The disease severity was recorded by using 0-9 scale at the time of harvesting. Details of experiment given below.

Location	MARS Dharwad	MARS Dharwad
Season	*Kharif* 2012-13	*Kharif* 2013-14
Dates of planting	June 15th, July 1st, July 15th , August 1st	June 15th, July 1st, July 15th
Genotypes	Byadgi Kaddi, Byadgi Dabbi, Sankeshwar and Guntur	Byadgi Kaddi, Byadgi Dabbi and Sankeshwar
Plot size	3.0 X 3.0 m	5.0 X 5.0 m
No. of lines	5	10
Replications	3	3
Design	RCBD	RCBD

3.4 Development of IDM strategies for disease

3.4.1.1 Field evaluation of chilli genotypes

Chilli genotypes obtained from Agricultural Research Station, Devihosur and Genetics and Plant Breeding Department, UAS, Dharwad were screened under field condition at MARS Dharwad during *kharif* 2012 and *kharif* 2013. All 343 chilli genotypes were sown in three meter lines of two rows. Five plants were selected in each line and percent disease incidence, percent disease severity were recorded. The reaction of fruit infection was graded on 0-9 scale as described earlier.

3.4.2.2 *In vitro* Evaluation of genotypes

Chilli genotypes which found resistant and moderately resistant under field conditions during *kharif* 2013-14 were screened under artificial condition in laboratory using pinprick method (Susheela, 2012) of inoculation for identifying the resistant source against fruit rot disease. Fruit of uniform size of both green and red color of 38 genotypes were selected, surface sterilized with sodium hypochlorite (1%) and washed thoroughly with sterile distilled water. The sterilized pins were dipped in testing fungal spore suspension (1 x 10^6 spores/ml) for two min thereafter, fruits pricked with these pins to depth of 2-3 mm. Inoculated fruits were incubated in moist chamber at 25±2^{0}C for a week. The reaction of fruit infection was graded by using 0-9 scale.

3.4.3 Seed health management

3.4.3.1 Standard Blotter Method

The standard Blotter Method developed by Doyer in 1938 which was later included in the International Seed Testing Association Rules of 1999 was followed. Four hundred seeds of each variety were tested by employing standard blotter method in 3 replications. Three pieces of blotting paper of 90 mm size were moistened with sterile distilled water and placed in 90 mm sterilized Petriplates after draining excess water. Untreated seeds were placed at the rate of 25 seeds per Petriplate at equal distance in each Petriplate. The plates were incubated at room temperature (25±2°C) under alternate cycles of 12 hours light and darkness.

After eight days of incubation the seeds were examined under stereoscopic-binocular microscope for the associated fungi and they were identified based on "habit characters" (Anon., 2005).

3.4.3.2 Seed treatment of chemical fungicides

The effect of three systemic, two non systemic and six combiproduct fungicides at 2g/kg of seed were evaluated in nursery. The details of experiments are given here

Year: *kharif* 2013	Location: MARS, Dharwad
Variety: Byadagi Dabbi	Design: RCBD
No. of treatments : 11	Replications: 3
Type of nursery : Raised bed	Bed size: 2.0 X 1.0 m
Height : 10.0 cm	Line Spacing: 4.0 cm
Soil type: Black clay	Observations: Incidence of seedling rot and Vigour index

Vigour index was calculated by the formula, given by Abdul Baki and Anderson (1973).

Vigour index = Seed germination (%) x Seedling length (shoot length + root length (cm)).

Common Name	Chemical name	Trade Name	a.i. (%	Formulation
Captan	N-trichloromethyl mercapta 4-cyclolexene-1-2-dicarboximide-Ntrichlormethyl thiotetrahydropthalamide	Captaf	75	WP
Carbendazim	Methyl 2 Benzimidazole carbomate	Bavistin	50	WP
Pyraclostrobin	Methyl-*N*-(2-[1-(4chlorphenyl)-1*H*pyrazol3yl]oxymethylpheny)-(*N*-methoxy)carbamat	Headline	20	WG

Tebuconazole	1- (4-chlorophenol)-4.4diamethyle-3- (1, 2, 4-triazole-1-yl-methyle-pemtene-3-ol	Raxil	2	DS
Mancozeb	Manganese ethylene bis dithiocarbonate plus zinc	Indofil-M45	75	WP
Carboxin 37.5% + Thiram 37.5%	3-(3-5-dichlorophenyl)-N-(1-methyl ethyl)- 2-4-dioxo-1-lemadazolidine carboximide + tetramethyl thiuram disulphide	Vitavax power	75	WS
Carbendazim 25% + Mancozeb 50%	Methyl 2 Benzimidazole carbomate 25 + Manganese ethylene bis dithiocarbonate plus zinc50	Sprint	75	WS
Carbendazim 25% + Iprodione 25%	E(3-5-dichlorophenyl)-N-isopropyl, 2- (methoxy carbomyl)-benzimidazole	Quintal	50	WP
Hexaconazole 4% + Zineb 68%	RS-2- (2, 4-D)-1- (1H-1, 2, 4 Trizole-1-yl) hezan 2-ol 4 + Zineb 68	Avtar	72	WP
Metalaxyl 4% + Mancozeb 64%	Methyl N-(methoxyacetyl)-N-(2, 6-xylyl)-DL-alaninate; methyl 2-(((2, 6-dimethylphenyl)amino)propinate. + Manganese ethylene bis dithiocarbonate plus zinc	Ridomil-Gold	68	WP
Tricyclazole 18% + Mancozeb 62%	5-methyl-1, 2, 4-triazole (3, 4b) Benzothiazole 18 + Manganese ethylene bis dithiocarbonate plus zinc 62	Merger	80	WP

3.4.3.3 Seed treatment of bio-fungicides

The effect of four bio-fungicides collected from Institute of Organic Farming, UAS, Dharwad, *viz., Trichoderma harzianum, Pseudomonas fluorescens, Bacillus subtilis* and *Verticillium lecanii @* 10g/kg and their combination (5.0 + 5.0 g)were evaluated in nursery. The details of experiments are given here

Year: *kharif* 2013	Location: MARS, Dharwad
Variety: Byadagi Dabbi	Design: RCBD
No. of treatments : 9	Replications: 3
Type of nursery : Raised bed	Bed size: 2.0 X 1.0 m
Height : 10.0 cm	Line Spacing: 4.0 cm
Soil type: Black clay	Observations: Incidence of seedling rot and Vigour index

Treatment details

Treatments	Rate per kg seed
Trichoderma harzianum	10g
Pseudomonas fluorescens	10g
Bacillus subtilis	10g
T. harzianum + *P. fluorescens*	5g+5g
T. harzianum + *B. subtilis*	5g+5g
P. fluorescens + *B. subtilis*	5g+5g
T. harzianum + *Verticillium lecanii*	5g+5g
P. fluorescens + *Verticillium lecanii*	5g+5g
B. subtilis + *Verticilium lecanii*	5g+5g

3.4.4 Field efficacy of chemicals for the management of fruit rot and die-back disease of chilli during *kharif* 2012 and 2013

The efficacies of nine fungicides were tested against the management of fruit rot disease of chilli under natural endemic field condition. The details of experiments are given here

Year: *kharif 2*012 and 2013	Location: MARS, Dharwad
Variety: Byadagi Dabbi	Design: RCBD
No. of treatments : 09	Replications: 3
Plot size: 3.0 X 3.0 m (5 lines)	Spacing: 60.0 X 60.0 cm
Soil type: Black clay	Observations: Incidence and severity of die-back disease, fruit rot, and fruit yield

Common Name	Chemical name	TradeName	a.i. (%)	Formulation	Concentration%
Difenconazole	Cis, trans-3-chloro-4 (4-methyl-2- (1H-1, 2, 4- Traizole-1-y1, methyl)-1, 3-dioxolan-2-y1) phenyl 4 chlorophenyl ether	Score	25	EC	0.1
Propiconazole	1-[2- (2, 4-dichlorophenyl) pentyl]-1H-1, 2, 4-Triazole	Tilt	25	EC	0.1
Pyraclostrobin	Methyl-*N*-(2-[1-(4chlorphenyl)-1*H*pyrazol3yl]oxymethylpheny)-(*N*-methoxy)carbamat	Headline	20	WG	0.1
Tebuconazole	1-(4-chlorophenol)-4.4diamethyle-3- (1, 2, 4-triazole-1-yl-methyle-pemtene-3-ol	Folicur	25.9	EC	0.1
Carbendazim 12%+ Mancozeb 63%	Methyl 2 Benzimidazole carbomate 12 + Manganese ethylene bisdithiocarbonate plus zinc 63	Saaf	76	WP	0.25
Hexaconazole 4% + Zineb 68%	RS-2- (2, 4-D)-1- (1H-1, 2, 4 Trizole-1-yl) hezan 2-ol 4 + Zineb 68	Avatar	72	WP	0.25
Tricyclazole 18% + Mancozeb62%	5-methyl-1, 2, 4-triazole (3, 4b) Benzothiazole 18 + Manganese ethylene bisdithiocarbonate plus zinc 62	Merger	80	WP	0.25
Pyraclostrobin 5% + Metiram 55%	Methyl-*N*-(2-[1-(4chlorphenyl)-1*H*pyrazol3yl]oxymethylpheny)-(*N*-methoxy)carbamat + zinc ammoniate ethylene bis (dithiocarbamate) poly [ethylenebis(thiuram disulfide)]	Cabriotop	60	WG	0.25

3.4.5 Integrated management of fruit rot disease of chilli

Field experiment was conducted to develop IDM strategies. Experiments were laid out in four modules namely bio intensive module for both disease and insect pests (M1), bio-intensive module for disease with chemical pesticides for insect pests (M2), Adoptive module (M3) chemical intensive module (M4).

Year: *kharif 2*012 and 2013	Location: MARS, Dharwad
Variety: Byadagi Dabbi	Design: RCBD
No. of modules : 04	Plot size: 12.0 X 9.0 m (15 lines)
Spacing: 60.0 X 60.0 cm	Soil type: Black clay
Observations: Incidence and severity of fruit rot and die-back disease, fruit yield	

Details of treatments are given below

Stage/Application method	**Bio intensive module for both disease and insects. M1**	**Bio intensive module for disease with chemical pesticides for insects. M2**	**Adoptive module M3**	**Chemical intensive module M4**
Seed treatment	*Trichoderma harzianum* 6g/kg	*Trichoderma harzianum* 6g/kg	Carboxin 37.5 + thiram 37.5 WS (2.5g/kg)	Carboxin 37.5 + thiram 37.5 WS (2.5g/kg)
15 DAS spray	*Pseudomonas fluorescens* (10g/l)	*Pseudomonas fluorescens* (10g/l)	*Pseudomonas fluorescens* (10g/l)	Hexaconazole 5 EC (0.1%)
Seedling dip	*Pseudomonas fluorescens* (10g/l)	*Pseudomonas fluorescens* (10g/l)	*Pseudomonas fluorescens* (10g/l)	Carbendazim 50 WP (0.1%)

94 DAT spray	Neem oil (10ml/l)	Neem oil (10ml/l)	Neem oil (10ml/l)	Carbendazim 12% + Mancozeb 63% WP (0.25%)
108 DAT spray	*Bacillus subtilis* (10g/l)	*Bacillus subtilis* (10g/l)	Hexaconazole 5 EC (0.1%)	Difenconazole 25 EC (0.1%)
122 DAT spray	Neem oil (10ml/l)	Neem oil (10ml/l)	Propiconazole 25 EC (0.1%)	Pyraclostrobin 20% WG (0.1%)
130 DAT, spray	*Pseudomonas fluorescens* (10g/l)	*Pseudomonas fluorescens* (10g/l)	Carbendazim 12% + Mancozeb 63% WP (0.25%)	Mancozeb 75WP (2.5%)
Insect pest management				
15 DAS spray	*Verticillium lecanii* (4g/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)
30 DAT spray	*Verticillium lecanii* (4g/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Fenazaquin 10%EC (2.0 ml/l)
60 DAT spray	Neem oil (10ml/l)	Neem oil (10ml/l)	Neem oil (10ml/l)	Imidachloprid 17.80 SL, (0.5ml/l)
90 DAT spray	*Verticillium lecanii* (4g/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Spiromesifen 22.9% (0.75ml/l)	Imidachloprid 17.80 SL, (0.5ml/l) + Spiromesifen 22.9% (0.75ml/l)	Imidachloprid 17.80 SL, (0.5ml/l)+ Spiromesifen 22.9% (0.75ml/l)
125DAT, spray	*Nomuraea rileyi* (4g/l)	Indoxacarb 14.5 SC (0.5ml/l)	Indoxacarb 14.5 SC (0.5ml/l)	Indoxacarb14.5 SC (0.5ml/l)

3.5 Statistical analysis

Statistical analysis was carried out as per the procedures given by Panse and Sukhatme (1985). Actual data in percentage were converted to angular transformed values, before analysis according to the table given by Walter (1997). Fischer's method of analysis of variance was used for analysis and interpretation of the data as outlined by Gomez and Gomez (1984). The level of significance used in 'F' and 'T' tests was p=0.05. Critical differences were calculated wherever 'F' test was significant. Other statistical analysis *viz.,* calculation of correlation coefficients, regression equations *etc.* were done using MS-excel.

4. EXPERIMENTAL RESULTS

The experiments were conducted on various aspects of chilli fruit rot and die-back disease with reference to prevalence and distribution of disease, pathogen diversity, severity of the disease in various geographical regions of South India, isolation, identification, morphological and molecular variability of pathogens and their quick detection by molecular method to know the complexity of causal organisms. Role of weather parameters in disease development and survival ability of pathogens, host range and cross inoculations were studied. Further, seed health management and integrated disease management strategies comprising screening of genotypes for resistance, evaluation of chemicals under field conditions and various disease management modules were studied for identification of the best management module with maximum C:B ratio which helps the farming community to a greater extent. These experiments were conducted in the laboratory as well as in the field during 2012 and 2013 at the Department of Plant Pathology, College of Agriculture and MARS, UAS, Dharwad. The results thus obtained are presented in different sections under this chapter.

4.1 Survey, isolation and identification of pathogen/s to study the distribution in different geographical regions of South India

4.1.1 Survey

A roving survey was carried out to know the incidence and severity of fruit rot disease during 2012 and 2013 in major chilli growing states of South India *viz.*, Andhra Pradesh (Guntur, Kurnool), Maharashtra (Solapur) and Karnataka (Bagalkot, Belgavi, Bellary, Dharwad, Gadag, Haveri, Koppal, , Raichur). The observations are presented in Table 1a, 1b, 2a, 2b and 3 (Plate 3).

Year 2012-13

Among three states the highest fruit rot incidence (19.97%) with 13.77 PDI was observed in Maharashtra followed by Karnataka (18.13%, 11.78 PDI) where as the highest die-back incidence (10.55%) with 43.90 PDI was observed in Andhra Pradesh followed by Karnataka (8.59%, 37.36 PDI) (Table 3).

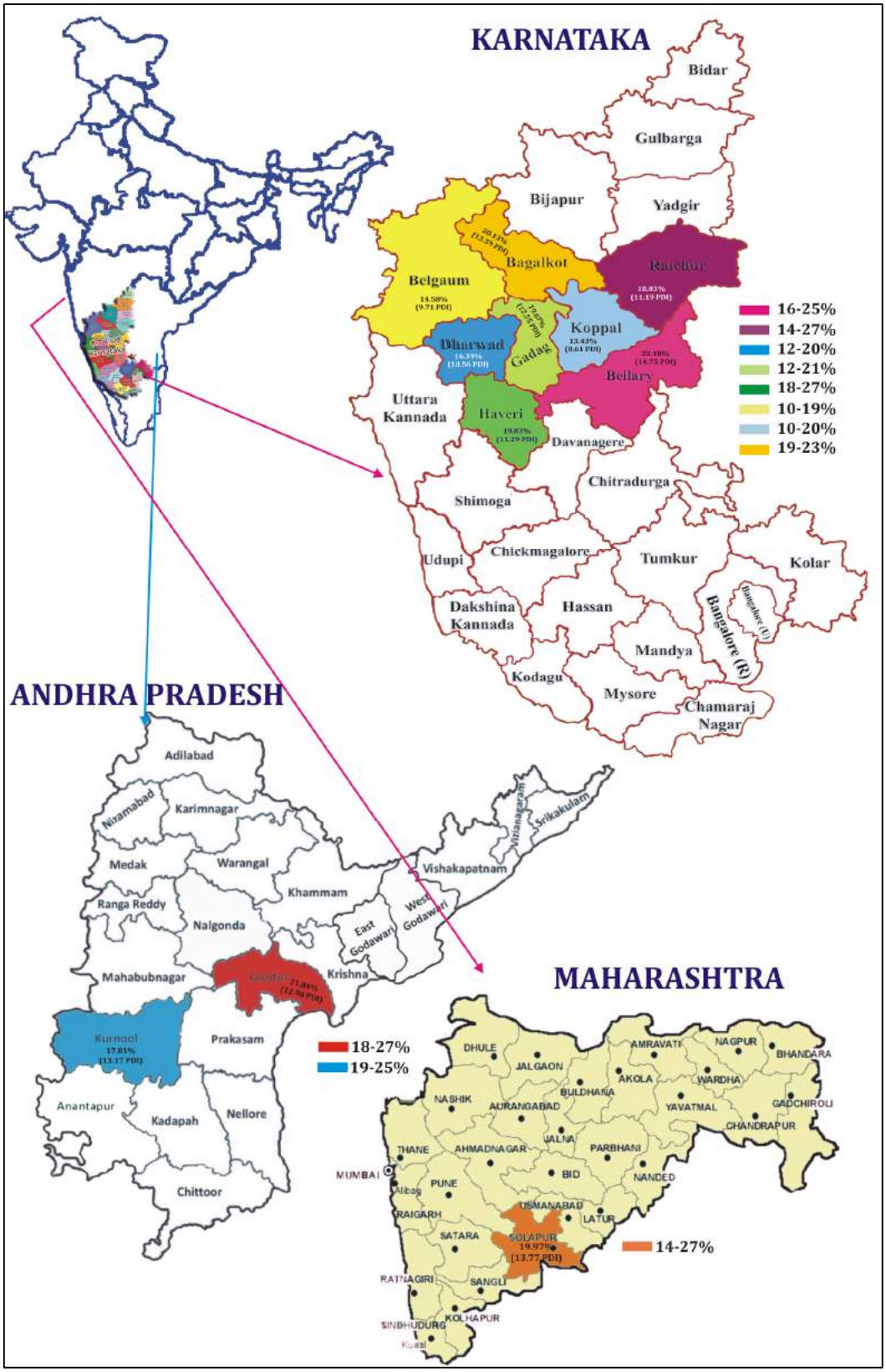


Plate 3 Chilli fruit rot incidence and severity in Karnataka, Andhra Pradesh and Maharashtra

Karnataka

Data pertaining to survey conducted during 2012-13 are presented in Table 1a and 1b. Among the 56 villages the highest fruit rot incidence of 27.52 per cent with 19.60 PDI was recorded in Hirekotnekal village of Manvi taluk, Raichur district followed by Koluru (26.52%, 18.60 PDI) village of Bellary district. The highest die-back incidence of 13.18 per cent with 48.91 PDI was observed in Hulkoti village of Gadag taluk. Among the 15 taluks highest fruit rot incidence of 22.87 per cent with 16.07 PDI was observed in Bellary taluk followed by Manvi (21.70%, 13.95 PDI). The lowest fruit rot incidence of 11.36 per cent and 7.38 PDI was observed in Kustagi taluk. The highest die-back incidence of 10.83 per cent with 43.79 PDI was observed in Hubli taluk. In Gangavati taluk die-back disease was absent followed by 5.77 per cent with 28.50 PDI was observed in Koppal taluk. Among the seven districts of Karnataka the highest fruit rot incidence of 21.71 per cent with 14.99 PDI was observed in Bellary followed by Raichur (20.24%, 12.55 PDI), where as the lowest fruit rot incidence of 12.83 per cent with 8.09 PDI was observed in Koppal. The highest die-back incidence of 10.65 per cent with 43.19 PDI was observed in Gadag, where as the lowest die-back incidence of 4.29 per cent with 30.50 PDI was observed in Koppal.

Andhra Pradesh

Among the 12 villages the highest fruit rot incidence of 24.82 per cent with 19.20 PDI was recorded in Madire village of Adoni taluk followed by Alur (21.48%, 16.75 PDI) village of Adoni taluk. The highest die-back incidence of 13.21 per cent with 49.41 PDI was observed in Dharmapuram village of Mantralaya taluk. Among the four taluks of Kurnool district the highest fruit rot incidence of 20.20 per cent with 15.74 PDI was observed in Adoni taluk followed by Mantralaya (19.60%, 11.85 PDI), where as lowest fruit rot incidence of 13.23 per cent and 10.42 PDI was observed in Emmiganur taluk. The highest die-back incidence of 11.20 per cent with 45.09 PDI was observed in Mantralaya taluk followed by Adoni (10.68%, 43.99 PDI), where as lowest die-back incidence of 10.00 per cent with 40.11 PDI was observed in Emmiganur taluk (Table 1a, 1b Plate.4).

Table 1a: Detailed survey on chilli fruit rot and dieback disease during 2012-13 in South India

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Karnataka	Bagalkot	Bagalkot	Kagalgombe	2.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	19.18	13.42	11.48	46.38	-	+	-	-	-
			Lokapur	2.5	Fruiting	Byadgi kaddi	Sole crop	I	Black	22.75	15.64	9.27	34.28	+	-	-	+	-
			Kaladagi	2.0	Fruiting	Byadgi Dabbi	Sole crop	I	Red	18.48	11.73	10.27	37.82	+	-	-	+	-
			Mean							**20.13**	**13.59**	**10.34**	**39.49**					
	Range									**19-23**	**11-16**	**9-12**	**34-47**					
	Mean									**20.13**	**13.59**	**10.34**	**39.49**					
	Bellary	Bellary	Koluru	4.0	Fruiting	Byadgi Kaddi	Sole crop	I	Red	26.52	18.60	8.42	39.84	+	-	-	-	+
			Raravi	6.0	Fruiting	Guntur	Sole crop	I	Black	18.36	13.40	6.74	34.46	+	-	+	+	-
			Sindigeri	4.0	Fruiting	Byadgi Dabbi	Sole crop	R	Red	23.72	16.21	7.89	36.92	+	+	-	-	+
										22.87	**16.07**	**7.68**	**37.07**					
			Kerur	3.0	Fruiting	Byadgi Dabbi	Sole crop	R	Red	16.49	11.25	8.94	52.48	+	-	-	+	+
		Siraguppa	Siraguppa	4.0	Fruiting	Guntur	Sole crop	I	Red	18.62	14.79	10.46	41.92	-	+	-	+	-
			Shanvaspur	4.0	Fruiting	Byadgi Dabbi	Sole crop	I	Red	24.71	16.93	10.00	52.16	+	+	-	-	-
			Sirigeri cross	2.0	Fruiting	Byadgi Dabbi	Sole crop	I	Red	22.41	12.64	12.94	39.92	+	-	-	+	-
			Mean							**20.55**	**13.90**	**10.58**	**44.67**					
	Range									**16-25**	**11-19**	**7-13**	**34-53**					
	Mean									**21.71**	**14.99**	**9.13**	**40.87**					
	Dharwad	Dharwad	Amminabhavi	1.5	Fruiting	Byadgi Dabbi	Onion	R	Black	18.96	10.97	9.46	38.92	+	-	-	-	-
			Byahatti	2.0	Fruiting	Byadgi Dabbi	Onion	R	Black	15.48	9.34	8.72	34.83	-	+	-	-	+
			Govankoppa	1.5	Fruiting	Sitara	Sole crop	R	Black	12.73	9.21	9.14	35.82	+	-	+	-	-
			Kumbapur farm	2.0	Fruiting	Byadgi Dabbi	Sole crop	I	Red	19.54	12.46	8.76	33.94	+	-	-	+	+
			Somapur	1.0	Fruiting	Byadgi Dabbi	Onion	R	Black	21.73	13.81	10.16	31.24	+	-	-	-	+

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
			Shivalli	1.5	Fruiting	Byadgi Dabbi	Onion	R	Black	24.14	12.07	9.43	40.78	+	-	-	+	-
			UAS Campus	2.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	22.73	11.73	8.93	41.05	+	+	+	+	+
									Mean	**19.33**	**11.37**	**9.23**	**36.65**					
		Hubli	Hubli	2.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	14.25	10.71	12.83	48.29	+	-	-	-	+
			Hebsur	2.5	Fruiting	Byadgi Dabbi	Onion	R	Black	12.34	9.27	9.13	38.92	+	-	-	+	-
			Shirguppi	2.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	16.27	11.35	10.52	44.16	+	+	-	-	-
									Mean	**14.29**	**10.44**	**10.83**	**43.79**					
Karnataka	Dharwad	Kundgol	Gudigeri	2.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	15.14	10.76	10.18	41.7	+	-	-	+	-
			Kundagol	5.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	17.19	11.41	9.27	40.31	+	-	-	-	+
			Sharewad	4.0	Fruiting	Byadgi Dabbi	Sole crop	R	Black	15.52	10.16	12.13	42.91	+	-	-	+	-
			Savnsi	2.0	Fruiting	Byadgi Kaddi	Sole crop	R	Black	12.31	8.94	9.43	36.81	+	-	-	-	-
									Mean	**15.04**	**10.32**	**10.25**	**40.01**					
		Navalgund	Alagavadi	3.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	14.13	11.74	9.14	35.27	+	-	-	+	-
			Byalal	2.5	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	16.10	12.15	8.92	34.93	+	-	-	+	-
			Gummagola	2.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	11.83	9.82	9.47	36.72	+	-	-	-	+
									Mean	**14.02**	**11.24**	**9.18**	**35.64**					
	Range									**12-20**	**9-14**	**8-13**	**31-49**					
	Mean									**15.67**	**10.84**	**9.87**	**39.02**					
	Gadag	Gadag	Binkadakatti	3.0	Fruiting and flowering	Gadag Local	Sole crop	R	Black	12.76	9.24	9.13	40.24	-	+	-	-	+
			Badrapur	2.0	Fruiting and flowering	Byadgi Dabbi	Cotton , onion	R	Black	16.81	12.16	10.47	43.28	+	-	-	+	-
			Dumdur	1.5	Fruiting and flowering	Byadgi Dabbi	Cotton, onion	R	Black	20.47	14.38	9.81	40.31	+	-	-	+	-

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
			Hulkoti	2.0	Fruiting and flowering	Byadgi Dabbi	Cotton , onion	R	Black	18.32	10.13	13.18	48.91	+	-	-	-	+
									Mean	**17.09**	**11.48**	**10.65**	**43.19**					
	Range									**12-21**	**9-15**	**9-14**	**40-49**					
	Mean									**17.09**	**11.48**	**10.65**	**43.19**					
	Haveri	Haveri	Byadgi	2.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	I	Black	20.19	12.20	7.43	32.31	+	+	-	-	+
			Devihosur	3.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	R	Black	16.31	9.12	8.24	34.31	+	-	+	-	+
			Dummihal	1.5	Fruiting and flowering	Byadgi Kaddi	Sole crop	R	Black	14.28	8.41	9.21	39.21	+	-	-	+	-
									Mean	**16.92**	**9.91**	**8.29**	**35.28**					
Karnataka		Ranebennur	Guttal	2.0	Fruiting and flowering	Dyavanur Dabbi	Sole crop	R	Black	18.41	11.02	8.11	32.51	+	+	-	-	+
			Kadaramandalgi	2.5	Fruiting and flowering	Byadgi Dabbi	Sole crop	I	Black	26.18	14.17	9.02	34.10	+	-	-	-	-
			Lingadahalli	2.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	R	Black	18.21	10.43	0.00	0.00	+	-	+	-	-
			Ranebennur	1.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	R	Black	23.40	12.10	8.14	34.32	+	-	-	+	-
									Mean	**21.55**	**11.93**	**6.32**	**33.64**					
	Range									**18-27**	**10-15**	**0-9**	**0-35**					
	Mean									**19.23**	**10.92**	**7.30**	**34.46**					
	Koppal	Gangavati	Budugumpa	2.0	Fruiting and flowering	Local	Sole crop	I	Red	14.25	9.01	0.00	0.00	+	+	-	-	-
			Kanakapur	1.5	Fruiting and flowering	Byadgi Kaddi	Sole crop	I	Red	9.71	4.83	0.00	0.00	-	+	-	+	-
									Mean	**11.98**	**6.92**	**0**	**0**					

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
		Koppal	Basapur	2.0	Fruiting and flowering	Guntur	Sole crop	I	Red	13.16	8.42	0.00	0.00	+	-	-	-	-
			Beluru	1.5	Fruiting and flowering	Gadag local	Sole crop	I	Red	19.20	10.28	9.46	43.48	+	+	-	-	+
			Bommanal	2.0	Fruiting and flowering	Byadgi Kaddi	Sole crop	I	Red	12.30	9.20	5.20	27.4	+	-	-	+	-
			Dambarahalli	2.0	Fruiting and flowering	Guntur	Sole crop	I	Red	16.82	11.64	9.36	40.24	+	-	-	-	-
			Talakall	1.5	Fruiting and flowering	Byadgi Dabbi	Sole crop	R	Black	14.20	10.24	4.82	31.4	+	+	-	-	+
									Mean	**15.14**	**9.96**	**5.77**	**28.50**					
Karnataka		Kustagi	Chikkatebinahal	2.0	Fruiting and flowering	Local	Sole crop	I	Red	12.30	7.92	8.94	38.00	+	-	-	+	-
			Kustagi	2.5	Fruiting and flowering	Byadgi Kaddi	Sole crop	I	Red	10.42	6.84	4.20	26.10	+	-	-	-	+
									Mean	**11.36**	**7.38**	**6.57**	**32.05**					
	Range									**10-20**	**4-12**	**0-10**	**0-44**					
	Mean									**12.83**	**8.09**	**6.17**	**30.50**					
	Raichur	Manvi	Herekotneekal	4.0	Fruiting and flowering	Guntur	Sole crop	I	Black	27.52	19.60	9.42	39.84	+	-	-	+	+
			Kapgal	3.5	Fruiting and flowering	Byadgi kaddi	Sole crop	I	Black	16.04	10.32	9.66	38.33	+	+	-	-	+
			Neer manvi	3.0	Fruiting and flowering	Guntur	Sole crop	I	Red	21.55	11.93	6.32	17.73	+	-	-	-	+
									Mean	**21.70**	**13.95**	**8.47**	**31.97**					
		Raichur	Belgammanadoddi	4.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	I	Black	22.87	11.07	10.68	47.07	+	-	+	-	+

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R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
			Mandapura	40	Fruiting and flowering	Byadgi Dabbi	Sole crop	I	Black	15.28	8.54	9.21	39.21	+	+	-	+	+
			Nelhal	5.0	Fruiting and flowering	Guntur	Sole crop	I	Black	23.40	12.10	8.14	34.32	+	-	-	+	+
			Panchamukhi	4.0	Fruiting and flowering	Byadgi Kaddi	Sole crop	R	Black	14.02	11.24	9.18	35.64	+	+	-	+	-
			Raichur	5.0	Fruiting and flowering	Byadgi Dabbi	Sole crop	I	Black	19.73	12.01	10.14	42.10	+	-	-	+	+
			Raladoddi	4.0	Fruiting and flowering	Guntur	Sole crop	I	Red	21.55	11.93	6.32	17.73	-	+	-	+	-
									Mean	**18.79**	**11.16**	**8.59**	**36.01**					
Range										**14-27**	**10-19**	**6-11**	**17-47**					
Mean										**20.24**	**12.55**	**8.53**	**33.99**					
Andhra Pradesh	Kurnool	Adoni	Alur	2.0	Fruiting and flowering	Byadgi Kaddi	Sole crop	I	Black	21.48	16.75	11.20	47.35	-	+	-	+	-
			Madire	3.0	Fruiting and flowering	Brahma theja	Sole crop	I	Black	24.82	19.20	10.51	38.24	+	-	-	+	-
			Marakattu	2.0	Fruiting and flowering	Guntur	Sole crop	I	Black	20.31	14.26	-	-	+	-	+	-	+
									Mean	**20.20**	**15.74**	**10.68**	**43.99**					
		Emmiganur	Bodikanda	2.0	Fruiting and flowering	Theja	Sole crop	I	Black	12.50	9.71	8.17	38.16	+	-	-	+	-
			Emmiganur	2.5	Fruiting and flowering	Guntur	Sole crop	I	Red	16.89	12.40	12.00	44.28	+	+	-	-	+
			Hanumapuram	3.0	Fruiting and flowering	C-341	Sole crop	I	Black	10.72	9.10	-	-	-	+	-	-	+
			Kotekallu	3.0	Fruiting and flowering	Guntur	Sole crop	I	Red	12.80	10.45	9.82	37.90	+	-	-	+	-
									Mean	**13.23**	**10.42**	**10.00**	**40.11**					

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Geno type	Inter crop / sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
		Mantralaya	Dharmapuram	2.5	Fruiting and flowering	Guntur	Sole crop	I	Red	21.41	13.20	13.21	49.41	+	-	-	+	-
			Halaharavi	2.0	Fruiting and flowering	Theja	Sole crop	R	Black	18.31	11.45	9.67	42.46	+	-	-	-	-
			Kalludevarakunta	2.0	Fruiting and flowering	Guntur	Sole crop	I	Red	20.26	12.00	10.72	43.41	-	+	-	-	+
			Manthralaya	2.0	Fruiting and flowering	Guntur	Sole crop	I	Red	18.40	10.73	-	-	+	-	+	+	-
									Mean	**19.60**	**11.85**	**11.20**	**45.09**					
		Nandavaram	Mugathi	2.0	Fruiting and flowering	Guntur	Sole crop	I	Red	14.20	12.73	10.32	46.40	+	-	-	-	-
Range										**9-25**	**9-20**	**8-13**	**37-50**					
Mean										**16.81**	**12.69**	**10.55**	**43.90**					
Maharashtra	Solapur	Pandarapur	Mangalaveda	2.0	Fruiting and flowering	Local	Sole Crop	I	Black	26.82	20.45	8.60	36.25	+	+	-	+	-
			Pandarapur	2.5	Fruiting and flowering	Capsicum	Sole Crop	I	Red	14.20	9.48	-	-	+	-	-	-	-
			Sangola	2.0	Fruiting and flowering	Local	Sole Crop	I	Red	18.91	11.40	6.80	33.90	+	-	-	+	+
									Mean	**19.97**	**13.77**	**7.70**	**35.07**					
Range										**14-27**	**9-21**	**6-9**	**33-37**					
Mean										**19.97**	**13.77**	**7.70**	**35.07**					

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent

Table 1b : Mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2012-13 in different taluks of Karnataka, Andhra Pradesh and Maharashtra

State	District	Taluka	Fruit rot		Die back	
			Incidence (%)	PDI	Incidence (%)	PDI
Karnataka	Bagalkot	Bagalkot	20.13	13.59	10.34	39.49
		Mean	**20.13**	**13.59**	**10.34**	**39.49**
	Bellary	Bellary	22.87	16.07	7.68	37.07
		Siraguppa	20.55	13.90	10.58	44.67
		Mean	**21.71**	**14.99**	**9.13**	**40.87**
	Dharwad	Dharwad	19.33	11.37	9.23	36.65
		Hubli	14.29	10.44	10.83	43.79
		Kundgol	15.04	10.32	10.25	40.01
		Navalgund	14.02	11.24	9.18	35.64
		Mean	**15.67**	**10.84**	**9.87**	**39.02**
	Gadag	Gadag	17.09	11.48	10.65	43.19
		Mean	**17.09**	**11.48**	**10.65**	**43.19**
	Haveri	Haveri	16.92	9.91	8.29	35.28
		Ranebennur	21.55	11.93	6.32	33.64
		Mean	**19.23**	**10.92**	**7.30**	**34.46**
	Koppal	Gangavati	11.98	6.92	0	0
		Koppal	15.14	9.96	5.77	28.50
		Kustagi	11.36	7.38	6.57	32.05
		Mean	**12.83**	**8.09**	**6.17**	**30.50**
	Raichur	Manvi	21.70	13.95	8.47	31.97
		Raichur	18.79	11.16	8.59	36.01
		Mean	**20.24**	**12.55**	**8.53**	**33.99**
Andhra Pradesh	Kurnool	Adoni	20.20	15.74	10.68	43.99
		Emmiganur	13.23	10.42	10.00	40.11
		Mantralaya	19.60	11.85	11.20	45.09
		Nandavaram	14.20	12.73	10.32	46.40
		Mean	**16.81**	**12.69**	**10.55**	**43.90**
Maharashtra	Solapur	Pandarapur	19.97	13.77	7.70	35.07
		Mean	**19.97**	**13.77**	**7.70**	**35.07**

Maharashtra

Among three villages of Pandarpur taluk of Solapur district the highest fruit rot incidence of 26.82 per cent with 20.45 PDI was observed in Mangalveda followed by Sangola (18.91%, 11.40 PDI) and also the highest die-back incidence of 8.60 per cent with 36.25 PDI was observed in Mangalveda followed by Sangola (6.80%, 33.90 PDI).

Year 2013-14

The highest fruit rot incidence of 20.33 per cent with 13.31 PDI was observed in Andhra Pradesh followed by Karnataka (18.12%, 11.25 PDI), where as the highest die-back incidence of 11.44 per cent with 41.67 PDI was observed in Andhra Pradesh followed by Karnataka (9.54%, 38.92 PDI) (Table 3).

Karnataka

Data pertaining to survey conducted during 2013-14 are presented in Table 2a and 2b. Among the 57 villages the highest fruit rot incidence of 27.13 per cent with 16.21 PDI was recorded in Dumdur village of Gadag taluk, Gadag district followed by Sirigeri cross (26.73%, 16.79 PDI) village of Siraguppa taluk Bellary district, where as the lowest fruit rot incidence of 10.20 per cent and 8.40 PDI was observed in Salahalli village of Soundatti taluk of Belgaum district. The highest die-back incidence of 12.94 per cent with 44.32 PDI was observed in Sirigeri cross of Siraguppa taluk Bellary district. The lowest die-back incidence 1.00 per cent with 10.24 PDI was observed in Kanakapur village of Gangavati taluk Koppal district where as die-back disease was absent in Basapur village of Koppal district. Among the 15 taluks highest fruit rot incidence of 24.10 per cent with 15.21 PDI was observed in Siraguppa taluk of Bellary district followed by Gadag (22.24%, 13.62 PDI). The lowest fruit rot incidence of 11.83 per cent and 7.34 PDI was observed in Gangavati taluk. The lowest die-back incidence of 1.50 per cent with 11.27 PDI was observed in Gangavati taluk of Koppal district. Among the seven districts of Karnataka the highest fruit rot incidence of 22.65 per cent with 14.51 PDI was observed in Bellary followed by Gadag (22.24%, 13.62 PDI), where as the lowest fruit rot incidence of 14.02 per cent with 9.13 PDI was observed in Koppal. The highest die-back incidence of 11.70 per cent with 44.64 PDI was observed in

Table 2a: Detailed survey on chilli fruit rot and dieback disease during 2013-14 in South India

State	District	Taluka	Village/place	Area (ha)	Stage of crop	Geno type	Inter Crop / Sole Crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Karnataka	Bellary	Bellary	Koluru	4.0	Flowering and Fruiting	Byadgi Kaddi	Sole Crop	I	Red	22.14	14.94	6.73	35.24	+	-	-	-	+
			Raravi	6.0	Flowering and Fruiting	Guntur	Sole Crop	I	Black	20.00	12.21	8.42	39.82	+	-	+	+	-
			Sindigeri	4.0	Flowering and Fruiting	Byadgi Dabbi	Sole Crop	R	Red	21.47	14.32	8.21	40.96	+	+	-	-	+
									Mean	**21.20**	**13.82**	**7.79**	**38.67**					
		Siraguppa	Kerur	3.0	Flowering and Fruiting	Byadgi Dabbi	Sole Crop	R	Red	21.37	13.76	8.94	47.41	+	-	-	+	+
			Siraguppa	4.0	Fruiting	Guntur	Sole Crop	I	Red	24.00	14.91	10.46	38.32	-	+	-	+	-
			Shanvaspur	4.0	Flowering and Fruiting	Byadgi Dabbi	Sole Crop	I	Red	24.32	15.40	10.00	50.64	+	+	-	-	-
			Sirigeri cross	2.0	Flowering and Fruiting	Byadgi Dabbi	Sole Crop	I	Red	26.73	16.79	12.94	44.32	+	-	-	+	-
									Mean	**24.10**	**15.21**	**10.58**	**45.17**					
	Range									**20-27**	**12-17**	**6-11**	**35-48**					
	Mean									**22.65**	**14.51**	**9.18**	**41.92**					
	Belgavi	Soundatti	Inamhongal	2.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	18.19	11.20	10.19	42.70	-	+	-	-	-
			Panchagav	2.0	Fruiting and flowering	Byadgi Dabbi	Onion, coriander	R	Black	15.30	10.00	9.20	41.31	+	-	-	+	-
			Salahalli	1.5	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	10.20	8.40	12.12	40.91	+	-	-	+	-
			Soundatti	2.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	14.62	9.25	9.40	35.81	+	-	-	-	+
									Mean	**14.58**	**9.71**	**10.23**	**40.18**					
	Range									**10-19**	**8-11**	**9-12**	**35-42**					
	Mean									**14.58**	**9.71**	**10.23**	**40.18**					
	Dharwad	Dharwad	Amminabhavi	1.5	Fruiting	Byadgi Dabbi	Onion	R	Black	20.18	11.86	10.32	40.28	+	-	-	-	-
			Byahatti	2.0	Fruiting	Byadgi Dabbi	Onion	R	Black	16.39	9.86	10.86	40.12	-	+	-	-	+
			Govankoppa	1.5	Fruiting	Byadgi Kaddi	Sole Crop	R	Black	14.12	9.64	9.26	38.19	+	-	+	-	-
			Kumbapur farm	2.0	Fruiting	Byadgi Dabbi	Sole Crop	I	Red	16.24	11.83	9.14	36.85	+	-	-	+	+
			Somapur	1.0	Fruiting	Byadgi Dabbi	Onion	R	Black	20.74	10.91	9.20	38.94	+	-	-	-	+
			Shivalli	1.5	Fruiting	Byadgi Dabbi	Onion	R	Black	22.92	11.43	8.49	34.17	+	-	-	+	-
			UAS Campus	2.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	26.84	14.35	9.12	63.84	+	+	+	+	+
									Mean	**19.63**	**11.41**	**9.48**	**38.34**					

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R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Genotype	Inter crop / Sole crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Karnataka		Hubli	Hubli	2.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	18.27	12.14	12.83	48.29	+	-	-	-	+
			Hebsur	2.5	Fruiting	Byadgi Dabbi	Onion	R	Black	13.84	10.13	9.13	38.92	+	-	-	+	-
			Shirguppi	2.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	18.27	12.10	10.52	44.16	+	+	-	-	-
									Mean	**16.79**	**11.46**	**10.83**	**43.79**					
		Kundgol	Gudigeri	2.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	16.42	11.12	10.18	41.70	+	-	-	+	-
			Kundagol	5.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	20.83	12.76	9.27	40.31	+	-	-	-	+
			Sharewad	4.0	Fruiting	Byadgi Dabbi	Sole Crop	R	Black	17.32	11.20	12.13	42.91	+	-	-	+	-
			Savnsi	2.0	Fruiting	Byadgi Kaddi	Sole Crop	R	Black	14.91	10.28	9.43	36.81	+	-	-	-	-
			Mean							**17.37**	**11.34**	**10.25**	**40.43**					
		Navalgund	Alagavadi	3.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	16.27	12.37	11.25	39.19	+	-	-	+	-
			Byalal	2.5	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	13.27	10.21	9.64	37.12	+	-	-	+	-
			Gummagola	2.0	Fruiting and flowering	Byadgi Dabbi	Onion	R	Black	14.28	11.14	10.82	41.36	+	-	-	-	+
									Mean	**14.61**	**11.24**	**10.57**	**39.22**					
	Range									**13-21**	**9-15**	**8-13**	**36-64**					
	Mean									**17.10**	**11.36**	**10.28**	**40.45**					
	Gadag	Gadag	Binkadakatti	3.0	Fruiting and flowering	Gadag Local	Sole Crop	R	Black	18.91	11.86	11.43	42.16	-	+	-	-	+
			Badrapur	2.0	Fruiting and flowering	Byadgi Dabbi	Cotton , Onion	R	Black	22.17	14.28	12.73	46.21	+	-	-	+	-
			Dumdur	1.5	Fruiting and flowering	Byadgi Dabbi	Cotton, Onion	R	Black	27.13	16.21	10.45	43.27	+	-	-	+	-
			Hulkoti	2.0	Fruiting and flowering	Byadgi Dabbi	Cotton , Onion	R	Black	20.74	12.14	12.18	46.92	+	-	-	-	+
			Mean						**Mean**	**22.24**	**13.62**	**11.70**	**44.64**					
	Range									**18-28**	**11-15**	**10-13**	**42-47**					
	Mean									**22.24**	**13.62**	**11.70**	**44.64**					
	Haveri	Haveri	Byadgi	2.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	I	Black	22.18	13.41	9.40	42.24	+	+	-	-	+
			Devihosur	3.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	R	Black	18.24	10.84	10.04	44.60	+	-	+	-	+
			Dummihal	1.5	Fruiting and flowering	Byadgi Kaddi	Sole Crop	R	Black	19.24	12.01	9.82	42.91	+	-	-	+	-
			Mean						**Mean**	**19.88**	**12.08**	**9.75**	**43.25**					
		Ranebennur	Guttal	2.0	Fruiting and flowering	Dyavanur Dabbi	Sole Crop	R	Black	20.61	10.14	9.42	41.50	+	+	-	-	+
			Kadaramandalgi	2.5	Fruiting and flowering	Byadgi Dabbi	Sole Crop	I	Black	22.40	11.84	10.13	46.31	+	-	-	-	-

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R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/ place	Area (ha)	Stage of crop	Genotype	Inter Crop / Sole Crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Karnataka			Lingadahalli	2.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	R	Black	21.08	10.97	8.21	31.42	+	-	+	-	-
			Ranebennur	1.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	R	Black	19.80	11.94	9.31	44.29	+	-	-	+	-
									Mean	**20.97**	**11.22**	**9.27**	**40.88**					
	Range									**18-23**	**10-14**	**9-11**	**42-47**					
	Mean									**20.43**	**11.65**	**9.51**	**42.06**					
		Gangavati	Budugumpa	2.0	Fruiting and flowering	Local	Sole Crop	I	Red	12.24	8.28	2.00	12.30	+	+	-	-	-
			Kanakapur	1.5	Fruiting and flowering	Byadgi Kaddi	Sole Crop	I	Red	11.42	6.41	1.00	10.24	-	+	-	+	-
			Mean						**Mean**	**11.83**	**7.34**	**1.5**	**11.27**					
		Koppal	Basapur	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	12.01	8.13	0.00	0.00	+	-	-	-	-
			Beluru	1.5	Fruiting and flowering	Gadag local	Sole Crop	I	Red	21.40	12.18	10.18	45.60	+	+	-	-	+
			Bommanal	2.0	Fruiting and flowering	Byadgi Kaddi	Sole Crop	I	Red	14.80	11.42	7.21	31.20	+	-	-	+	-
			Dambarahalli	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	18.42	12.82	9.36	40.24	+	-	**-**	**-**	**-**
			Talakall	1.5	Fruiting and flowering	Byadgi Dabbi	Sole Crop	R	Black	15.86	10.90	4.82	11.40	+	+	-	-	+
			Mean						**Mean**	**16.50**	**11.09**	**6.31**	**25.68**					
		Kustagi	Chikkatebinahal	2.0	Fruiting and flowering	Local	Sole Crop	I	Red	14.60	9.84	10.20	43.82	+	-	-	+	-
			Kustagi	2.5	Fruiting and flowering	Byadgi Kaddi	Sole Crop	I	Red	12.84	8.08	5.80	28.62	+	-	-	-	+
			Mean						**Mean**	**13.72**	**8.96**	**8.00**	**36.22**					
	Range									**11-22**	**8-13**	**0-11**	**0-46**					
	Mean									**14.02**	**9.13**	**5.27**	**24.39**					
	Raichur	Manvi	Herekottekal	4.0	Fruiting and flowering	Guntur	Sole Crop	I	Black	15.94	9.42	7.73	36.24					
			Kapgal	3.5	Fruiting and flowering	Byadgi kaddi	Sole Crop	I	Black	11.34	9.66	10.25	40.43	+	-	-	+	+
			Neer manvi	3.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	11.22	6.32	9.27	40.88	+	+	-	-	+
			Mean						**Mean**	**12.83**	**8.47**	**9.08**	**39.18**					
		Raichur	Belgammana doddi	4.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	I	Black	22.87	11.07	9.79	42.67	+	-	-	-	+
			Mandapura	4.0	Fruiting and flowering	Byadgi Dabbi	Sole Crop	I	Black	15.28	8.54	10.82	44.91	+	-	+	-	+

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R- rainfed, I – Irrigated, + Present - Absent

State	District	Taluka	Village/place	Area (ha)	Stage of crop	Geno type	Inter Crop / Sole Crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Karnataka			Nelhal	5	Fruiting and flowering	Guntur	Sole Crop	I	Black	23.40	12.10	9.31	40.29	+	+	-	+	+
			Panchamukhi	4	Fruiting and flowering	Byadgi Kaddi	Sole Crop	R	Black	14.02	11.24	10.57	39.22	+	-	-	+	+
			Raichur	5	Fruiting and flowering	Byadgi Dabbi	Sole Crop	I	Black	19.73	12.01	9.84	39.41	+	+	-	+	-
			Raladoddi	4	Fruiting and flowering	Guntur	Sole Crop	I	Red	21.55	11.93	9.27	40.88	+	-	-	+	+
			Mean						**Mean**	**18.79**	**11.16**	**9.96**	**40.94**					
	Range									**11-24**	**6-13**	**7-11**	**36-45**					
	Mean									**15.81**	**9.82**	**9.52**	**40.06**					
Andra Pradesh	Guntur	Sattanpalli	Kattavaripalem	5.0	Fruiting and flowering	LCA-960	Sole Crop	I	Black	19.47	10.26	9.10	38.92	-	+	-	+	-
			Medikonduru	4.0	Fruiting and flowering	LCA-960	Sole Crop	I	Black	24.29	12.40	10.25	41.34	+	-	-	**-**	**-**
			Paaldagu	3.0	Fruiting and flowering	Theja	Sole Crop	I	Black	18.48	11.74	10.00	40.00	+	+	-	**-**	**+**
			Pedakurpadu	2.5	Fruiting and flowering	G-888	Sole Crop	I	Black	20.50	12.45	8.26	36.20	+	-	-	**+**	**+**
			Perecherla	4.0	Fruiting and flowering	Eldom-5	Sole Crop	I	Black	27.00	15.13	13.50	34.25	+	-	+	**-**	**-**
			Mean						**Mean**	**21.94**	**12.39**	**10.22**	**40.14**					
		Krosuru	Ananthapuram	4.0	Fruiting and flowering	Theja	Sole Crop	I	Black	19.60	12.36	12.80	39.50	-	+	-	**+**	**+**
			Bayyavaram	5.0	Fruiting and flowering	G-888	Sole Crop	I	Black	20.00	12.00	10.80	38.48	-	+	-	**-**	**+**
			Peasapada	4.0	Fruiting and flowering	Theja	Sole Crop	I	Black	25.61	16.34	14.80	40.45	+	-	-	**-**	**-**
			Mean						**Mean**	**21.73**	**13.56**	**12.8**	**39.47**					
			Range							**18-27**	**10-17**	**8-15**	**34-42**					
			Mean							**21.84**	**12.98**	**11.51**	**39.80**					
	Kurnool	Emmiganur	Bodikanda	2.0	Fruiting and flowering	Theja	Sole Crop	I	Black	14.71	11.20	10.82	41.43	+	-	-	**+**	**-**
			Emmiganur	2.5	Fruiting and flowering	Guntur	Sole Crop	I	Red	18.62	14.17	10.41	46.81	+	-	-	+	-
			Hanumapuram	3.0	Fruiting and flowering	Guntur	Sole Crop	I	Black	13.60	10.32	-	-	+	+	-	-	+
			Kotekallu	3.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	15.67	12.48	10.43	44.81	-	+	-	-	+
									Mean	**15.65**	**12.04**	**10.55**	**44.35**					

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, **+** Present - Absent

State	District	Taluka	Village / place	Area (ha)	Stage of crop	Geno type	Inter Crop / Sole Crop	R/I	Soil type	Fruit rot		Die back		Pathogens noticed				
										Incidence (%)	PDI	Incidence (%)	PDI	Cc	Cg	Ca	F	A
Andra Pradesh		Mantralaya	Dharmapuram	2.5	Fruiting and flowering	Guntur	Sole Crop	I	Red	22.76	14.92	11.50	47.14	+	-	-	+	-
			Halaharavi	2.0	Fruiting and flowering	Theja	Sole Crop	R	Black	20.70	12.81	10.72	45.63	+	-	-	+	-
			Kalludevarakunta	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	22.49	13.27	14.81	40.12	+	-	-	-	-
			Mantralaya	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	21.81	12.25	4.86	10.52	-	+	-	-	+
			Mean						**Mean**	**21.94**	**13.31**	**10.47**	**35.85**					
		Nandavaram	Mugathi	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Red	16.40	13.10	12.19	48.90	+	-	+	+	-
		Adoni	Alur	2.0	Fruiting and flowering	Byadgi Kaddi	Sole Crop	I	Black	22.92	17.40	10.41	46.18	+	-	-	-	-
			Madire	3.0	Fruiting and flowering	Brahma theja	Sole Crop	I	Black	23.18	17.82	14.26	40.10	-	+	-	+	-
			Marakattu	2.0	Fruiting and flowering	Guntur	Sole Crop	I	Black	22.70	16.31	*	*	+	-	-	+	-
			Mean						**Mean**	**21.30**	**16.16**	**12.29**	**45.06**					
		Range								**13-24**	**10-18**	**10-15**	**10-49**					
		Mean								**18.82**	**13.65**	**11.38**	**43.54**					

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,* A – *Alternaria* sp., F – *Fusarium* spp.
R- rainfed, I – Irrigated, + Present - Absent * not found

Table 2b: Mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2013-14 in different taluks of Karnataka, Andhra Pradesh.

State	District	Taluka	Fruit rot		Die back	
			Incidence (%)	PDI	Incidence (%)	PDI
Karnataka	Bellary	Bellary	21.20	13.82	7.79	38.67
		Siraguppa	24.10	15.21	10.58	45.17
		Mean	**22.65**	**14.51**	**9.18**	**41.92**
	Belgavi	Soundatti	14.58	9.71	10.23	40.18
			14.58	**9.71**	**10.23**	**40.18**
	Dharwad	Dharwad	19.63	11.41	9.48	38.34
		Hubli	16.79	11.46	10.83	43.79
		Kundgol	17.37	11.34	10.25	40.43
		Navalgund	14.61	11.24	10.57	39.22
		Mean	**17.10**	**11.36**	**10.28**	**40.45**
	Gadag	Gadag	22.24	13.62	11.70	44.64
		Mean	**22.24**	**13.62**	**11.70**	**44.64**
	Haveri	Haveri	19.88	12.08	9.75	43.25
		Ranebennur	20.97	11.22	9.27	40.88
		Mean	**20.43**	**11.65**	**9.51**	**42.06**
	Koppal	Gangavati	11.83	7.34	1.5	11.27
		Koppal	16.50	11.09	6.31	25.68
		Kustagi	13.72	8.96	8.00	36.22
		Mean	**14.02**	**9.13**	**5.27**	**24.39**
	Raichur	Manvi	12.83	8.47	9.08	39.18
		Raichur	18.79	11.16	9.96	40.94
		Mean	**15.81**	**9.82**	**9.52**	**40.06**
Andhra Pradesh	Guntur	Sattanpalli	21.94	12.39	10.22	40.14
		Krosuru	21.73	13.56	12.80	39.47
		Mean	**21.84**	**12.98**	**11.51**	**39.80**
	Kurnool	Adoni	21.30	16.16	12.29	45.06
		Emmiganur	15.65	12.04	10.55	44.35
		Mantralaya	21.94	13.31	10.47	35.85
		Nandavaram	16.40	13.10	12.19	48.90
		Mean	**18.82**	**13.65**	**11.38**	**43.54**

Gadag, where as the lowest die-back incidence of 5.27 per cent with 24.39 PDI was observed in Koppal.

Andhra Pradesh

Among the 20 villages the highest fruit rot incidence of 27.00 per cent with 15.13 PDI was recorded in Perecherla village of Sattanapalli taluk followed by Peasapadu (25.61%, 16.34 PDI) village of Krosuru taluk. Among six taluks the highest fruit rot incidence of 21.94 per cent with 13.31 PDI was observed in Mantralaya where as the highest die-back incidence of 12.80 per cent with 39.47 PDI was recorded in Krosuru taluk of Guntur district. The lowest fruit rot incidence of 15.65 per cent with 12.04 PDI was observed in Emmiganur taluk where as lowest die-back incidence of 10.22 per cent with 40.14 PDI was observed in Sattanapalli taluk of Guntur district. Among the two districts the highest fruit rot incidence of 21.84 per cent with 12.98 PDI was observed in Guntur, where as the highest die-back incidence of 11.51 per cent with 39.80 PDI was recorded in Guntur (Table 2a, 2b).

4.1.2 Distribution of fruit rot and die-back incidence and severity during 2012-13 and 2013-14

4.1.2.1 Rainfed and irrigated conditions

During 2012-13 survey (Table 4a) totally 355 fields were visited. Among them 145 fields were rainfed which recorded 16.96 per cent of fruit rot incidence with 11.10 PDI where as die-back incidence was 9.20 per cent with 36.16 PDI. In 210 irrigated fields recorded 18.69 per cent of fruit rot incidence with 12.25 PDI, die-back incidence of 7.54 per cent with 35.44 PDI was recorded. In 2013-14 totally 385 fields were visited, among them 165 fields were rainfed which recorded 18.37 per cent of fruit rot incidence with 11.58 PDI where as 10.01 per cent of die-back incidence with 40.03 PDI was observed. In 220 irrigated fields 19.23 per cent of fruit rot incidence with 12.22 PDI, where as 9.03 per cent of die-back incidence with 34.11 PDI was observed.

4.1.2.2 Red and black soil

During 2012-13 survey (Table 4b) totally 355 fields were visited. Among them 130 fields were under red soil which recorded 17.97 per cent of fruit rot incidence with

Table 3: District wise mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2012-13 and 2013-14 of Karnataka, Andhra Pradesh and Maharashtra

State	District	Fruit rot						Die-back					
		Incidence (%)			PDI			Incidence (%)			PDI		
		2012-13	2013-14	Mean	2012-13	2013-14	Mean	2012-13	2013-14	Mean	2012-13	2013-14	Mean
Karnataka	Bagalkot	20.13	-	20.13	13.59	-	13.59	10.34	-	10.34	39.49	-	39.49
	Belgavi	-	14.58	14.58	-	9.71	9.71	-	9.18	9.18	-	40.18	40.18
	Bellary	21.71	22.65	22.18	14.99	14.51	14.75	9.13	10.23	9.68	40.87	41.92	41.40
	Dharwad	15.67	17.10	16.39	10.84	10.28	10.56	9.87	11.36	10.62	39.02	40.45	39.74
	Gadag	17.09	22.24	19.67	11.48	13.62	12.55	10.65	11.70	11.18	43.19	44.64	43.92
	Haveri	19.23	20.43	19.83	10.92	11.65	11.29	7.30	9.51	8.41	34.46	42.06	38.26
	Koppal	12.83	14.02	13.43	8.09	9.13	8.61	4.29	5.27	4.78	30.50	24.39	27.45
	Raichur	20.24	15.81	18.03	12.55	9.82	11.19	8.53	9.52	9.03	33.99	40.06	37.03
Mean		**18.13**	**18.12**	**18.12**	**11.78**	**11.25**	**11.51**	**8.59**	**9.54**	**9.06**	**37.36**	**38.92**	**38.14**
Andhra Pradesh	Guntur	-	21.84	21.84	-	12.98	12.98	-	11.51	11.51	-	39.80	39.80
	Kurnool	16.81	18.82	17.81	12.69	13.65	13.17	10.55	11.38	10.96	43.90	43.54	43.72
	Mean	**16.81**	**20.33**	**19.82**	**12.69**	**13.31**	**13.07**	**10.55**	**11.44**	**11.23**	**43.90**	**41.67**	42.79
Maharashtra	Solapur	19.97	-	19.97	13.77	-	13.77	7.70	-	7.70	35.07	-	35.07
	Mean	**19.97**	**-**	**19.97**	**13.77**	**-**	**13.77**	**7.70**	**-**	**7.70**	**35.07**	**-**	35.07

- Not visited

11.88 PDI where as die-back incidence was 8.76 per cent with 37.30 PDI. Remaining 225 fields were under black soil which recorded 18.10 per cent fruit rot incidence with 11.90 PDI. Die-back incidence of 9.22 per cent with 37.85 PDI was observed. In 2013-14 totally 385 fields were visited among them 150 fields were under red soil which recorded 18.10 per cent of fruit rot incidence with 11.90 PDI, where as 9.22 per cent of die-back incidence with 37.85 PDI was observed. Remaining 235 fields were under black soil recorded 19.02 per cent fruit rot incidence with 11.86 PDI, where as 10.26 per cent of die-back incidence with 40.69 PDI was observed.

4.1.2.3 Sole and inter crop

During 2012-13 survey (Table 4c) totally 355 fields were visited. Among them 252 fields were sole crop which recorded 18.05 per cent of fruit rot incidence with 11.81 PDI where as 8.55 per cent of die-back incidence with 35.80 PDI was observed. In 103 inter crop fields recorded 17.30 per cent fruit rot incidence with 11.44 PDI, die-back incidence 9.81 per cent with 38.56 PDI. In 2013-14 totally 385 fields were visited among them 284 fields were sole crop which recorded 19.12 per cent of fruit rot incidence with 12.09 PDI where as 9.54 per cent of die-back incidence with 38.91 PDI was observed. Remaining 101 inter crop fields recorded 17.75 per cent fruit rot incidence with 11.29 PDI, where as 10.40 per cent die-back incidence with 40.48 PDI was observed.

4.1.2.4 In different chilli genotypes

The prevalence of fruit rot and die-back disease in different genotypes was also recorded during the survey (Table 5). The high fruit rot incidence (21.88 %) was recorded in LCA -960 with 11.33 PDI followed by Byadgi Dabbi (19.51 per cent, 11.80 PDI), where as less fruit rot incidence (10.72 %) was observed in C-341 with 9.10 PDI followed by Byadgi Kaddi genotype (15.87 %, 11.09 PDI). The high die-back incidence (10.84 %) was recorded in Theja with 42.91 PDI followed by Gadag local (10.05%, 42.87 PDI), where as less die-back incidence (7.81 %) was observed in Byadgi Kaddi with 29.20 PDI.

Table 4a: Mean fruit rot and die-back incidence and severity under rainfed and irrigated condition in the survey during 2012-13 and 2013-14

Year	Rain fed					Irrigated				
	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI
2012-13	145	16.96	11.10	9.20	36.16	210	18.69	12.25	7.54	35.44
2013-14	165	18.37	11.58	10.01	40.03	220	19.23	12.22	9.03	34.11
Mean	**155**	**17.66**	**11.34**	**9.60**	**38.09**	**215**	**18.96**	**12.23**	**8.28**	**34.77**

Table 4b: Mean fruit rot and die-back incidence and severity in red soil and black soil during the survey during 2012-13 and 2013-14

Year	Red soil					Black soil				
	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI
2012-13	130	17.97	11.78	8.76	37.30	225	18.10	11.90	9.22	37.85
2013-14	150	18.10	11.90	9.22	37.85	235	19.02	11.86	10.26	40.69
Mean	**140**	**18.03**	**11.84**	**8.99**	**37.57**	**230**	**18.56**	**11.88**	**9.74**	**39.27**

Table 4c: Mean fruit rot and die-back incidence and severity in sole crop and inter cropping system during the survey during 2012-13 and 2013-14

Year	Sole crop					Inter crop				
	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI	Total fields	Fruit rot incidence (%)	Fruit rot PDI	Die-back incidence (%)	Die-back PDI
2012-13	252	18.05	11.81	8.55	35.80	103	17.30	11.44	9.81	38.56
2013-14	284	19.12	12.09	9.54	38.91	101	17.75	11.29	10.40	40.48
Mean	**256**	**18.58**	**11.95**	**9.04**	**37.35**	**102**	**17.52**	**11.36**	**10.10**	**39.52**

Table 5 : Prevalence of fruit rot and die-back disease in different chilli genotypes in the survey during 2012-13 and 2013-14

Genotype	Fruit rot						Dieback					
	Incidence (%)			PDI			Incidence (%)			PDI		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
Byadgi Dabbi	18.41	20.61	19.51	11.71	11.89	11.80	9.39	10.01	9.70	36.88	40.67	38.78
Byadgi Kaddi	15.98	15.77	15.88	11.08	11.10	11.09	7.58	8.04	7.81	27.50	30.90	29.20
Dyavanur dabbi	18.55	19.28	18.92	11.02	10.14	10.58	8.11	9.42	8.77	32.51	41.5	37.01
Guntur	18.63	18.79	18.71	12.50	12.17	12.33	8.76	9.14	8.95	32.54	35.36	33.95
Theja	18.54	20.38	19.46	13.45	13.71	13.58	9.45	12.23	10.84	39.62	46.19	42.91
Gadag Local	15.98	20.15	18.06	9.76	12.02	10.89	9.29	10.80	10.05	41.86	43.88	42.87
C-341	10.72	-	10.72	9.1	-	9.1	-	-	-	-	-	-
LCA-960	-	21.88	21.88	-	11.33	11.33	-	9.67	9.67	-	40.13	40.13
G-888	20.25	-	20.25	-	12.22	12.22	-	9.53	9.53	-	42.34	42.34

- Not recorded

a. Interaction with farmer during survey in Emmiganur

b. Severely infected fruit

c. All fruits are infected

d. Infection on pedicel

e. Loss due to fruit lot

f. Dieback

Plate 4 Observations during survey

4.1.2.5 Symptoms observed during investigation

During survey different symptoms of the disease were noticed on seeds, seedlings, twigs, fruit and pedicel (Plate 5).

Seeds: Discolored seeds with presence of mycelial bit were commonly observed in infected fruits. Such seeds were tested by standard blotter paper method which revealed growth of fungi on seeds. Further, it also showed seed and seedling rot. Acervulii of *Colletotrichum* were observed on plumule and radicle (Plate 5 a).

Seedling: When infected seeds were sown in sterile soil, they showed softening, rotting and decaying of tissues at collar region leading to damping off symptoms (Plate 5 b, c).

Twigs: Necrosis of tender twigs from the tip to backwards with brown to grayish white straw colored lesions developed. Further entire branch withered with defoliation. Black dots of fruiting bodies (acervulii) of pathogen were observed (Plate 5 d).

Fruit: Circular to elliptical sunken spots with salmon color and acervuli with conidia observed on *Colletotrichum* infected both red and green colored fruits (Plate 6 a, b, c, d, e). Black color spore masses with sunken lesions on *Alternaria* infected fruit (Plate 7 a and b). Drying of fruit from tip with white mycelial growth accompanied pink color spore mass observed on *Fusarium* infected fruits (Plate 7 c, d, e, f, g).

Pedicel: Brown color discoloration with black acervuli observed (Plate 5 e, f).

4.1.2.6 Predominance of pathogen/s causing fruit rot disease

Predominance of various pathogens observed during survey is furnished in Table 6. The results revealed that *C. capsici* alone was 9.22 per cent and *C. gloeosporioides* 1.42 per cent where as *C. acutatum*, *A. alternata* and *Fusarium* spp. were not found alone. In combination of *C. capsici* and *Fusarium* spp. found 28.37 per cent where as *C. capsici* with *A. alternata* was 11.35 per cent.

4.1.1.7 Frequency of pathogen/s

In order to determine the frequency of fungal pathogen/s associated with chilli samples showing typical fruit rot and dieback symptoms were kept in a moist chamber

Table 6: Predominance of pathogen/s observed in the survey during 2012-13 and 2013-14

Pathogens	Per cent Predominance of pathogen/s		
	2012	2013	Mean
Cc	7.46	10.81	9.22
Cg	1.49	1.35	1.42
Ca	0.00	0.00	0.00
F	0.00	0.00	0.00
A	0.00	0.00	0.00
Cc + Cg	4.48	4.05	4.26
Cc+ Ca	2.99	4.05	3.55
Cc+ F	28.36	28.38	28.37
Cc+ A	10.45	12.16	11.35
Cg+ Ca	0.00	0.00	0.00
Cg+ F	5.97	5.41	5.67
Cg+ A	5.97	5.41	5.67
Ca+ F	0.00	0.00	0.00
Ca+ A	0.00	0.00	0.00
F+ A	0.00	0.00	0.00
Cc+ Cg+ Ca	0.00	0.00	0.00
Cc + F + A	8.96	5.41	7.09
Cc+ Cg+ F	2.99	1.35	2.13
Cc+ Ca +A	2.99	4.05	3.55
Cg +Ca +F	0.00	0.00	0.00
Cc + Cg +A	10.45	10.81	10.64
Cc +Ca +F	2.99	2.70	2.84
Cg +F +A	1.49	1.35	1.42
Ca +F +A	0.00	0.00	0.00
Ca+Cg+A	0.00	0.00	0.00
Cc+Cg +Ca+F	0.00	0.00	0.00
Cc+Cg+Ca+A	0.00	0.00	0.00
Ca+Cg+F+A	0.00	0.00	0.00
Cc+Ca+F+A	0.00	0.00	0.00
Cc+Cg+F+A	1.49	1.35	1.42
Cc+Ca+Cg+F	0.00	0.00	0.00
Cc+Cg+Ca+F+A	1.49	1.35	1.42

Cc – *Colletotrichum capsici* Cg – *C. gloeosorioides,* Ca – *C. acutatum,*
A – *Alternaria* sp., F – *Fusarium* spp.

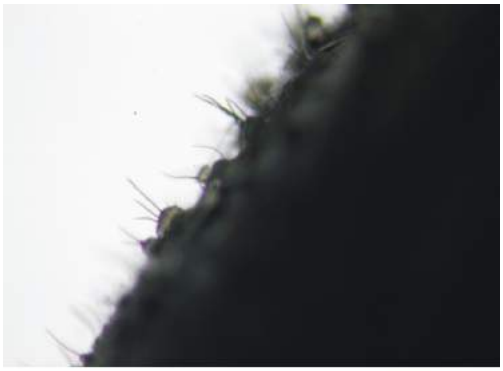
a. Seed rot (50X)

b. Damping-off

c. Seedling rot

d. Dieback

e. On pedicel



f. Acervulii on pedicel (50X)

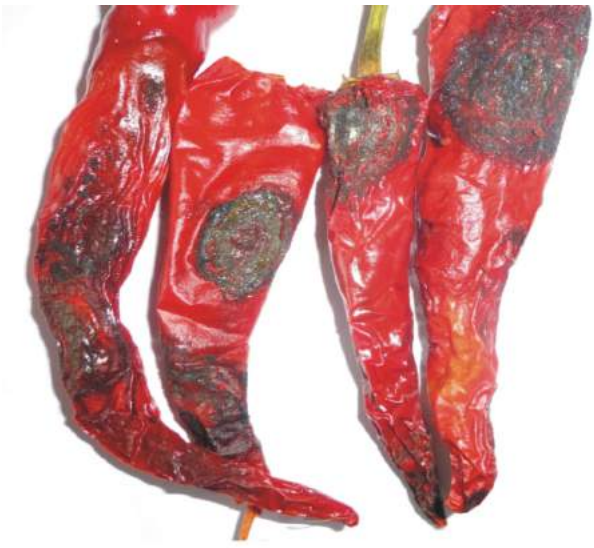
Plate 5 Symptoms caused by chilli fruit rot pathogens

a. Initial specks on green fruits

b. Enlargement of specks

c. Sunken lesions on green fruits

d. Complete rotting of green fruits



e. On red fruits

Plate 6 Symptoms caused by Colletotrichum spp. on chilli fruits

a. Sunken lesions

b. Black colour conidial mass

c. Pink colour conidial masse

c. Pink colour conidial mass

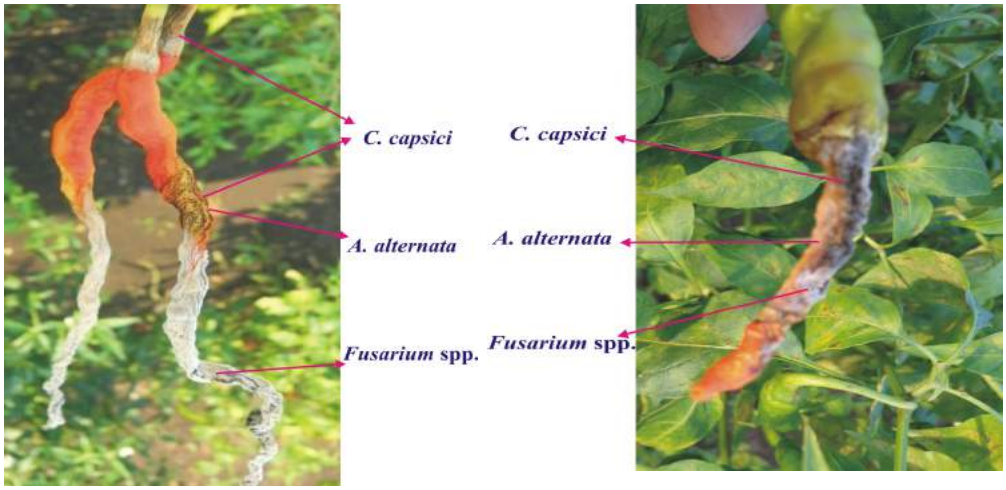
Alternaria infected fruits

Fusarium infected fruits

d. Rotting from tip of fruits

e. Conidial mass (black and pink)

Colletotrichum and Fusarium mixed infecetion



f. Mixed infection

Plate 7 Symptoms caused by A. alternata, Fusarium spp. on chilli fruits and mixed infection

as described in 3.1.2.2. The observations (Table 7) showed that *C. capsici* recorded highest frequency of 38.56 per cent followed by *A. alternata* (18.98 %), where as *C. acutatum* occurred in lowest frequency of 5.04 per cent.

4.1.1.8 Pathogenecity test

C.capsici C. gloeosporioides* and *C. acutatum

All three species of *Colletotrichum* caused a depressed sunken, discolored, circular to irregular spots of 5 to 10 mm sizes after two days of inoculation (DAI) on fruit by pin prick method. The spots became black to grey in color after ten DAI. On these discolored lesions salmon colored spore mass was found fifteen DAI. When the diseased fruit was cut open inner surface of the skin was found to be covered with black somatic masses of pathogen. Seeds were discolored and distinguished from healthy seeds (Plate 8).

A. alternata

Sunken discolored, circular spots of 5 to 10 mm size was observed after two DAI on fruit by pin prick method. Lesions became darker and covered by black moldy growth of fungus was observed at ten DAI. On these lesions heavy sporulation of black color was found on fifteen DAI.

F. oxysporum* and *F. sporotrichioides

Water soaked sunken lesions of 5 to 10 mm size was seen after two DAI on fruit and covered by whitish pink moldy growth of fungus was observed on ten DAI. On these lesions sporulation was found as pink color mass on fifteen DAI.

4.2 Morphological characterization and molecular variability of pathogen/s

4.2.1 Morphological characterization

Pathogens were isolated by plating infected parts on PDA. The isolates were purified by establishing single spore culture as explained in 3.1.2.3. Morphological and cultural characters of the *C. capsici, C. gloeosporioides, C. acutatum, A. alternata* and

Table 7: Frequency of pathogen/s isolated from chilli fruit rot disease

Pathogens	Frequency (%)		Mean frequency (%)
	2012-13	2013-14	
Colletotrichum capsici	37.25	39.87	38.56
C. gloeosporioides	15.68	14.11	14.89
C. accutatum	4.57	5.52	5.04
Fusarium oxysporum	10.17	12.07	11.12
F. sporotrichioides	13.23	9.28	11.25
Alternaria alternata	18.95	19.01	18.98

a. *C. capsici* b. *C. gloeosporioides* c. *C. acutatum* d. *A. alternata* e. *F. sporotrichioides* f. *F. oxysporum* g. Control

Plate 8 Proving pathogenecity of C. capsici, C. gloeosporioides, C. acutatum, A. alternata, F. sporotrichioides and F.oxysporum

F. oxysporum, F*. sporotrichioides* were recorded on PDA and explained in Table 8, 9, 10, 11, 12 and 13 (Plate 9 and 10) .

C. capsici

Among the 25 isolates of *C. capsici,* growth characters of colony varied from white to grey color, flat to raised fluffy and smooth regular to coarse irregular margin on PDA. Acervuli size varied between 130.0 to 162.6 µm with setae length 145.4 to 179.1 µm. Medium to good sporulation (20 – 60 spores/ microscopic field under 100X) with falcate shaped spores of size between 13.5 - 21.2 X 3.2 - 4.8 µm with single oil globule at center was observed under 400X magnification (Table 8, Plate 9 a, Plate 11 a and b).

C. gloeosporioides

Among the 20 isolates of *C. gloeosporioides,* growth characters of colony on PDA varied from white to grey color, where as in three isolates Cg-9, Cg-10 and Cg-12 whitish saffron color was observed with flat to raised fluffy and smooth regular to coarse irregular margin. Sectoring was observed in three isolates (Cg-4, Cg-12 and Cg-20). Medium to excellent sporulation (20 – 80 spores/ microscopic field under 100X) of cylindrical shaped spores with oil globules and size between 12.5 - 16.7 X 1.6 - 2.8 µm was observed under 400X magnification (Table 9, Plate 9 b Plate 11 c and d).

C. acutatum

Among the 12 isolates of *C. acutatum,* growth characters of colony on PDA varied from whitish pink to pink color, where as in one isolate (Ca-1) brownish pink color observed with flat to fluffy and smooth regular to coarse irregular margin. Sectoring was observed in two isolates Ca-8 and Ca-12. Medium to good sporulation (20 – 60 spores/ microscopic field under 100X) of fusiform shaped spores and size between 11.4 - 14.1 X 1.1 - 2.3 µm was observed under 400X magnification (Table 10 Plate 9 c Plate 11c).

A. alternata

Among the 10 isolates of *A. alternata,* growth characters of colony on PDA varied from ash to dark ash color with medium fluffy to raised fluffy and smooth regular to

Table 8 : Morphological and cultural diversity of different isolates of *C. capsici*

Isolates	Source	Colony color	Type of margin	Mycelial growth	Texture	Radial growth after 10 days (mm)	Sporulation	Acrvuli Diameter (µm)	Setae length (µm)	Conidia size (µm) length X width
Cc-1	Koluru	Grey	Regular	Flat	Smooth	46.0	+++	135.5	159.05	16.5 X 4.3
Cc-2	Siraguppa	Whitish Grey	Regular	Flat	Smooth	50.0	+++	152.2	172.30	17.4 X 4.8
Cc-3	Salahalli	Grey	Regular	Fluffy	Smooth	48.0	+++	130.0	149.71	14.5 X 3.9
Cc-4	UAS Dharwad	Grey	Regular	Fluffy	Smooth	57.0	++	159.8	176.24	19.6 X 4.7
Cc-5	Kundgol	Whitish Grey	Regular	Fluffy	Smooth	54.0	+++	146.2	167.41	14.7 X 3.6
Cc-6	Byalal	Whitish Grey	Regular	Flat	Smooth	49.0	+++	137.1	163.50	16.5 X 4.1
Cc-7	Hulkoti	Grey	Regular	Flat	Coarse	59.0	++	162.2	178.12	18.4 X 4.5
Cc-8	Byadgi	Grey	Regular	Fluffy	Smooth	47.0	+++	134.5	157.03	20.1 X 4.8
Cc-9	Basapur	Whitish Grey	Regular	Fluffy	Smooth	58.0	++	150.1	170.26	19. 2 X 3.9
Cc-10	Chikkatembinahal	Whitish Grey	Regular	Fluffy	Smooth	54.0	++	128.2	147.16	13.5 X 3.6
Cc-11	Nelhal	Grey	Irregular	Flat	Coarse	62.0	+++	161.7	177.35	18.09 X 3.7
Cc-12	Panchamukhi	Grey	Regular	Fluffy	Smooth	59.0	++	145.3	165.20	19.7 X 4.8
Cc-13	Belgammanadoddi	Whitish Grey	Regular	Flat	Smooth	60.0	+++	134.0	160.74	13.4 X 3.3
Cc-14	Emmiganur	Whitish Grey	Irregular	Fluffy	Coarse	58.0	+++	138.1	164.93	16.3 X 3.4
Cc-15	Dharmapuram	Grey	Irregular	Flat	Smooth	61.0	++	159.2	176.71	17.3 X 4.1
Cc-16	Mantralya	Whitish Grey	Regular	Fluffy	Smooth	49.0	+++	136.4	158.14	21.2 X 4.6
Cc-17	Mugathi	White	Regular	Fluffy	Coarse	54.0	++	150.1	172.37	16.2 X 3.6
Cc-18	Madire	Whitish Grey	Regular	Flat	Smooth	57.0	+++	130.5	145.40	18.7 X 3.8
Cc-19	Paaladagu	Grey	Irregular	Fluffy	Smooth	61.0	+++	146.5	166.81	16.5 X 4.3
Cc-20	Kattavaripalem	Whitish Grey	Regular	Fluffy	Coarse	59.0	++	135.3	157.31	17.2 X 4.6
Cc-21	Bayyavaram	White	Regular	Fluffy	Smooth	60.0	+++	162.6	179.10	19. 3X 3.7
Cc-22	Mangalveda	Whitish Grey	Irregular	Fluffy	Smooth	56.0	+++	137.1	162.91	13.6 X 3.4
Cc-23	Sangola	Grey	Regular	Flat	Smooth	59.0	+++	156.2	174.80	16.3 X 3.2
Cc-24	Aurangabad	Whitish Grey	Regular	Fluffy	Coarse	62.0	++	142.4	168.62	18.4 X 3.6
Cc-25	Coimbatore	Grey	Irregular	Fluffy	Smooth	58.0	+++	131.8	160.73	17.1 X 3.9

++++: Excellent : 60 – 80 spores / microscopic field (100X) +++ : Good : 40 – 60 spores / microscopic field (100X)
++ : Medium 20 – 40/ spores / microscopic field (100X) + : Slow 10 – 20 / spores / microscopic field (100X)

Table 9 : Morphological and cultural diversity of different isolates of *C .gloeosporioides*

Isolates	Source	Colony color	Type of margin	Mycelial growth	Texture	Radial growth after 10 days mm	Conidia Size (µm) length X width	Sporulation
Cg-1	Kagalgombe	Grey	Regular	Flat	Smooth	67.0	14.5 X 2.3	+++
Cg-2	Shanvaspura	Greyish	Irregular	Fluffy	Coarse	72.0	15.4 X 2.8	++
Cg-3	Inamhongal	Grey	Irregular	Flat	Coarse	70.0	12.5 X 1.9	++++
Cg-4	Byahatti	Greyish	Irregular	Fluffy sectoring	Coarse	78.0	13.6 X 2.7	++
Cg-5	UAS Dharwad	Grey	Regular	Fluffy	Coarse	69.0	12.7 X 2.1	++++
Cg-6	Shirguppi	Grey	Irregular	Fluffy	Coarse	71.0	14.5 X 2.3	+++
Cg-7	Binkadkatti	Greyish	Irregular	Flat	Smooth	74.0	15.4 X 2.6	+++
Cg-8	Guttal	Greyish	Regular	Flat	Smooth	66.0	16.1 X 2.8	+++
Cg-9	Kanakapur	Whitish to Saffron	Regular	Flat	Smooth	80.0	15. 2 X 2.4	+++
Cg-10	Beluru	Whitish to Saffron	Regular	Flat	Coarse	76.0	13.5 X 2.6	++
Cg-11	Mandapur	Grey	Irregular	Flat	Coarse	81.0	16.09 X 1.7	++++
Cg-12	Raladoddi	Whitish to Saffron	Irregular	Flat sectoring	Smooth	78.0	14.7 X 2.1	++
Cg-13	Hanumapuram	Grey	Irregular	fluffy	Coarse	76.0	13.4 X 2.1	+++
Cg-14	Alur	Whitish	Regular	Flat	Coarse	81.0	14.3 X 2.2	+++
Cg-15	Kalludevarakunta	Grey	Irregular	Fluffy	Coarse	80.0	15.3 X 2.4	++
Cg-16	Mangalaveda	Greyish	Irregular	Fluffy	Smooth	74.0	16.2 X 2.6	++
Cg-17	Medikonduru	Greyish	Regular	Fluffy	Smooth	79.0	14.2 X 1.6	+++
Cg-18	Percherela	Greyish	Regular	Fluffy	Coarse	74.0	16.7 X 1.8	++
Cg-19	Ananthapuram	Greyish	Regular	Fluffy	Coarse	80.0	14.5 X 2.3	+++
Cg-20	Coimbatore	Grey	Regular	Flat Sectoring	Coarse	88.0	15.2 X 2.6	+++

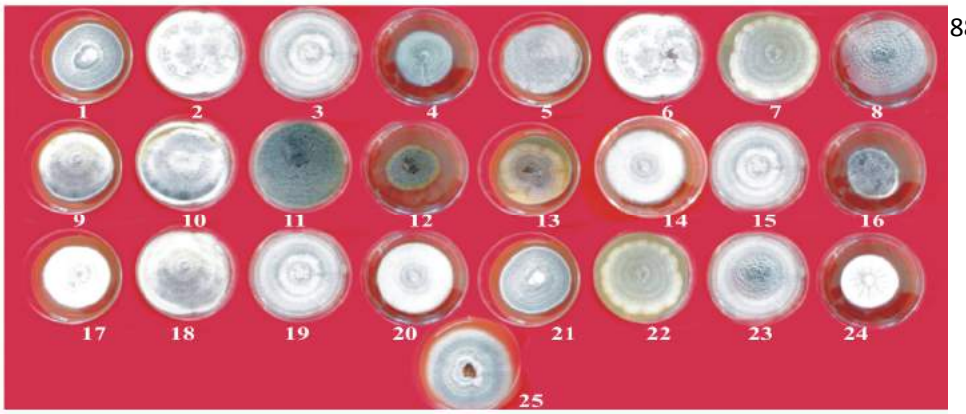
++++: Excellent : 60 – 80 spores / microscopic field (100X)
+++ : Good : 40 – 60 spores / microscopic field (100X)
++ : Medium 20 – 40/ spores / microscopic field (100X)
+ : Slow 10 – 20 / spores / microscopic field (100X)

Table 10: Morphological and cultural diversity of different isolates of *C. acutatum*

Isolates	Source	Colony color	Type of margin	Mycelial growth	Texture	Radial growth after 10 days (mm)	Conidia Size (µm) length X width	Sporulation
Ca-1	Raravi	Brownish pink	Regular	Lightly fluffy	Smooth	86.0	12.3 X 1.3	+++
Ca-2	Govanakoppa	Whitish saffron	Regular	Flat	Smooth	88.0	14.1 X 2.3	+++
Ca-3	UAS Dharwad	Whitish pink	Irregular	Fluffy	Coarse	84.0	13. 2 X 1.4	++
Ca-4	Binkadakatti	Pink	Regular	Fluffy	Smooth	90.0	11.5 X 1.6	++
Ca-5	Byadgi	Whitish pink	Regular	Flat	Smooth	76.0	14.09 X 1.7	++
Ca-6	Devihosur	Pinkish	Regular	Flat	Coarse	88.0	12.7 X 1.1	++
Ca-7	Lingadahalli	Whitish pink	Irregular	Flat	Coarse	86.0	11.4 X 1.1	+++
Ca-8	Budugumpa	Pink	Regular	Flat sectoring	Coarse	90.0	12.5 X 1.3	+++
Ca-9	Belgammanadoddi	Whitish	Irregular	Flat	Smooth	89.0	12.4 X 1.8	++
Ca-10	Mantralaya	Whitish saffron	regular	Fluffy	Coarse	86.0	11.5 X 1.2	+++
Ca-11	Marakattu	Whitish pink	Regular	Fluffy	Coarse	74.0	12.6 X 1.4	+++
Ca-12	Pedakurpadu	Pink	Regular	Flat sectoring	Coarse	84.0	13.2 X 2.0	+++

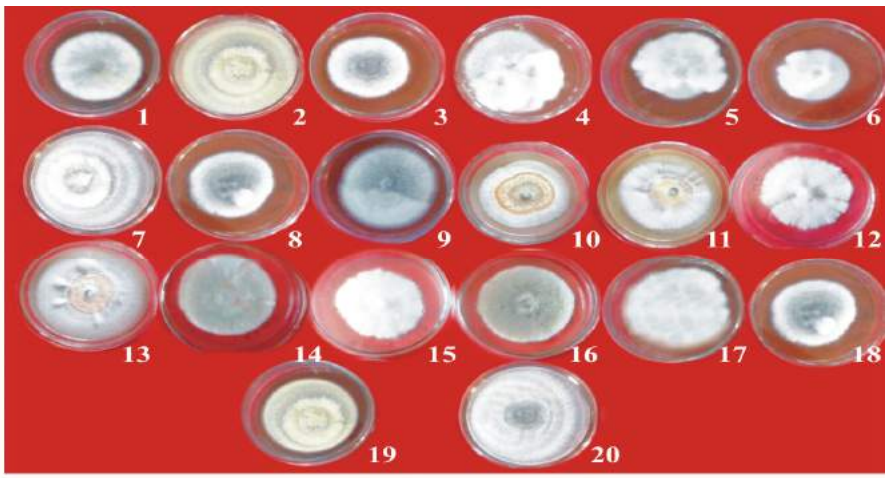
+++ : Good : 40 – 60 spores / microscopic field (100X)
++ : Medium 20 – 40/ spores / microscopic field (100X)
+ : Slow 10 – 20 / spores / microscopic field (100X)

Cc-1	Koluru
Cc-2	Siraguppa
Cc-3	Salahalli
Cc-4	UAS Dharwad
Cc-5	Kundgol
Cc-6	Byalal
Cc-7	Hulkoti
Cc-8	Byadgi
Cc-9	Basapur
Cc-10	Chikkatembinahal
Cc-11	Nelhal
Cc-12	Panchamukhi
Cc-13	Belgammanadoddi
Cc-14	Emmiganur
Cc-15	Dharmapuram
Cc-16	Mantralya
Cc-17	Mugathi
Cc-18	Madire
Cc-19	Paaladagu
Cc-20	Kattavaripalem
Cc-21	Bayyavaram
Cc-22	Mangalveda
Cc-23	Sangola
Cc-24	Aurangabad
Cc-25	Coimbatore



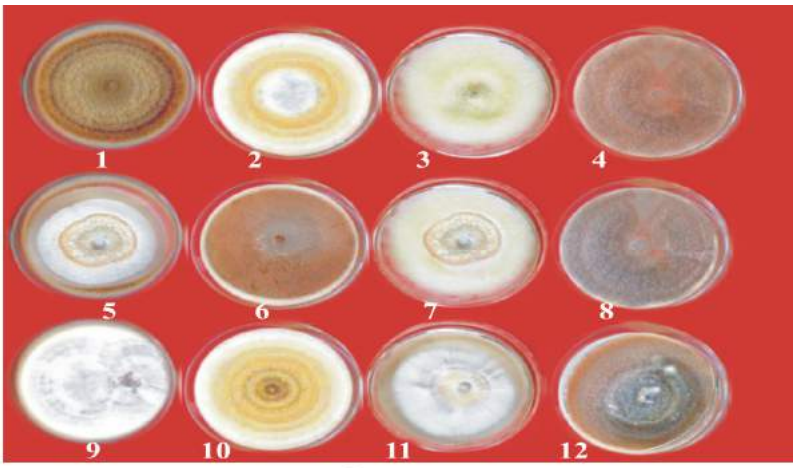
a. *C. capsici*

Cg-1	Kagalgombe
Cg-2	Shanvaspura
Cg-3	Inamhongal
Cg-4	Byahatti
Cg-5	UAS Dharwad
Cg-6	Shirguppi
Cg-7	Binkadkatti
Cg-8	Guttal
Cg-9	Kanakapur
Cg-10	Beluru
Cg-11	Mandapur
Cg-12	Raladoddi
Cg-13	Hanumapuram
Cg-14	Alur
Cg-15	Kalludevarakunta
Cg-16	Mangalaveda
Cg-17	Medikonduru
Cg-18	Percherela
Cg-19	Ananthapuram
Cg-20	Coimbatore



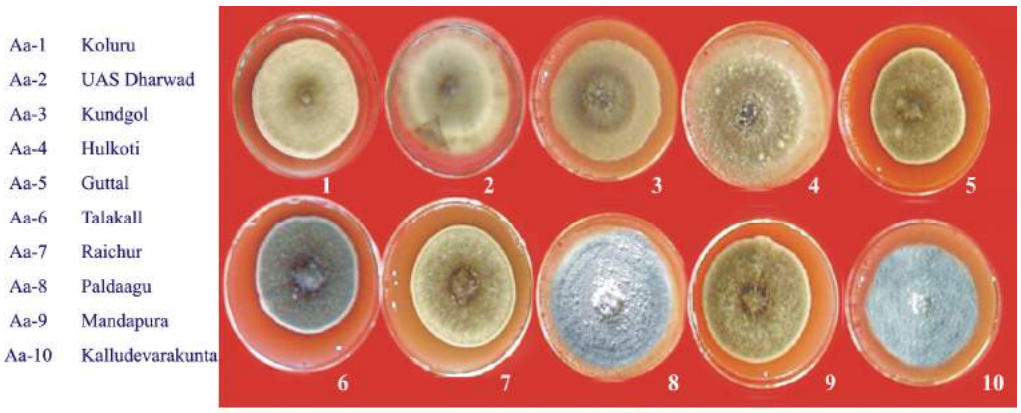
b. *C. gloeosporioides*

Ca-1	Raravi
Ca-2	Govanakoppa
Ca-3	UAS Dharwad
Ca-4	Binkadakatti
Ca-5	Byadgi
Ca-6	Devihosur
Ca-7	Lingadahalli
Ca-8	Budugumpa
Ca-9	Belgammanadoddi
Ca-10	Mantralaya
Ca-11	Marakattu
Ca-12	Pedakurpadu

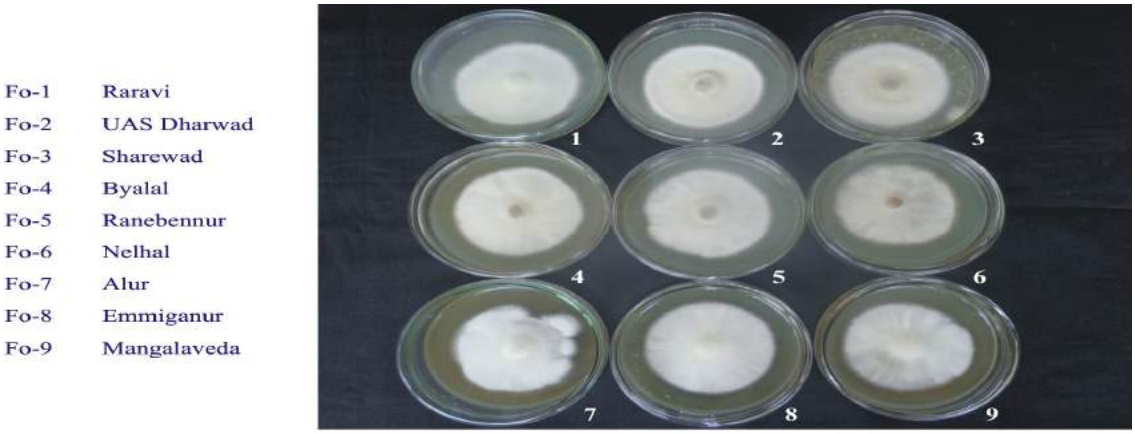


c. *C. acutatum*

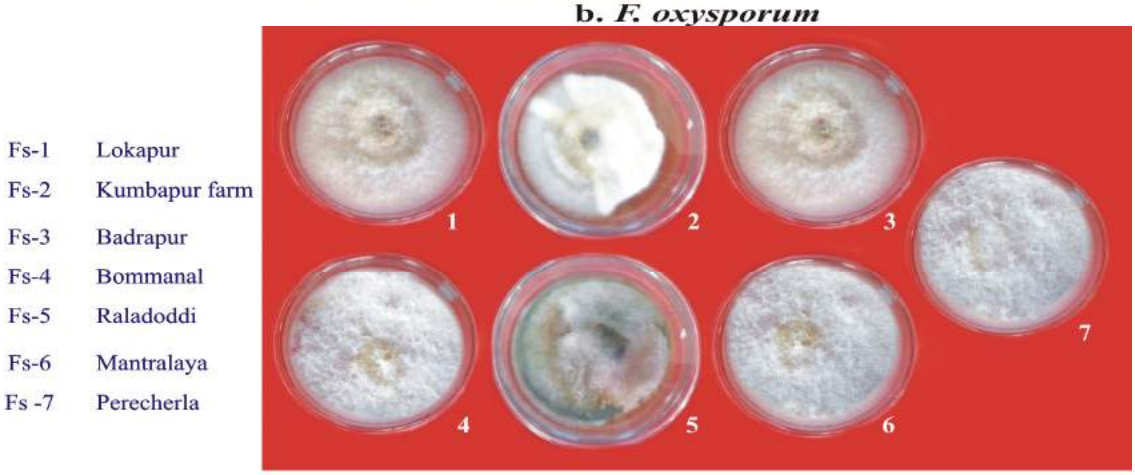
Plate 9 Cultural and morphological diversity of different isolates of C. capsici,C.gloeosporioides and C.acutatum on PDA



a. *A. alternata*



b. *F. oxysporum*



c. *F. sporotrichioides*

Plate 10 Cultural and morphological diversity of different isolates of A. alternata, F.oxysporum and F.Sporotrichioides on PDA

coarse irregular margin. Medium to excellent sporulation (20 – 70 spores/ microscopic field under 100X) of muriform spores with beak with 3 – 5 horizontal septa 1 – 2 vertical septa, with spore size varied between 14.1 - 21.8 X 6.1 - 8.4 µm was observed under under 400X magnification (Table 11 Plate 10 a, Plate 12 a).

F. oxysporum

Among the nine isolates of *F. oxysporum* growth characters of colony on PDA varied from white to whitish purple color with flat, smooth and regular margin except Fo-7 which is irregular. Medium to excellent sporulation (20 – 70 spores/ microscopic field under 100X) of falcate macro conidia with 3 – 5 horizontal septa and size varied between 22.01 - 32.10 X 3.2- 5.2µm was observed under 400X magnification (Table12 Plate 10 b, Plate 12 b).

F. sporotrichioides

Among the seven isolates of *F. sporotrichioides,* growth characters of colony on PDA varied from light brown to white rose color, fluffy, smooth to coarse and regular to irregular margin. Good to excellent sporulation (20 – 70 spores/ microscopic field under 100X) of falcate macro conidia with 3 – 5 horizontal septa and size varied between 32.1 - 42.0 X 3.4-5.2µm, micro conidia were globose of size varied between 6.5-7.0 X 2.5 – 3.0 µm were observed under 400X magnification (Table 13 Plate 10c, Plate 12 c).

4.2.2 Molecular characterization and variability of pathogen/s

4.2.2.1 Isolation of Genomic DNA

Genomic DNA of the fungi were isolated as described in material and methods. The DNA obtained was observed by running on 1.0 per cent agarose gel electrophoresis. The DNA obtained was about 7000-8000 bp of whole genomic DNA of *Colletotrichum* spp. *Fusarium* spp. and *Alternaria* sp. with nanodrop equipment concentration of 91µg/µl of DNA.

Table 11: Morphological and cultural diversity of different isolates of *Alternaria alternata*

Isolates	Source	Colony color	Type of margin	Mycelial growth	Texture	Radial growth after 10 days (mm)	Conidia Size (µm) Length X width	Length of beak (µm)	No. of septa in conidia HS	No. of septa in conidia VS	Sporulation
Aa-1	Koluru	Ash	Regular	Medium fluffy	Smooth	72.0	19.12 X 8.1	3.90	4-5	1-2	+++
Aa-2	UAS Dharwad	Ash	Regular	Medium fluffy	Smooth	75.0	16.9 X 7.2	3.60	4-5	0-1	+++
Aa-3	Kundgol	Ash	Regular	Raised fluffy	Smooth	79.0	21.3 X 8.4	6.82	4-6	1-2	+++
Aa-4	Hulkoti	Ash	Irregular	Raised fluffy	Coarse	84.0	15.1 X 6.5	3.20	3-5	0-1	++
Aa-5	Guttal	Dark ash	Regular	Raised fluffy	Smooth	67.0	21.8 X 8.2	4.21	4-5	0-1	+++
Aa-6	Talakall	Dark ash	Regular	Raised fluffy	Coarse	74.0	18.4 X 7.9	3.61	4-6	1-2	++++
Aa-7	Raichur	Ash	Regular	Medium fluffy	Smooth	75.0	22.3 X 9.2	7.21	4-5	1-2	+++
Aa-8	Paldaagu	Dark ash	Regular	Raised fluffy	Smooth	79.0	14.8 X 6.1	3.10	4-5	0-1	++++
Aa-9	Mandapura	Ash	Irregular	Raised fluffy	Coarse	76.0	20.8 X 7.9	4.11	3-5	0-2	+++
Aa-10	Kalludevarakunta	Dark ash	Regular	Raised fluffy	Smooth	78.0	14.1 X 6.3	3.00	4-5	0-1	++++

++++: Excellent : 50 – 70 spores / microscopic field (100X) +++ : Good : 30 – 50 spores / microscopic field (100X)

++ : Medium 20 – 30/ spores / microscopic field (100X) + : Slow 10 – 20 / spores / microscopic field (100X)

Table 12: Morphological and cultural diversity of different isolates of *Fusarium oxysporum*

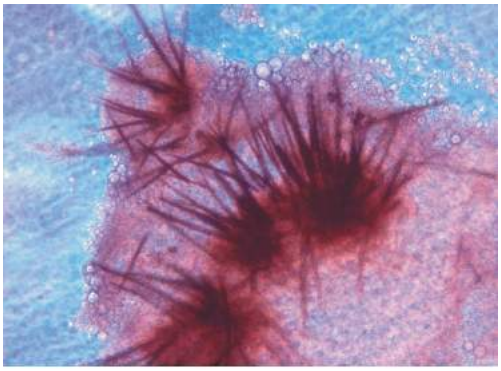
Isolates	Source	Colony color	Type of margin	Radial growth after 10 days (mm)	Macroconidia Size (µm)	Sporulation
Fo-1	Raravi	White	Regular	68.0	22.01 X 3.2	++++
Fo-2	UAS Dharwad	Whitish purple	Regular	70.0	23.12 X 4.1	++++
Fo-3	Sharewad	White	Regular	69.0	26.2 X 5.1	++++
Fo-4	Byalal	White	Regular	73.0	32.10 X 4.0	+++
Fo-5	Ranebennur	Whitish purple	Regular	72.0	24.12 X 3.6	++++
Fo-6	Nelhal	White	Regular	70.0	30.21 X 5.0	++++
Fo-7	Alur	White	Irregular	68.0	27.30 X 3.7	++++
Fo-8	Emmiganur	White	Regular	72.0	29.21 X 4.5	++
Fo-9	Mangalaveda	White	Regular	71.0	26.32 X 5.2	++++

++++: Excellent : 50 – 70 spores / microscopic field (100X)
+++ : Good : 30 – 50 spores / microscopic field (100X)
++ : Medium 20 – 30/ spores / microscopic field (100X)
+ : Slow 10 – 20 / spores / microscopic field (100X)

Table 13: Morphological and cultural diversity of different isolates *Fusarium sporotrichioides*

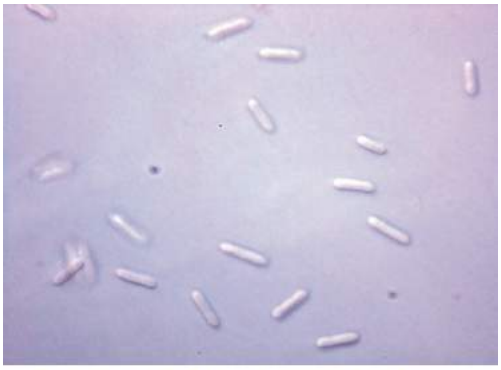
Isolates	Source	Colony color	Type of margin	Texture	Radial growth after 10 days (mm)	Macroconidia Size (µm)	Sporulation
Fs-1	Lokapur	Light brown	Irregular	Coarse	89.0	33.2 X 4.6	++++
Fs-2	Kumbapur farm	White rose	Regular	Smooth	82.0	36.0 X 4.2	+++
Fs-3	Badrapur	Light brown	Irregular	Coarse	90.0	32.1 X 3.4	++++
Fs-4	Bommanal	Light brown	Regular	Smooth	89.0	41.3 X 5.2	+++
Fs-5	Raladoddi	White rose	Irregular	Coarse	88.0	34.6 X 3.6	++++
Fs-6	Mantralaya	White rose	Regular	Smooth	90.0	42.0 X 4.8	++++
Fs -7	Perecherla	Light brown	Irregular	Coarse	90.0	40.2 X 4.3	++++

++++: Excellent : 50 – 70 spores / microscopic field (100X)
+++ : Good : 30 – 50 spores / microscopic field (100X)
++ : Medium 20 – 30/ spores / microscopic field (100X)
+ : Slow 10 – 20 / spores / microscopic field (100X)

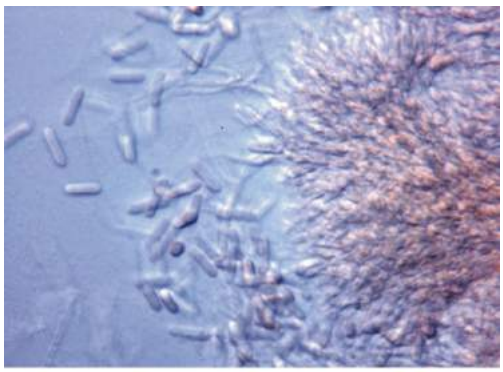


a. Acervulii of *C. capsici*

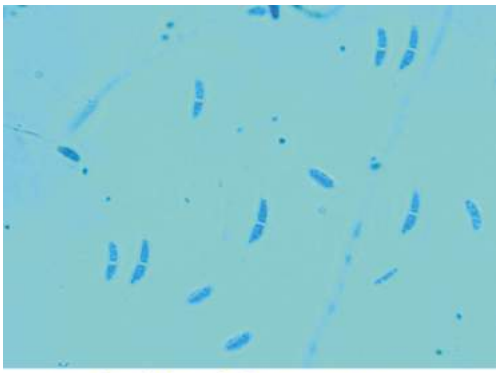
b. Conidia of *C. capsici*



c. Conidia of *C. gloeosporioides*

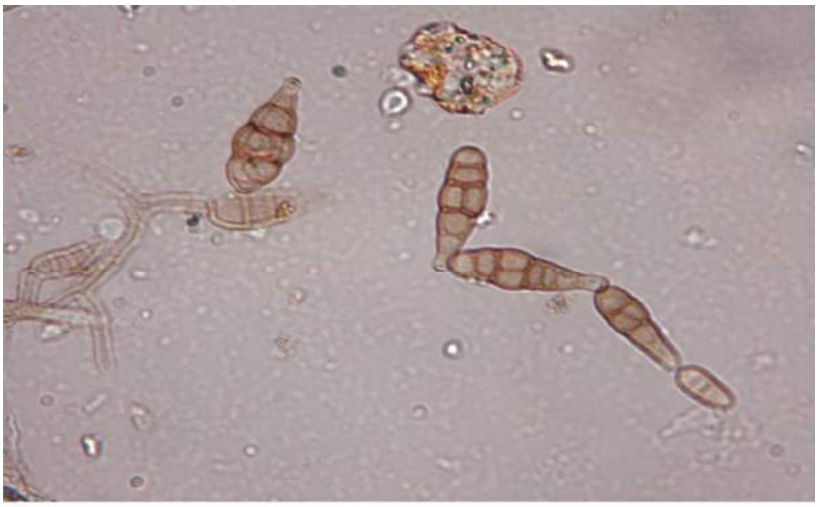


d. Spore boll of *C. gloeosporioides*

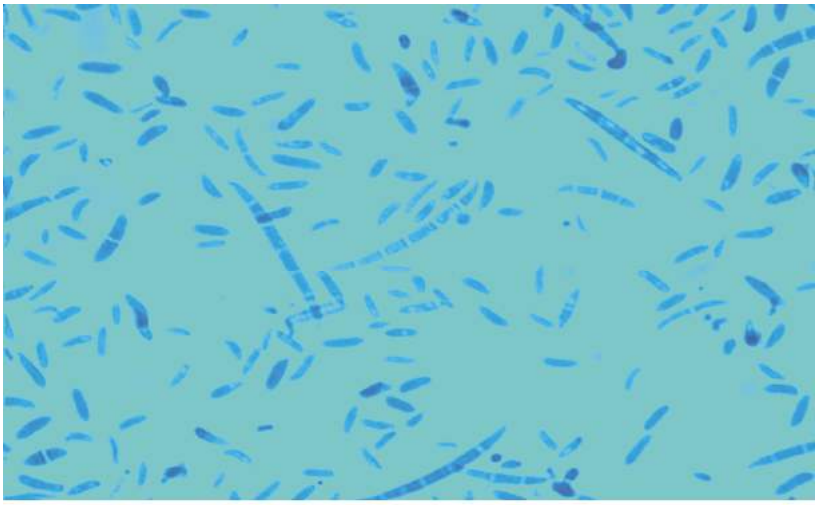


e. Conidia of *C. acutatum*

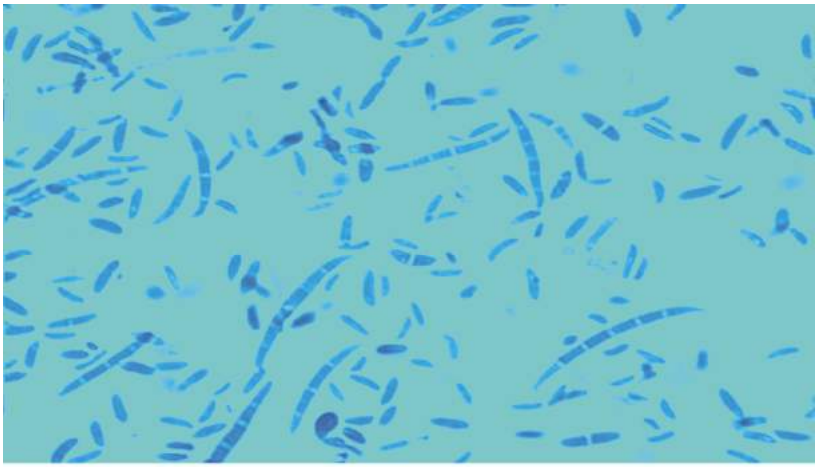
Plate 11: Fruiting body and spore morphology of Colletotrichum spp. (400X)



a. *A. alternata*



b. *F. oxysporum*



c. *F. sporotrichioides*

Plate 12: Spore morphology of A. alternata, F. oxysporum and F.sporotrichioides (400X)

4.2.2.2 Amplification of ITS-1 and ITS-4 region

The full length ITS rDNA region was amplified with ITS-1 (5'-TCCGTAGGTGAACCTGCGG-3') and ITS-4 (5'-TCCTCCGCTTATTGATATGC-3') primers for isolates of *Colletotrichum* spp., *Alternaria* sp., *Fusarium* spp. and DNA amplicon was observed at the region 560 bp with a concentration of around 437 µg/ µl.. The amplified products were checked on 1.4 per cent agarose gel electrophoresis (Plate 13)

4.2.2.3 DNA sequencing

The DNA sequences were obtained for ITS rDNA. The sequences of these isolates are given below.

***Colletotrichum* spp. isolates**

1.
CACCCTTTGTGACATACCTTAACTGTTGCTTCGGCGGGTAGGCGTCCCCTAAAAAGGACGTCTCC
CGGCCCTCTCCCGTCCGCGGGTGGGGCGCCCGCCGGAGGATAACCAAACTCTGATTTAACGAC
GTTTCTTCTGAGTGACACAAGCAAATAATCAAAACTTTTAACAACGGATCTCTTGGTTCTGGCATC
GATGAAGAACGCAGCGAAATGCGATAAGTAATGTGAATTGCAGAATTCAGTGAATCATCGAATCT
TTGAACGCACATTGCGCCCGCCAGCATTCTGGCGGGCATGCGTCATTTCAACCCTCAAGCTCTG
CTTGGTGTTGGGGCTCTACGGTTGACGTAGGCCCTTAAAGGTAGTGGCGGACCCTCTCGGAGCC
TCCTTTGCGTAGTAACATTTCGTTGTTCGAGCGTCATTTCAACCCTCAAGCTCTGCTTGGTGTTGG
GGCTCTACGGTTGACGTAGGCCCTTAAAGGTAGTGGCGGACCCTCTCGGAGCCTCCTTTGCGTA
GTAACATTTCGTCTCGCATTGGGATTCGGAGGGACTCTAGCCGTAAAACCCCCAATTTTACTAAG
GTTGACCTCGGATCAGGTAGGAATACCCGCTGAACTTA AGCATATCATAGCCGG

2.

GTGCACTGAGATGCGCTCTACACCCTTTGTGACATACCTATAACTGTTGCTTCGGCGGGTAGGGT
CTCCGCGACCCTCCCGGCCTCCCGCCTCCGGGCGGGTCGGCGCCCGCCGGAGGATAACCAAA
CTCTGATTTAACGACGTTTCTTCTGAGTGGTACAAGCAAATAATCAAAACTTTTAACAACGGATCT
CTTGGTTCTGGCATCGATGAAGAACGCAGCGAAATGCGATAAGTAATGTGAATTGCAGAATTCAG
TGAATCATCGAATCTTTGAACGCACATTGCGCCCGCCAGCATTCTGGCGGGCATGCCTGTTCGA
GCGTCATTTCAACCCTCAAGCTCTGCTTGGTGTTGGGGCCCTACAGGACCCTCTCGGAGCCTCC
TTTGCGTAGTAACTTTACGTCTCGCAGGTGGGATCCGGAGGGACTCTTGCCGTAAAACCCCCAAT
TTTCCAAAGGTTGACCTCGGATCAGGTAGGAATACCCGCTCTGAGTTTTACCCCCAAACCCTTTG
TGAAAATACCTATAACTGTTGCTTCGCGGGAAGGTCTCCCGAC

3.

GGCACCACCAGGGGTGGANNCTGCGGCTTAATTTGACTCAACACGGGGAAACTCACCAGGTCCA
GACACAATGAGGATTGACAGATTGAGAGCTCTTTCTTGATTTTGTGGGTGGTGGTGCATGGCCGT
TCTTAGTTGGTGGAGTGATTTGTCTGCTTAATTGCGATAACGAACGAGACTTAACCTGCTAAATAG
CCCGTATTGCTTTGGCAGTACGCCGGCTTCTTAGAGGGACTATGGCTCAAGCCGATGGAAGTTT

GAGGCAATAACAGGTCTGTGATGCCCTTAGATGTTCTGGGCCGCACGCGCGTTACACTGACGGA
GCCAGCGAGTTCTCCCTTGGCCGGAAGGCCCGGGTTGCAGAATTCAGTGAATCATCGAATCTTT
GAACGCACATTGCGCTCGCCAGCATTCTGGCGAGCATGCCTGTTCGAGCGTCATTTCAACCCTC
AAGCACCGCTTGGTTTTGGGGCCCCACCTAACGTCTCGCACTGGGATCCGGAGGGACTCTTGCC
GTAAAACCCCCAAATTTTTTACAGGTTGACCTCGGATCAGGTAGGAATACCCG CTGAACTTAA

***Alternaria* sp. isolate**

TTCTTTTTCCTGCATAACCGAGATCCCGCTGGCGCCGCGCTGCTTCGGTTGATGCTCCATTAGTG
TGATTCTTATCTGTTGATTTGGTGGTTCGGTGGCGGGCTGGCCGCTCCGGCTGGAAAGAGCCCG
CTTTTGTAATTGCACTCGTGCTGTGAGTGTTGTCTGAAGAAATGTGTAATTAATAAAACTTTCATGA
ATCGAGCTCTTGGCTCTGGCATCGATGAATGCCACAACGAAAGGGAATTGCTAATGTCAATTAAT
CAATTTATCTTTTCACCCAATCTGTGCCCTTTGGTTGTCCCCCCGGCATGTCCGAGGGACCGGCC
TGTGTACCCTCCAGCTTTGCTTGCAGTTGGACGTCGTGCCTGGAGCTTTGCTGGACACTCGCCTT
AAAGTAATTGGCAGCCGGCCTACTGGTTTCGGAGCGCACCACAAGTCGCACTCTCTATCACCAAA
GGTCTAGCATCCATTAAGCCTTTTTTCAACTTTTGACCTCGGATCAGGTAGGGATACCCGCTGAA
CTTAAGCATATCAATAAGCGGAGGAA

***Fusarium* spp. isolates**

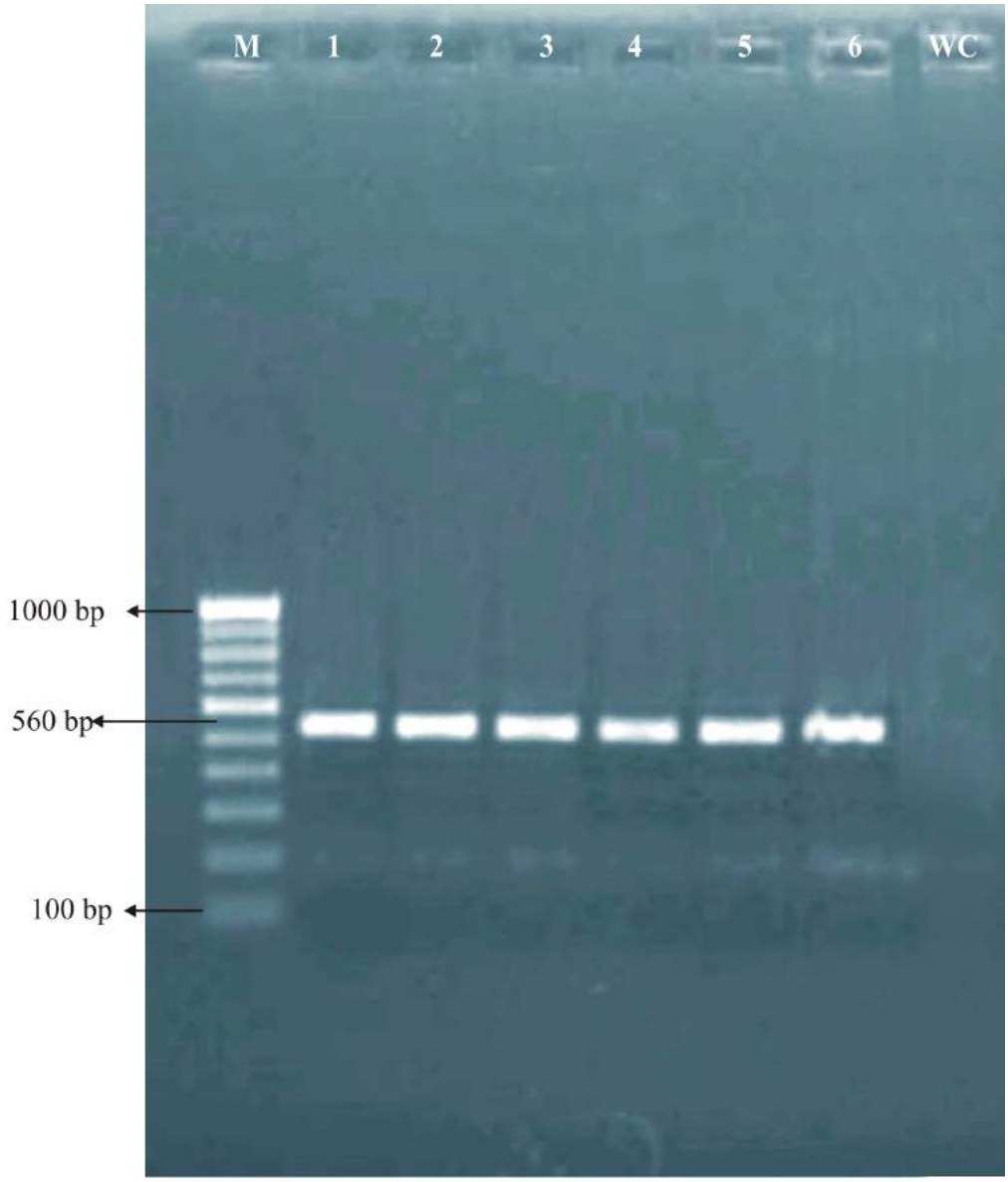
1.

GAGTTTTCCGGGGGGGGGAAAGAGTTCACTCCCAACCCCTGTGAACATACCACTTGTTGCCTCGG
CGGATCAGCCCGCTCCCGGTAAAACGGGACGGCCCGCCAGAGGACCCCTAAACTCTGTTTCTAT
ATGTAACTTCTGAGTAAAACCATAAATAAATCAAAACTTTCAACAACGGATCTCTTGGTTCTGGCAT
CGATGAAGAACGCAGCAAAATGCGATAAGTAATGTGAATTGCAGAATTCAGTGAATCATCGAATC
TTTGAACGCACATTGCGCCCGCCAGTATTCTGGCGGGCATGCCTGTTCGAGCGTCATTTCAACCC
TCAAGCACAGCTTGGTGTTGGGACTCGCGTTAATTCGCGTTCCTCAAATTGATTGGCGGTCACGT
CGAGCTTCCATAGCGTAGTAGTAAAACCCTCGTTACTGGTAATCGTCGCGGCCACGCCGTTAAAC
CCCAACTTCTGAATGTTGACCTCGGATCAGGTAGGAATACCCGCTGAACTTAAGCATATCAATAA
GCGGAGGAAA

2.

GGGGGGTCTTTCGGCATTGCACTCAGGCCCCTGTGACATACCTATACGTTGCCTCGGCGGATCA
GCCCGCGCACAAAAACGGGACGGCCCGCCCGAGGACCCCTAAACTCTGTCTCTTAAAGAAACTT
CTGAGTAAAACAAACAAATAAATCAAAACTTTCAACACCGGATCTCTTGGTTCTGGTTTTTCTCAAA
AAACCCCCCCAAATTTTATAAGTAATGTGAGTTGCAGAATTCCCACCCACCCCCCCCAATCTCTCA
ACCCCC

DNA sequences of selected six isolates were compared using bioinformatics tool like NCBI (National Centre for Bioinformatics) BLAST (Basic Local Alignment Search Tool) programme. Basedon sequence comparison, the identification of *Colletotrichum* spp. (3 isolates) *Alternaria* sp. (1 isolate) and *Fusarium* spp. (2 isolates) isolates were confirmed as *C. capsici, C.gloeosporioides, C. acutatum, A. alternata* and *F. oxysporum, F. sporotrichioides* respectively. The list of isolates, accession number, per cent homology and name identified are given in (Table 14).



M - Marker
1- Kundgol (C)
2- UAS Dharwad (C)
3- Govankoppa (C)
4- Koluru (A)
5- UAS Dharwad (F)
6- Bommanal (F)
WC - Water control

Plate 13 Amplification of ITS1 and ITS4 region of representative Colletotrichum spp., Alternaria sp.and Fusarium spp.

Table 14: Comparison and identity of chilli fruit rot causing pathogens isolates with gene bank in NCBI BLAST program

Sl. No	Accession number	NCBI BLAST Hit results	Max. score	Total score	Query coverage (%)	E-value (%)	Max. Ident. (%)
1	KF147902.1	*Colletotrichum capsici* isolate CCM 18S ribosomal RNA gene, partial sequence; internal transcribed spacer 1, 5.8S ribosomal RNA gene, and internal transcribed spacer 2, complete sequence; and 28S ribosomal RNA gene, partial sequence	793	793	100	0	100
2	KC895535.1	*Colletotrichum gloeosporioides* isolate CJBB21-25 18S ribosomal RNA gene, partial sequence; internal transcribed spacer 1, 5.8S ribosomal RNA gene, and internal transcribed spacer 2, complete sequence; and 28S ribosomal RNA gene, partial sequence	854	854	86	0.0	99
3	AJ749694.1	*Colletotrichum acutatum* ITS1, 5.8S rRNA gene and ITS2, isolate $PT_2$27	665	665	100	0.0	94
4	EU87848.1	*Alternaria alternata* isolate G2 A1-32 internal transcribed spacer 1, partial sequence; 5.8S ribosomal RNA gene, complete sequence; and internal transcribed spacer 2, partial sequence	48.1	128	100	2e-07	100
5	KC351189.1	*Fusarium sporotrichioides* 18S ribosomal RNA gene, partial sequence	436	436	99	3e-119	97
6	FR750924.1	*Fusarium sporotrichioides* genomic DNA containing 18S rRNA gene, ITS1, 5.8S rRNA gene, ITS2, 28S rRNA gene, culture collection MTCC:7375	172	172	83	7e-40	87
7	JN232187.1	*Fusarium oxysporum* isolate 847 18S ribosomal RNA gene, partial sequence; internal transcribed spacer 1, 5.8S ribosomal RNA gene, and internal transcribed spacer 2, complete sequence; and 28S ribosomal RNA gene, partial sequenc	278	278	83	2e-71	94

4.2.2.4 Specific amplification of *C. capsici, C. gloeosporioides, C. acutatum, A. alternata* and *Fusarium* spp.

DNA amplification was observed with fairly consistent band for *C. capsici* at 450 bp, for *C. gloeosporioides* fairly consistent band was observed with CgInt region at 450 bp and *C. acutatum* at 490 bp with concentration of 437 µg/µl. Whereas, *A. alternata* amplification was observed at 390 bp and for *Fusarium* spp. approximately at 550-570 bp. The amplified products were checked on 1.4 per cent agarose gel electrophoresis (Plate 14, 15, 16, 17, and 18).

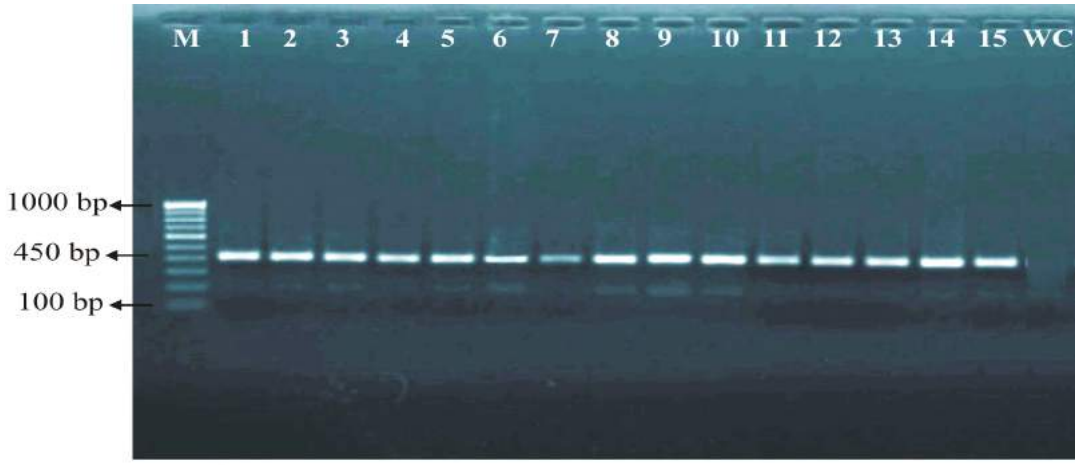
4.2.2.5 Analysis of the genetic variability among the species of *C. capsici, C. gloeosporioides, C.acutatum, A. alternata* and *Fusarium* spp using PCR-RFLP

The products of the PCR ITS rDNA digestion with *Hind III* revealed that no restriction sites were present. The digestion with *HaeIII,* resulted in a characteristic pattern of three fragments in all the isolates. *C. capsici* isolates shown four clusters, in cluster-I (1, 7, 14, 15, 17, 21), cluster – II (2, 4, 5, 6, 22, 20, 18, 16, 23, 12, 10, 11), cluster – III (3, 8, 24, 19, 13, 9) and cluster – IV (25) (Plate19). *C. gloeosporioides* isolates shown five clusters, in cluster-I (1, 7, 10, 20, 27), cluster – II (2), cluster – III (3, 5, 6, 9, 18, 14, 15, 11, 13), cluster – IV (4, 8, 16) and cluster –V (12, 19) (Plate 20). *C. acutatum* isolates shown three clusters, in cluster-I (1, 5, 7, 12, 10), cluster – II (3, 4, 6, 11, 8) and cluster – III (2, 9) (Plate 21).

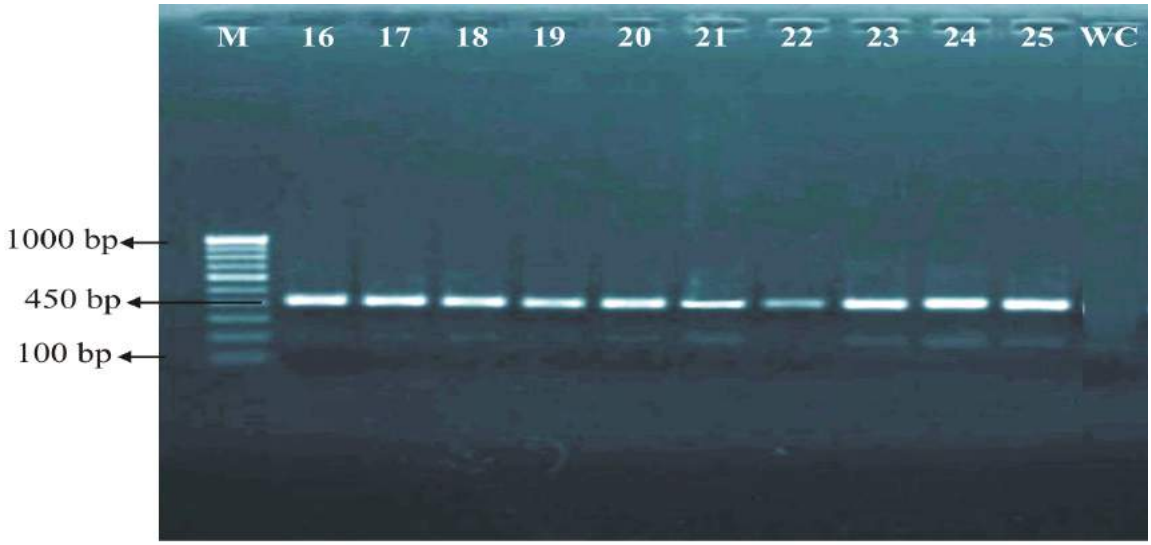
The digestion with *Taq I,* resulted in a characteristic pattern of three fragments in *Alternaria* and *Fusarium* isolates. *A. alternata* isolates shown two clusters cluster-I (1, 2, 3, 4, 6, 7, 9) and cluster – II (5, 8, 9) (Plate 22). *Fusarium* isolates shown five clusters, in cluster-I (1, 3, 4, 7, 9), cluster – II (2, 5, 6, 14, 8, 10), cluster – III (16) cluster – IV (11, 12, 15) and cluster – V (13) (Plate 23) .

4.2.2.6 Quick detection of fruit rot fungal pathogens from host tissue

PCR amplification with specific primers of DNA extracted from infected host tissues i.e., seed, fruit, pedicel and dieback stem revealed that, *C. capsici* was amplified by species specific primer (C.cap-f and C.cap-r) as single band at 450bp (Plate 24). *C. gloeosporioides, C. acutatum,* amplified by species specific primers (CgInt and CaInt) at 450



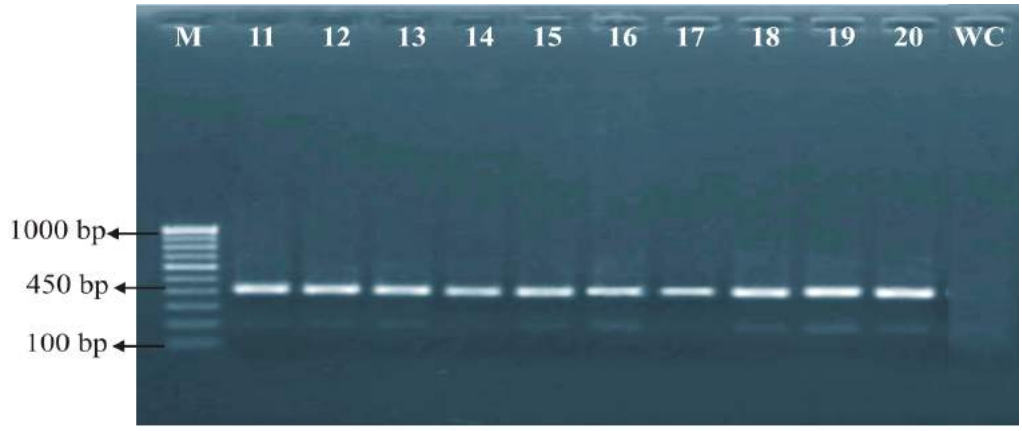
M -	Marker	Cc-6	Byalal	Cc-11	Nelhal
Cc-1	Koluru	Cc-7	Hulkoti	Cc-12	Panchamukhi
Cc-2	Siraguppa	Cc-8	Byadgi	Cc-13	Belgammanadoddi
Cc-3	Salahalli	Cc-9	Basapur	Cc-14	Emmiganur
Cc-4	UAS Dharwad	Cc-10	Chikkatembinahal	Cc-15	Dharmapuram
Cc-5	Kundgol			WC -	Water control



M -	Marker	Cc-21	Bayyavaram
Cc-17	Mugathi	Cc-22	Mangalveda
Cc-18	Madire	Cc-23	Sangola
Cc-19	Paaladagu	Cc-24	Aurangabad
Cc-20	Kattavaripalem	Cc-25	Coimbatore
		WC -	Water control

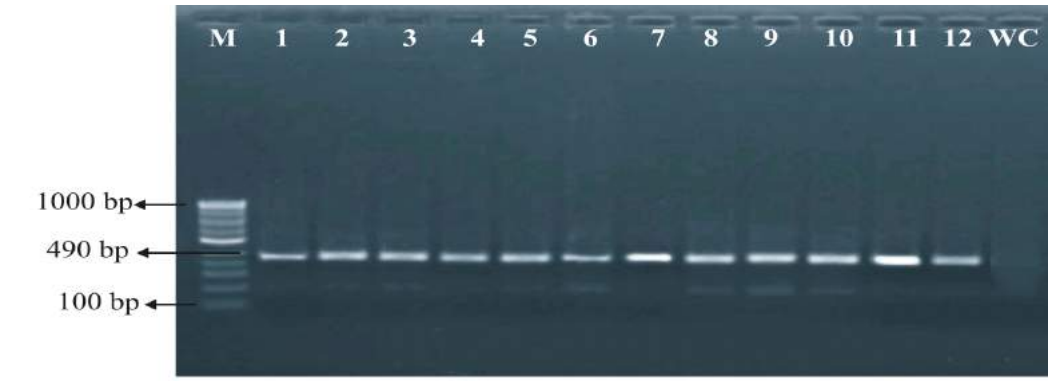
Plate 14: Specific amplification of Colletotrichum capsici by C.cap primer

M -	Marker		
Cg-1	Kagalgombe	Cg-6	Shirguppi
Cg-2	Shanvaspura	Cg-7	Binkadkatti
Cg-3	Inamhongal	Cg-8	Guttal
Cg-4	Byahatti	Cg-9	Kanakapur
Cg-5	UAS Dharwad	Cg-10	Beluru
		WC -	Water control



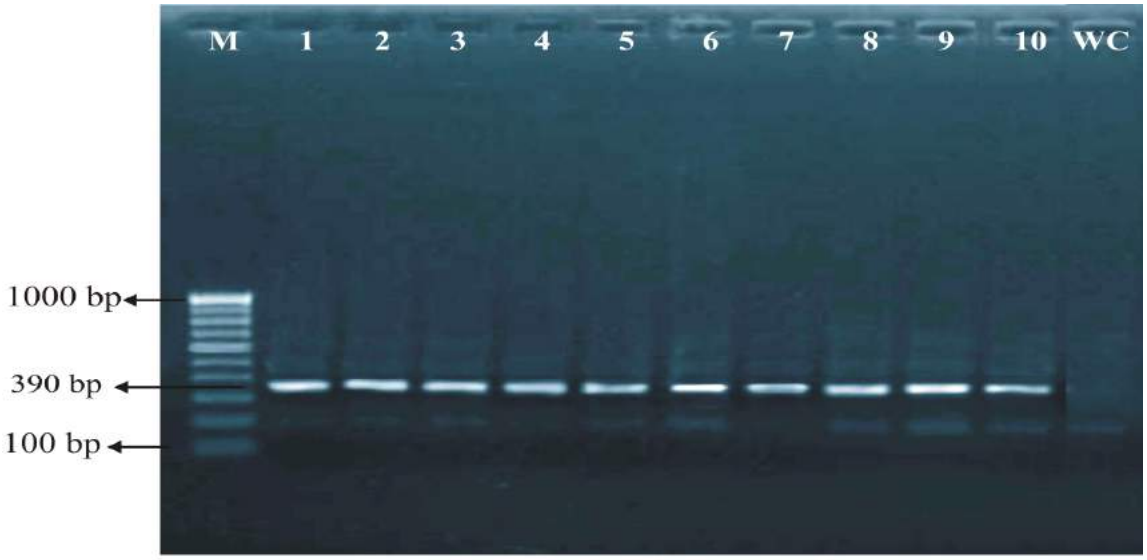
M -	Marker		
Cg-11	Mandapur	Cg-16	Mangalaveda
Cg-12	Raladoddi	Cg-17	Medikonduru
Cg-13	Hanumapuram	Cg-18	Percherela
Cg-14	Alur	Cg-19	Ananthapuram
Cg-15	Kalludevarakunta	Cg-20	Coimbatore
		WC -	Water control

Plate 15 Specific amplification of Colletotrichum gloeosporioides at CgInt region



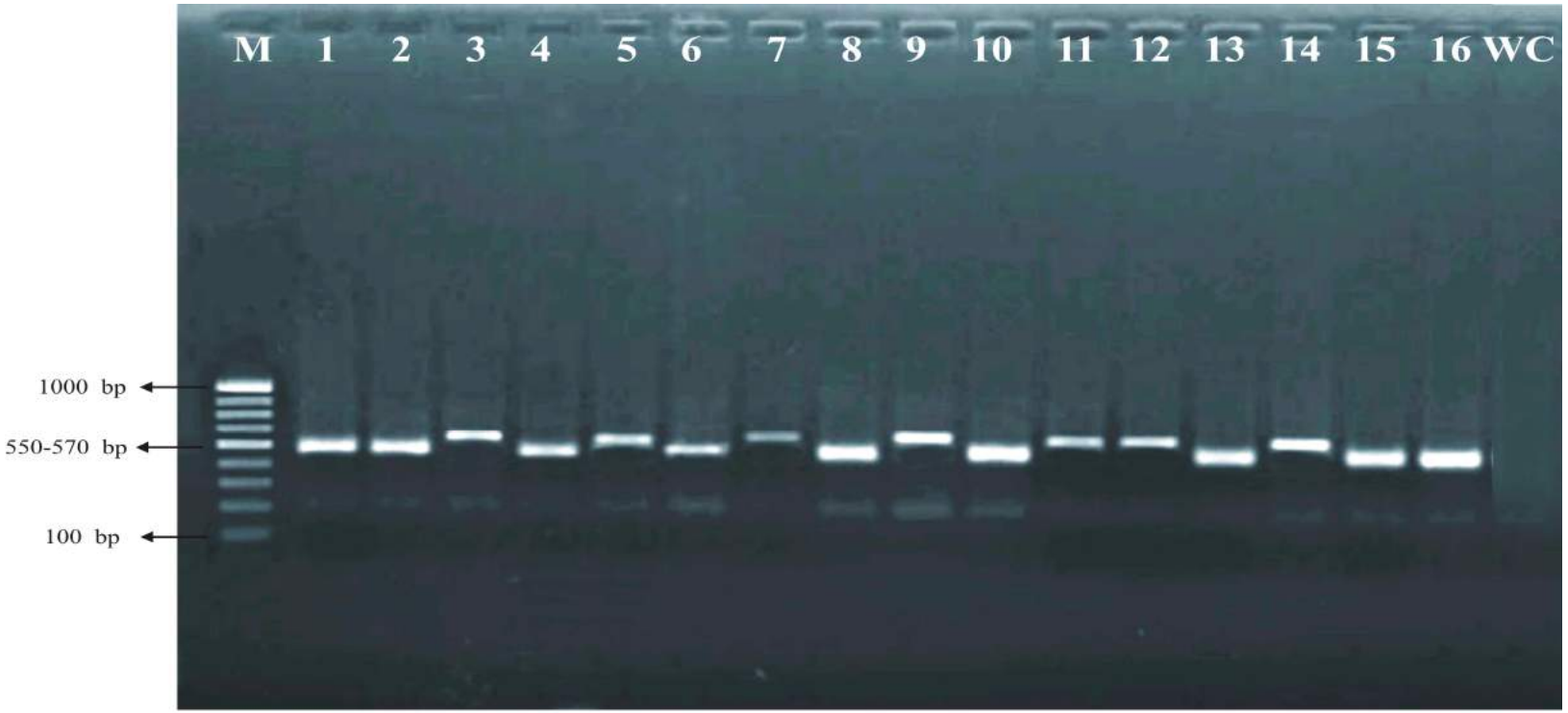
M -	Marker	Ca-7	Lingadahalli
Ca-1	Raravi	Ca-8	Budugumpa
Ca-2	Govanakoppa	Ca-9	Belgammanadoddi
Ca-3	UAS Dharwad	Ca-10	Mantralaya
Ca-4	Binkadakatti	Ca-11	Marakattu
Ca-5	Byadgi	Ca-12	Pedakurpadu
Ca-6	Devihosur	WC -	Water control

Plate 16 Specific amplification of Colletotrichum acutatum at CaInt region



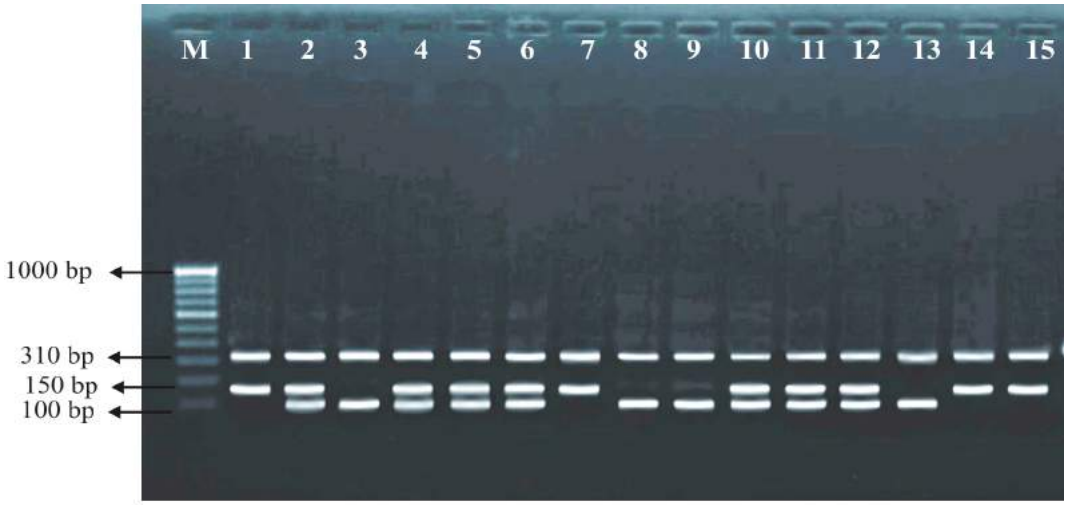
M -	Marker	Aa-6	Talakall
Aa-1	Koluru	Aa-7	Raichur
Aa-2	UASDharwad	Aa-8	Paldaagu
Aa-3	Kundgol	Aa-9	Mandapura
Aa-4	Hulkoti	Aa-10	Kalludevarakunta
Aa-5	Guttal	WC -	Water control

Plate 17 Specific amplification of Alternaria alternata by AAF and AAR primer

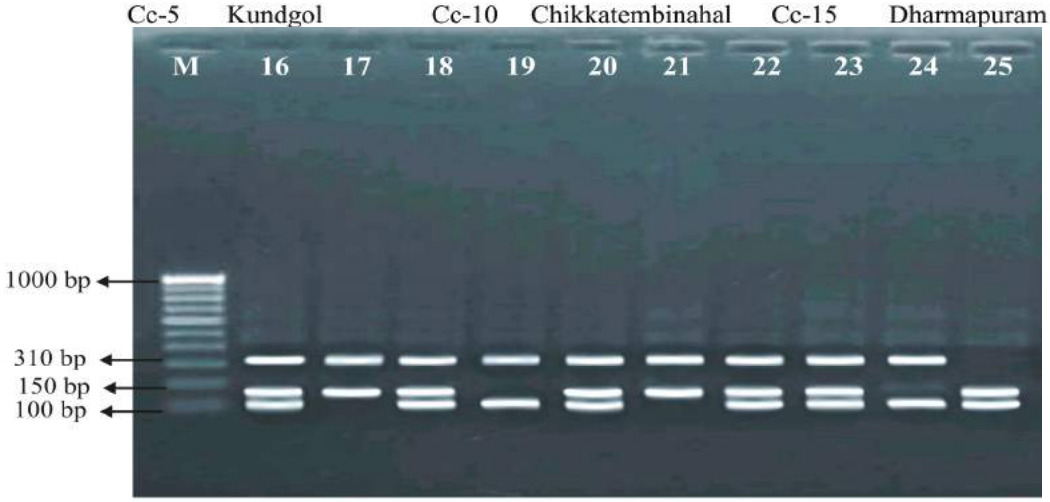


M -	Marker	9- Fo-9	Mangalaveda	4- Fo-4	Byalal	13- Fs-4	Bommanal
1- Fo-1	Raravi	10- Fs-1	Lokapur	5- Fo-5	Ranebennur	14- Fs-5	Raladoddi
2- Fo-2	UAS Dharwad	11- Fs-2	Kumbapur farm	6- Fo-6	Nelhal	15- Fs-6	Mantralaya
3- Fo-3	Sharewad	12- Fs-3	Badrapur	7- Fo-7	Alur	16 Fs -7	Perecherla
				8- Fo-8	Emmiganur	WC -	Water control

Plate 18 Specific amplification of Fusarium spp. by Tef.Fu primer

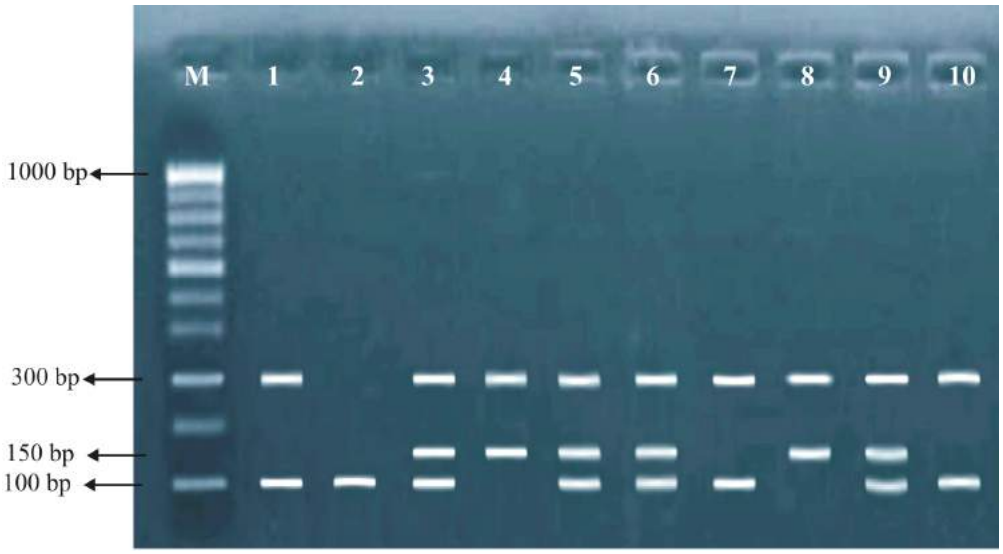


M -	Marker				
Cc-1	Koluru	Cc-6	Byalal	Cc-11	Nelhal
Cc-2	Siraguppa	Cc-7	Hulkoti	Cc-12	Panchamukhi
Cc-3	Salahalli	Cc-8	Byadgi	Cc-13	Belgammanadoddi
Cc-4	UAS Dharwad	Cc-9	Basapur	Cc-14	Emmiganur
Cc-5	Kundgol	Cc-10	Chikkatembinahal	Cc-15	Dharmapuram



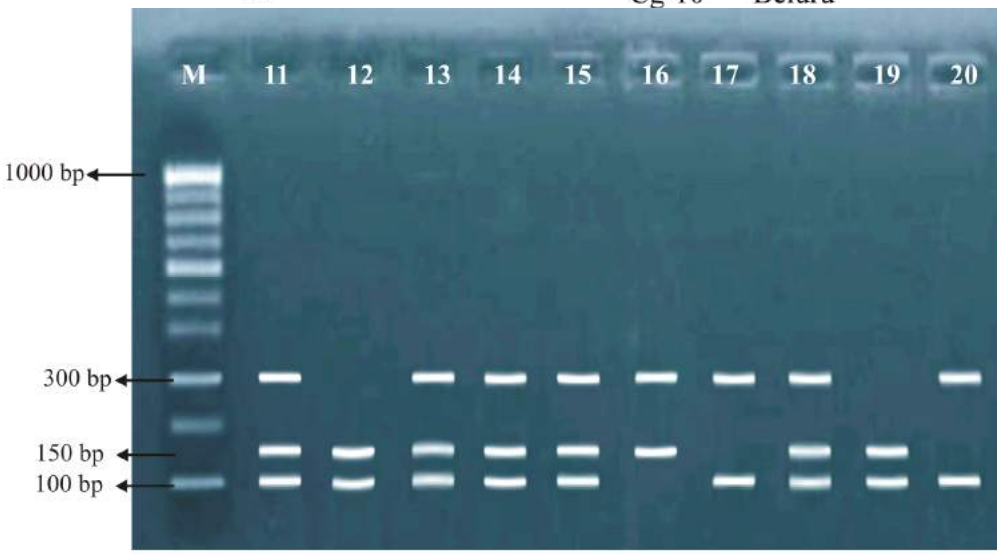
M -	Marker				
Cc-17	Mugathi	Cc-21	Bayyavaram		
Cc-18	Madire	Cc-22	Mangalveda		
Cc-19	Paaladagu	Cc-23	Sangola		
Cc-20	Kattavaripalem	Cc-24	Aurangabad	Cc-25	Coimbatore

Plate 19: PCR-RFLP pattern of C. capsici by HaeIII enzyme



M - Marker

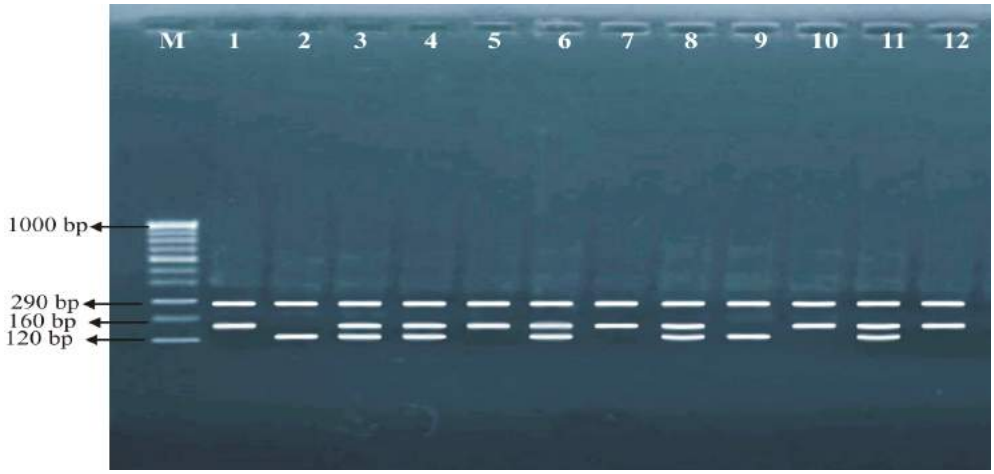
Cg-1	Kagalgombe	Cg-6	Shirguppi
Cg-2	Shanvaspura	Cg-7	Binkadkatti
Cg-3	Inamhongal	Cg-8	Guttal
Cg-4	Byahatti	Cg-9	Kanakapur
Cg-5	UAS Dharwad	Cg-10	Beluru



M - Marker

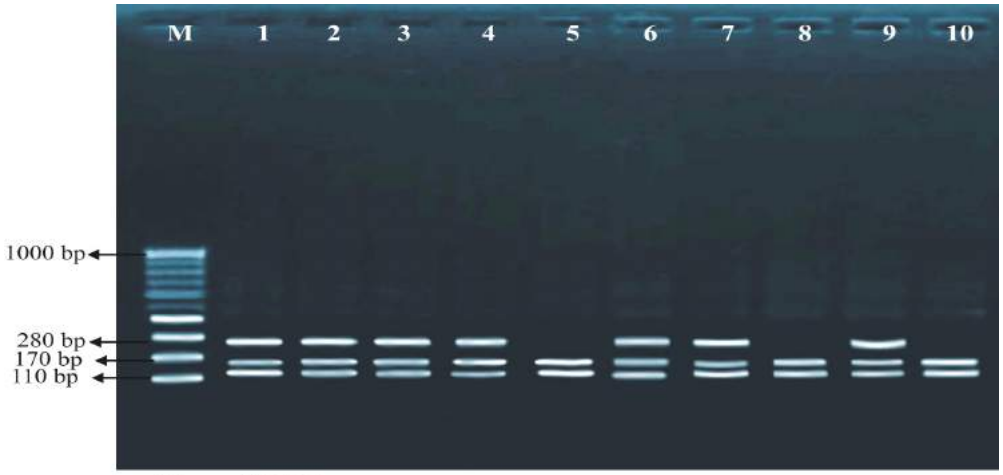
Cg-11	Mandapur	Cg-16	Mangalaveda
Cg-12	Raladoddi	Cg-17	Medikonduru
Cg-13	Hanumapuram	Cg-18	Percherela
Cg-14	Alur	Cg-19	Ananthapuram
Cg-15	Kalludevarakunta	Cg-20	Coimbatore

Plate 20: PCR-RFLP pattern of C. gloeosporioides by HaeIII enzyme



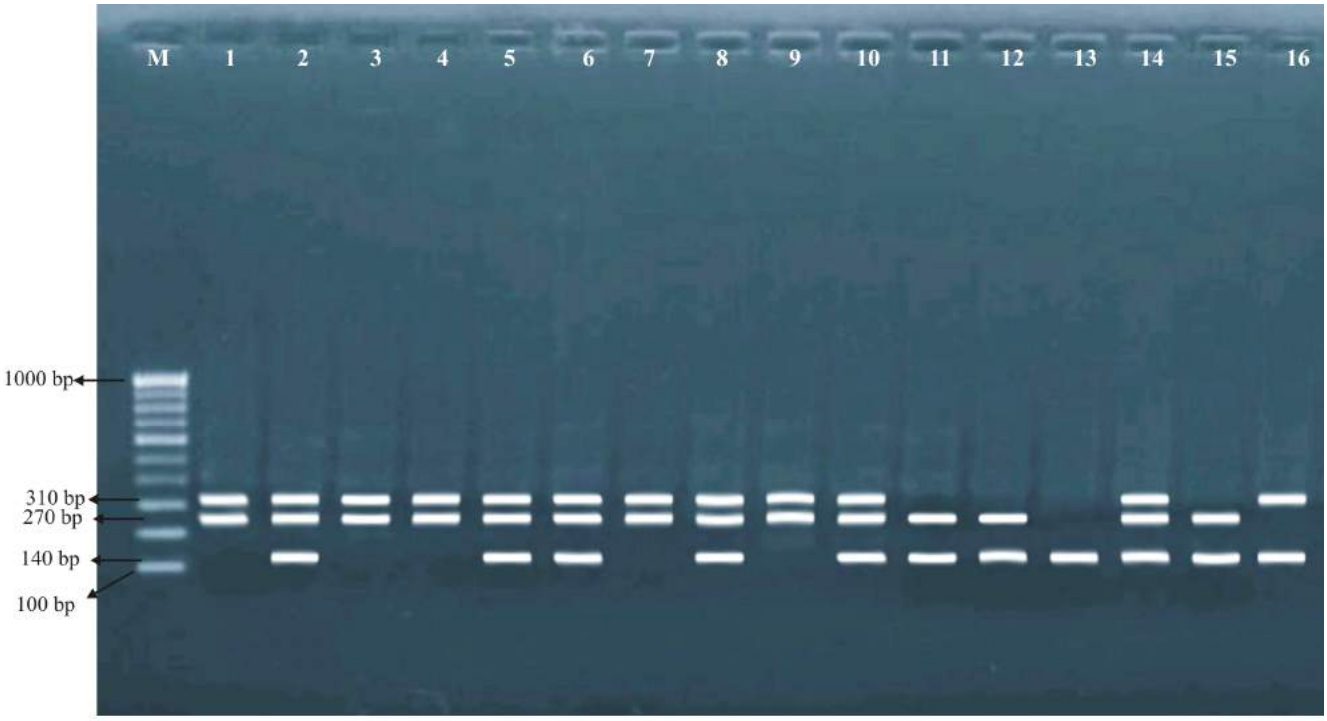
M -	Marker		
Ca-1	Raravi	Ca-7	Lingadahalli
Ca-2	Govanakoppa	Ca-8	Budugumpa
Ca-3	UAS Dharwad	Ca-9	Belgammanadoddi
Ca-4	Binkadakatti	Ca-10	Mantralaya
Ca-5	Byadgi	Ca-11	Marakattu
Ca-6	Devihosur	Ca-12	Pedakurpadu

Plate 21: PCR-RFLP pattern of C. acutatum by HaeIII enzyme



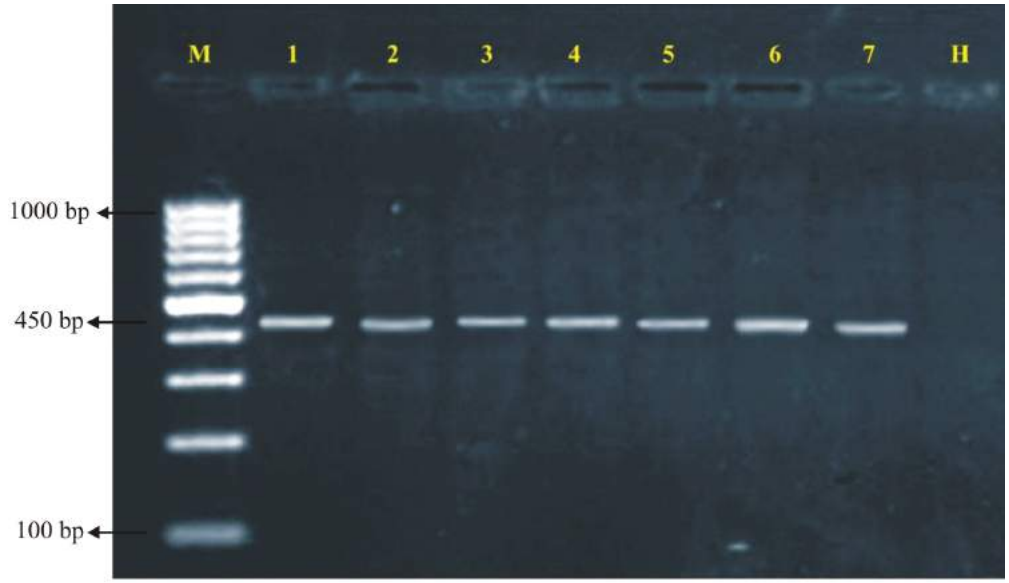
M -	Marker		
Aa-1	Koluru	Aa-6	Talakall
Aa-2	UAS Dharwad	Aa-7	Raichur
Aa-3	Kundgol	Aa-8	Paldaagu
Aa-4	Hulkoti	Aa-9	Mandapura
Aa-5	Guttal	Aa-10	Kalludevarakunta

Plate 22 PCR-RFLP pattern of A. alternata by TaqI enzyme



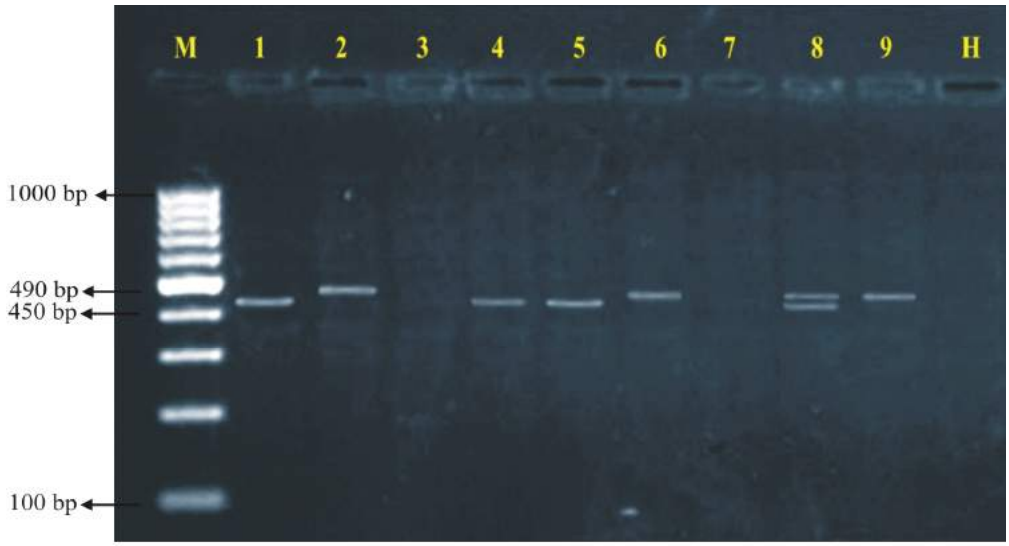
M -	Marker						
1- Fo-1	Raravi	5- Fo-5	Ranebennur	9- Fo-9	Mangalaveda	13- Fs-4	Bommanal
2- Fo-2	UAS Dharwad	6- Fo-6	Nelhal	10- Fs-1	Lokapur	14- Fs-5	Raladoddi
3- Fo-3	Sharewad	7- Fo-7	Alur	11- Fs-2	Kumbapur farm	15- Fs-6	Mantralaya
4- Fo-4	Byalal	8- Fo-8	Emmiganur	12- Fs-3	Badrapur	16 Fs -7	Perecherla

Plate 23 PCR-RFLP pattern of Fusarium spp. by TaqI enzyme



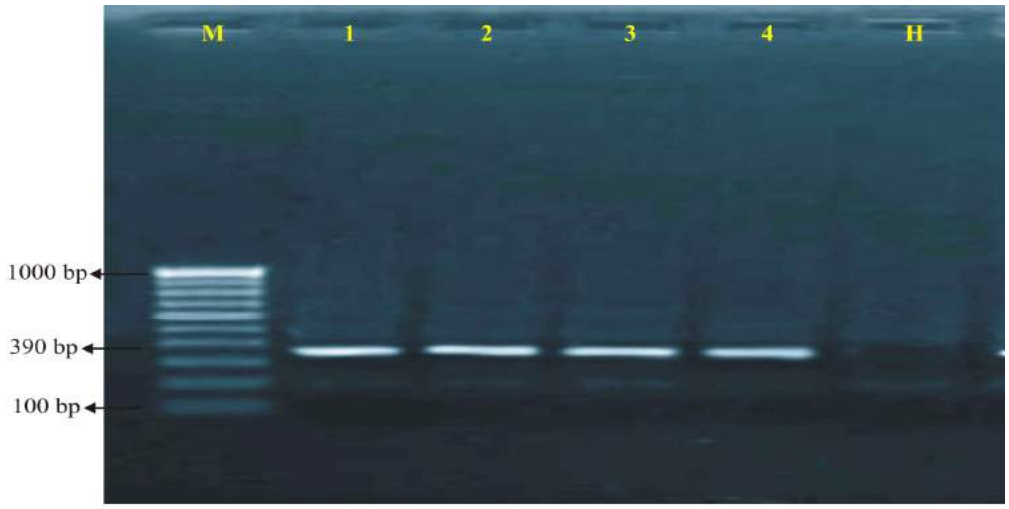
M: 100 bp Marker 1&2 = fruit 3= seed, 4&5= twig 6&7 = pedicel, from infected samples, and H: Healthy sample (negative control)

Plate 24 Detection of C. capsici by specific primer (C.cap)



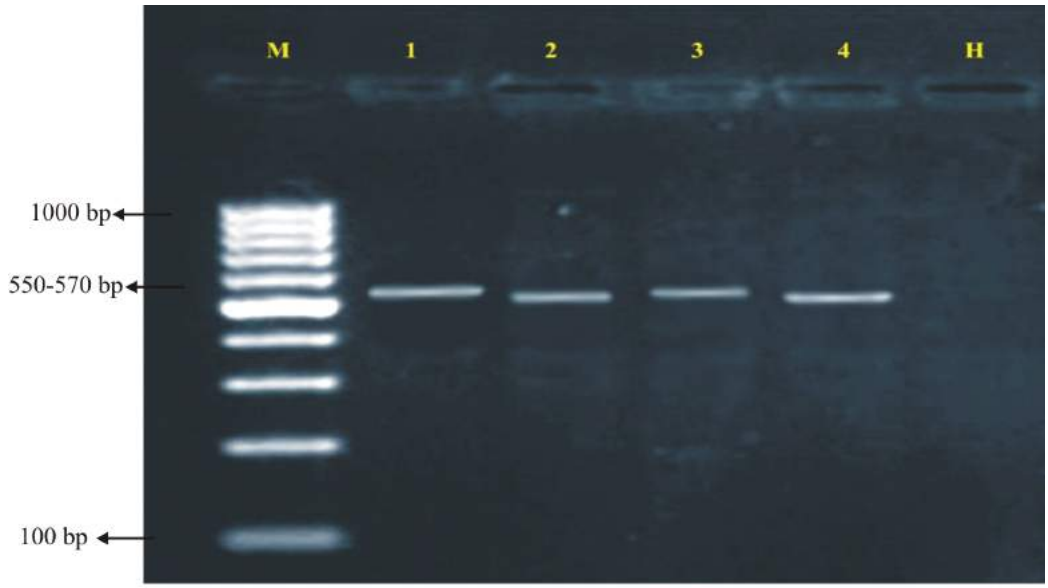
M: 100 bp Marker 1, 2 & 3= seed, 4&5 = twig 6&7 pedicel, 8&9 = fruit , from infected samples, and lane H: Healthy sample (negative control).

Plate 25 Detection of C. gloeoesporioides , C. acutataum by specific primer (CgInt and CaInt)



M: 100 bp Marker 1= seed 2= fruit 3= twig 4= pedicel from infected samples, and H: Healthy sample (negative control).

Plate 26 Detection of A. alternata by specific primer (AAF and AAR)



M: 100 bp Marker 1= fruit 2= seed 3= twig 4= pedicel from infected samples, and H: Healthy sample (negative control).

Plate 27 Detection of Fusarium by specific primer (Tef- Fu.)

and 490bp respectively (Plate 25) , *A. alternata* amplified by species specific primer (AAf and Aar) at 390bp (Plate 26) and *Fusarium* spp. were amplified at 550 – 570bp (Plate 27). From seed, fruit, die-back infected twigs, and fruit pedicel samples *C. capsici, C. gloeosporioides, C. acutatum, A. alternata* and *Fusarium* spp. were detected.

4.3 Epidemiology of the fruit rot disease in relation to climatic factors

4.3.1 Survival ability of *Colletotrichum* spp. *A. alternata* and *F. oxysporum* in plant debris

The present study was undertaken to know the survival period of *Colletotrichum* spp. *A. alternata* and *F. oxysporum* in host tissues as explained in materials and methods. The results obtained on recovery of fungus by its growth are presented in Table 15a and 15b.

The plant debris kept for survival ability in 2012-13 revealed that *Colletotrichum* spp. remained viable up to 165 days under laboratory conditions, 120 days on soil surface and 60 days under 10cm depth of soil condition. *A. alternata* remained viable up to 120 days under laboratory conditions, 90 days on soil surface and 45 days under 10cm depth of soil condition. *F. oxysporum* remained viable up to 150 days under laboratory conditions, 135 days on soil surface and 60 days under 10cm depth of soil condition. In 2013-14 *Colletotrichum* spp. remained viable up to 150 days under laboratory conditions, 105 days on soil surface and 60 days under 10cm depth of soil condition. *A. alternata* remained viable up to 105 days under laboratory conditions, 90 days on soil surface and 45 days under 10cm depth of soil condition. *F. oxysporum* remained viable up to 150 days under laboratory conditions, 120 days on soil surface and 60 days under 10cm depth of soil condition. The results indicated that the pathogen/s survived well in the infected host tissue for five to six months. The survival ability of these three pathogens was more in lab condition (150-165days) and which was reduced (90-125 days) on soil surface and still reduction in survival was recorded in 10cm depth of soil condition (45-60 days).

Table 15a: Survival ability of pathogen/s in infected plant debris under three different conditions during 2012-13

Days	*Colletotrichum* spp.			*Alterneria alternata*			*Fusarium oxysporum*.		
	Laboratory	Soil surface	10 cm depth of soil	Laboratory	Soil surface	10 cm depth of soil	Laboratory	Soil surface	10 cm depth of soil
0	+	+	+	+	+	+	+	+	+
15	+	+	+	+	+	+	+	+	+
30	+	+	+	+	+	+	+	+	+
45	+	+	+	+	+	+	+	+	+
60	+	+	+	+	+	-	+	+	+
75	+	+	-	+	+	-	+	+	-
90	+	+	-	+	+	-	+	+	-
105	+	+	-	+	-	-	+	+	-
120	+	+	-	+	-	-	+	+	-
135	+	-	-	-	-	-	+	+	-
150	+	-	-	-	-	-	+	-	-
165	+	-	-	-	-	-	-	-	-
180	-	-	-	-	-	-	-	-	-

+ Present - Absent

Table 15b: Survival ability of pathogen/s in infected plant debris under three different conditions during 2013-14

Days	*Colletotrichum* Spp.			*Alterneria alternata*			*Fusarium oxysporum*.		
	Laboratory	Soil surface	10 cm depth of soil	Laboratory	Soil surface	10 cm depth of soil	Laboratory	Soil surface	10 cm depth of soil
0	+	+	+	+	+	+	+	+	+
15	+	+	+	+	+	+	+	+	+
30	+	+	+	+	+	+	+	+	+
45	+	+	+	+	+	+	+	+	+
60	+	+	+	+	+	-	+	+	+
75	+	+	-	+	+	-	+	+	-
90	+	+	-	+	+	-	+	+	-
105	+	+	-	+	-	-	+	+	-
120	+	-	-	-	-	-	+	+	-
135	+	-	-	-	-	-	+	-	-
150	+	-	-	-	-	-	+	-	-
165	-	-	-	-	-	-	-	-	-

+ Present - Absent

4.3.2 Host range of *C. capsici*

To know the host range of *C. capsici* two solanaceous vegetables and seven legume hosts were tested. The results revealed that *C. capsici* can infect to all nine hosts. On solanaceous vegetables tomato and brinjal, chlorotic lesions were produced on 4th day after inoculation. These lesions turned to brown color leading to necrosis after seven days of inoculation. In legume crops like cowpea, green gram and black gram brown color horse shoe type lesions were observed after eight days after inoculation. An earliest visible chlorotic symptom was observed in pea after two days of inoculation, while maximum duration (six days) taken to produce the initial symptom in moth bean. Details are furnished in Table 16 and Plate 28.

4.3.3.1 Cross inoculation of *C. capsici*

Cross inoculation study of *C. capsici* among twig, pedicel and fruit of chilli revealed that *C. capsici* can cause seed rot, die-back of twigs, pedicel discoloration and fruit rot from all tested above ground parts of chilli plant by cross inoculation (Table 17 and Plate 29).

4.3.3.2 Pathogen interaction

Studies on host-pathogen interaction aimed at studying various symptoms produced by pathogens in combinations are presented in (Table 18 and Plate 30).

C. capsici + A. alternata

Symptoms appear on two days after inoculation as water soaked lesion of 1.0-1.5cm diameter. After five days of inoculation concentric rings with black color mold growth was observed on 2-3 cm diameter lesion, eight days after inoculation black color spore mass wer produced on these lesions (Plate 30a).

C. capsici + F. oxysporum

Symptoms appear on two days after inoculation as water soaked lesion of 0.5-1.0 cm diameter, after four days of inoculation pinkish white color mycelial growth was observed on 1.5 – 2.0 cm diameter lesion. Eight days after inoculation pink color spore mass were produced on these lesions (Plate 30b)..

Table 16. Hosts reaction to *Colletotrichum capsici* inoculation

Sl. No.	Host	Reaction	Days after inoculation	Symptoms observed
1	Tomato	+	4	Initiation of Chlorotic lesion
			6	Chlorotic lesion
			8	Chlorotic lesion turning to brown color necrotic lesion
2	Brinjal	+	4	Chlorotic lesion from margin of leaf
			6	Lesion turning to brown color
			8	Necrosis of leaf
3	Chick pea	+	4	Chlorotic lesions from margin of leaves
			6	Chlorotic lesions to brown color with drying from margin
			8	Necrosis of leaves
4	Moth bean	+	6	Chlorotic lesions from tip of leaves
			8	Chlorotic lesions turning to brown color
			10	Necrosis of leaf from tip of leaf
5	Green gram	+	4	Chlorotic lesions on lower surface of leaf
			6	Chlorotic lesions on upper surface of leaf
			8	Chlorotic lesions turning to reddish brown color horse shoe type symptoms on upper surface
6	Cowpea	+	4	Chlorotic lesions on lower surface of leaf
			6	Chlorotic lesions on upper surface of leaf
			8	Chlorotic lesions turning to reddish brown color horse shoe type symptoms on upper surface

Contd…

7	Black gram	+	4	Chlorotic lesions on lower surface of leaf
			6	Chlorotic lesions on upper surface of leaf
			8	Chlorotic lesions turning to reddish brown color horse shoe type symptoms on upper surface
8	Soybean	+	3	Chlorotic lesions on leaves
			5	Reddish brown color lesion
			7	Necrotic lesion
9	Pea	+	2	Chlorotic lesions on leaves
			4	Chlorotic lesions to brown color with necrosis
			6	Necrotic lesion

a. Tomato

b. Brinjal

c. Moth bean

d. Chickpea

e. Urdbean

f. Cowpea

g. Pea

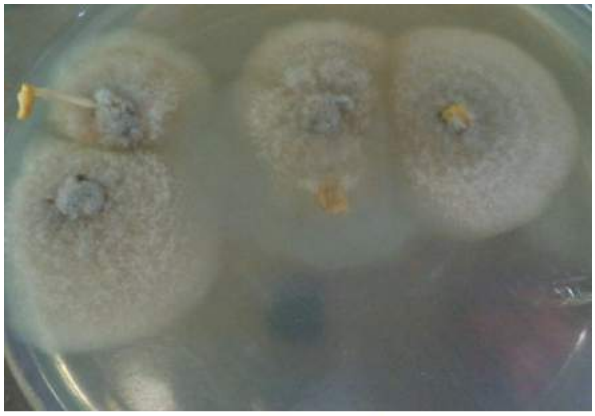
h. Greengram

i. Soybean

Plate 28 Host range of C. capsici

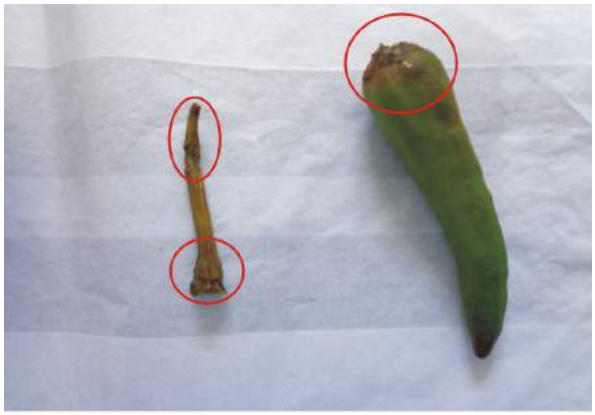
Table 17. Reaction on different parts of chilli by cross inoculation of *Colletotrichum capsici*

Isolated from	Inoculation to		
	Twig	Fruit	Pedicel
Seed	+	+	+
Twig	+	+	+
Fruit	+	+	+
Pedicel	+	+	+



a. On seeds

b. On twig



c. On pedicel

d. On fruit

Plate 29 Cross inoculation of C. capsici from seed to other parts

Table 18: Interaction effect of chilli fruit rot pathogens

Pathogen	First appearance of symptoms (DAI)	Symptom observed (DAI)	Symptom
C. capsici + A. alternata	2	2	Water soaked lesion of 1.0-1.5 cm diameter
		5	Concentric rings with black color mold growth was observed on 2.0-3.0 cm diameter lesion
		8	Black color spore mass produced on these lesions
C. capsici + F. oxysporum	2	2	Water soaked lesion of 0.5-1.0 cm diameter
		4	Pinkish white color mycelial growth was observed on 1.5 - 2 .0 cm diameter lesion
		8	Pink color spore mass produced on these lesions.
C. capsici + C. gloeosporioides + C. acutatum.	1	1	Water soaked lesion of 0.5 -1.0 cm diameter.
		7	Sunken lesion with salmon color spore mass produced on 1.5 - 2 .0 cm diameter lesion
C. capsici + A.alternata + F.oxysporum	1	1	Water soaked lesion of 0.5 – 1.0 cm diameter
		4	Greyish mycelial growth observed on 2.0 – 2.5 cm diameter
		6	Concentric rings with grayish salmon colored spore mass were produced on lesion

C. capsici + C. gloeosporioides + C. acutatum

Symptoms appear on one day after inoculation as water soaked lesion of 0.5 - 1.0 cm diameter. After seven days of inoculation sunken lesion with salmon color spore mass produced on 1.5 – 2.0 cm diameter lesion (Plate 30c).

C. capsici + A.alternata + F.oxysporum

Symptoms appear on one day after inoculation as water soaked lesion of 0.5 – 1.0 cm diameter, after four days of inoculation grayish mycelial growth observed on 2.0 – 2.5 cm diameter, six days after inoculation concentric rings with grayish salmon color spore mass were produced on these lesions (Plate 30d).

4.3.3.1 Effect of weather parameters on spore load of *Colletotrichum* spp.

An attempt was made to study the effect of various weather parameters on progression of spore load of major chilli fruit rot pathogen *Colletotrichum* spp. and fruit rot incidence. Weather factors *viz.,* temperature (max. and min.), relative humidity (Morning and Evening) and cumulative rainfall were noted from observatory during *kharif* 2012-13 (Table 19, 20). The weekly averages of various weather parameters, spore load and fruit rot incidence were recorded for the two cropping seasons. The correlation and multiple regression analysis was worked out and presented in Table 21a, 21b, 21c and 23a and 23b, Plate 31.

The number of spores trapped weekly varied as the disease severity progressed in the field. Air sampling carried out during 2012 indicated that, the first appearance of spores in the atmosphere was recorded after 41 days after transplanting. Maximum spore load (10.67) recorded during 43rd standard week with highest fruit rot incidence 15.33 per cent. In 2013 the first appearance of spores in the atmosphere was recorded after 34 days after transplanting. The spore load gradually increased, maximum spore load (13.74) recorded during 39th standard week with highest fruit rot incidence 19.27 per cent.

a. *C. capsici + A. alternata* b. *C. capsici + F. oxysporum* c. *C. capsici + C. gloeosporioi + C. acutatum* d. *C. capsici + A. alternata + F. oxysporum*

Plate 30 Symptoms produced by combination of C. capsici, C. gloeosporioides C. acutatum, A. alte

Plate 31 Aeroscope in field

Table 19. Effect of environmental factors in relation to spore load of *Colletotrichum spp.* and disease progression during *kharif* 2012 at MARS, Dharwad

Std. week	Stage of crop (DAT)	Average weekly spore load of *Colletotrichum*	Weekly incidence %	Temperature (°C)		Relative humidity (%)		Cumulative rainfall (mm)
				Maximum	Minimum	Morning	Evening	
25	-	0	0	28.7	20.7	92	66	15.6
26	6-12	0	0	27.6	20.7	92	79	28.8
27	13-19	0	0	26.6	20.7	94	75	58.0
28	20-26	0	0	28.8	20.8	92	66	66.0
29	27-33	0	0	26.6	20.9	93	79	114.4
30	34-40	0	0	27.0	21.0	93	74	139.2
31	41-47	2.20	3.33	26.7	20.4	93	76	163.4
32	48-54	3.61	4.67	26.6	20.8	95	80	203.6
33	55-61	4.00	7.67	27.5	20.2	93	69	218.0
34	62-68	4.20	9.33	28.3	20.6	93	68	226.2
35	69-75	6.80	10.67	25.8	20.2	95	84	238.6
36	76-82	6.00	11.67	26.4	20.7	94	85	267.0
37	83-89	8.74	13.00	27.8	20.1	93	75	268.8
38	90-96	7.28	11.71	28.8	18.6	85	59	270.0
39	97-102	10.32	17.67	30.7	19.3	88	55	319.8
40	103 -109	7.00	5.67	27.3	20.5	93	73	363.0
41	110-116	5.82	8.33	30.5	18.4	77	48	400.6
42	117-123	4.82	10.32	31.2	17.1	69	40	400.6
43	124-130	10.67	15.33	29.9	18.0	83	47	409.0
44	131-137	10.00	13.10	27.6	17.8	82	58	443.5

Table 20: Effect of environmental factors in relation to spore load of *Colletotrichum spp.* and disease progression during *kharif* 2013 at MARS, Dharwad

Std. week	Stage of crop (DAT)	Average weekly spore load	Weekly fruit rot incidence	Temperature (°C)		Relative humidity (%)		Cumulative rainfall (mm)
				Maximum	Minimum	Morning	Evening	
25	-	0	0	27.7	20.7	93	71	-
26	6-12	0	0	27.3	20.6	94	76	33.4
27	13-19	0	0	26.7	20.6	95	74	49.6
28	20-26	0	0	25.5	20.3	95	81	77.4
29	27-33	0	0	25.7	20.7	95	84	114.2
30	34-40	3.92	2.82	23.9	20.1	95	88	199.8
31	41-47	5.85	5.00	25.0	20.1	95	85	259.4
32	48-54	7.14	5.67	27.2	20.0	94	78	277.8
33	55-61	9.71	9.00	26.3	20.5	95	79	289.8
34	62-68	10.28	11.00	26.3	19.5	92	79	301.4
35	69-75	10.71	12.13	29.4	19.3	91	63	309.4
36	76-82	11.42	13.17	28.6	20.0	94	73	318.8
37	83-89	11.85	15.43	28.0	21.0	95	73	415.8
38	90-96	12.28	14.00	27.2	20.4	95	75	431.2
39	97-102	13.74	19.27	26.5	19.7	94	77	437.6
40	103 -109	8.1	6.31	27.5	20.0	93	73	447.8
41	110-116	6.28	8.19	29.2	19.4	93	59	447.8
42	117-123	5.71	9.96	30.3	19.4	90	50	465.4
43	124-130	9.32	11.53	27.8	20.0	92	73	513.0
44	131-137	10.41	12.83	31.03	17.7	87	50	513.0

The spore load of *Colletotrichum* spp. during *kharif* 2012 was positively and highly significantly correlated with cumulative rainfall (r = 0.86), positively correlated with maximum temperature (r = 0.34) and negatively correlatedwith relative humidity of morning and evening (r = -0.37 and r = -0.41) and minimum temperature r = -0.63.

In 2013 also highly significant positive co-relation of spore load was recorded with cumulative rainfall (r = 0.81), positively correlatedwith maximum temperature (r = 0.33) and negative correlation with morning (r = -0.25) and evening (r = -0.22) relative humidity and minimum temperature (r = -0.38).

In the pooled data of two consecutive years (2012 and 2013), cumulative rainfall recorded highly significant positive correlation (r = 0.84) and positively correlatedwith maximum temperature (r = 0.34). Whereas, other weather parameters *viz*., relative humidity of evening and morning were negatively correlated (Table 21a).

Hence, it could be inferred that among weather parameters selected for correlation on the spore load of *Colletotrichum* spp. cumulative rainfall and maximum temperature showed significantly positive correlation.

The coefficient of determinative value (R^2) was found to be 90 and 83 per cent in 2012 and 2013 respectively. There was variation in the spore load progression which was accounted by the linear functions of the independent variables such as maximum and minimum temperature, morning and evening relative humidity, rainfall and number of rainy days and dependent variable was spore load trapped by aeroscope (Table 22a and 21b). The regression equations are as below.

$Y_1 = -71.13 + 2.97X_1-5.56X_2+0.78X_3+0.42X_4+0.02X_5$ (for *kharif* 2012)

$Y_2 = -87.31+2.68X_1-4.76X_2+0.92X_3+0.36X_4+0.02X_5$ (for *kharif* 2013)

$Y_P =- 79.22+2.83\ X_1 – 5.16\ X_2 + 0.85X_3 + 0.39\ X_4 + 0.02X_5$ (for pooled data)

It is clear that from the table 21b that during 2012 predicted spore load was less compared to actual observed value. The difference between observed and predicted values showed a range of -0.11 to + 1.30. Similarly during 2013 the difference between observed and predicted values showed a range of -0.22 to + 2.48.

Table 21a. Correlation coefficient (r) of spore load of *Colletotrichum* spp. with weather parameters during *kharif* 2012 and 2013

Weather parameters	r values		
	2012	2013	Pooled
Maximum temperature (°C)	0.34	0.33	0.34
Minimum temperature (°C)	-0.63	-0.38	-0.51
Relative humidity (Morning) (%)	-0.37	-0.25	-0.31
Relative humidity (evening) (%)	-0.41	-0.22	-0.32
Cumulative Rainfall (mm)	0.86	0.81	0.84

Table 21b. Correlation coefficient (r) of fruit rot incidence with spore load and weather parameters during *kharif* 2012 and 2013

Weather parameters	r values		
	2012	2013	Pooled
Spore load	0.92	0.95	0.94
Maximum temperature (°C)	0.38	0.43	0.41
Minimum temperature (°C)	-0.63	-0.41	-0.52
Relative humidity (Morning) (%)	-0.39	-0.32	-0.36
Relative humidity (evening) (%)	-0.41	-0.35	-0.38
Cumulative Rainfall (mm)	0.77	0.82	0.80

Pooled analysis of two years on observed and predicted spore load of *Colletotrichum* spp. revealed that, the difference in range varied from -4.28 to +1.19

4.3.3.2 Effect of *Colletotrichum* spp. spore load and weather parameters on fruit rot disease

To know the effect of *Colletotrichum* spp. spore load and various weather parameters on fruit rot incidence an epidemiological study was attempted by monitoring the independent variables such as maximum and minimum temperature, relative humidity (morning and evening), rainfall and cumulative rainfall and dependent variable fruit rot incidence during *kharif* 2012and 2013. The weekly averages of weather parameters and fruit rot incidence were recorded for the two cropping seasons. The correlation and multiple regression analysis of independent variables were worked out (Table 20b).

The chilli fruit rot incidence during *kharif* 2012 was positively and highly significantly correlated with spore load (r = 0.92) followed by cumulative rainfall (r = 0.77), positively correlatedwith maximum temperature (r = 0.38) and negatively correlatedwith relative humidity of morning and evening (r = -0.39 and r = -0.41) and minimum temperature r = -0.63).

In 2013 also highly significant positive correlation was recorded with spore load (r = 0.95) followed by cumulative rainfall (r = 0.82), positively correlatedwith maximum temperature (r = 0.43) and negative correlation with morning (r = -0.32) and evening (r = -0.35) relative humidity and minimum temperature (r = -0.41).

In the pooled data of two consecutive years (2012 and 2013), spore load recorded highly significant positive correlation (r = 0.94) followed by cumulative rainfall (r = 0.80), and maximum temperature (r = 0.41). Whereas, other weather parameters *viz*., relative humidity of evening and morning were negatively correlated.

Hence, it could be inferred that spore load of *Colletotrichum* spp. and among weather parameters cumulative rainfall and maximum temperature showed significantly positive correlation on fruit rot incidence in chilli.

Table 22a: Multiple regression analysis between weather parameters on the spore load of *Colletotrichum spp.* during *kharif* 2012and 2013

Parameter	X_1 (Max. Temp.)			X_2 (Min. Temp.)			X_3 (Morn. RH)			X_4 (Even. RH)			X_5 (Cumulative Rainfall)		
	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled
β -value (RC)	2.97	2.68	2.83	-5.56	-4.76	-5.16	0.78	0.92	0.85	0.42	0.36	0.39	0.02	0.02	0.02
SE of β (r)	0.89	0.98	0.94	1.46	1.61	1.54	0.21	0.23	0.22	0.15	0.16	0.16	0.005	0.006	0.01
t value of β	3.32	2.73	3.03	-3.79	-2.95	-3.37	3.73	3.96	3.85	2.74	2.14	2.44	4.69	4.40	4.55
	2012					2013						Pooled			
Intercept (α)	-71.13					-87.31						-79.22			
R^2 value	0.90					0.83						0.87			
2012	$Y_1 = -71.13 + 2.97X_1 - 5.56X_2 + 0.78X_3 + 0.42X_4 + 0.02X_5$														
2013	$Y_2 = -87.31 + 2.68X_1 - 4.76X_2 + 0.92X_3 + 0.36X_4 + 0.02X_5$														
Pooled	$Y_P = -79.22 + 2.83\ X_1 - 5.16\ X_2 + 0.85X_3 + 0.39\ X_4 + 0.02X_5$														

Table 22b: Observed and predicted spore load of *Colletotrichum* spp. during *kharif* 2012and 2013

Standard weeks	2012			2013			Pooled		
	Observed	Predicted	Difference	Observed	Predicted	Difference	Observed	Predicted	Difference
30	0	-1.30	1.30	3.92	4.14	-0.22	1.96	1.42	0.54
31	2.20	2.47	-0.27	5.85	7.20	-1.35	4.03	4.84	-0.81
32	3.61	4.00	-0.39	7.14	10.50	-3.36	5.38	7.25	-1.88
33	4.00	4.11	-0.11	9.71	7.23	2.48	6.86	5.67	1.19
34	4.20	4.01	0.19	10.28	9.46	0.82	7.24	6.74	0.51
35	6.80	7.34	-0.54	10.71	12.20	-1.49	8.76	9.77	-1.02
36	6.00	6.55	-0.55	11.42	13.27	-1.85	8.71	9.91	-1.20
37	8.74	9.10	-0.36	11.85	9.77	2.08	10.30	9.44	0.86
38	7.28	7.47	-0.19	12.28	11.51	0.77	9.78	9.49	0.29
39	10.32	10.88	-0.56	13.74	12.89	0.85	12.03	11.89	0.15
40	7.00	6.43	0.57	8.10	11.99	-3.89	7.55	9.21	-1.66
41	5.82	5.38	0.44	6.28	14.36	-8.08	6.05	9.87	-3.82
42	4.82	5.09	-0.27	5.71	11.66	-5.95	5.27	8.38	-3.11
43	10.67	10.25	0.42	9.32	13.17	-3.85	10.00	11.71	-1.72
44	10.00	9.06	0.94	10.41	19.90	-9.49	10.21	14.48	-4.28

The coefficient of determinative value (R^2) was found to be 88 and 85 per cent in 2012 and 2013 respectively. There was variation in the fruit rot disease incidence which was accounted by the linear functions of the independent variables such as spore load, maximum and minimum temperature, morning and evening relative humidity, rainfall and number of rainy days and dependent variable was fruit rot disease incidence (Table 22a and 22b). The regression equations are as below.

$Y_1 = 75.79+0.41X_1+3.69X_2-6.40X_3+0.73X_4+0.52X_5+0.01X_6$ (for *kharif* 2012)

$Y_2= -106.48+0.35X_1+4.07X_2-5.95X_3+0.81X_4+0.57X_5+0.02X_6$ (for *kharif* 2013)

$Y_P = -91.14+0.38X_1+3.88X_2-6.18X_3+0.77X_4+0.55X_5+0.02X_6$ (for pooled)

It is clear that from the table 22b that during 2012 predicted fruit rot incidence was high compared to actual observed value. The difference between observed and predicted values showed a range of -0.43 to + 5.47. Similarly during 2013 the difference between observed and predicted values showed a range of -0.76 to + 1.88.

Pooled analysis of two years on observed and predicted fruit rot incidence *Colletotrichum* spp. revealed that, the difference in range varied from -0.66 to + 2.48

4.3.5 Effect of date of planting on fruit rot and die-back disease incidence and severity

A field trial was carried out to assess the effect of planting time on fruit rot and die-back disease development during 2012-13 *kharif* with four different dates, starting from 15th June to 1st August at fortnightly intervals with four genotypes Byadgi Kaddi, Byadgi Dabbi, Sankeshwar and Guntur at the Main Agricultural Research Station, Dharwad. Disease incidence and severity of both fruit rot and die-back were recorded (Table 24a). The results revealed that the highest fruit rot incidence 27.15 per cent with 29.24 PDI was observed in July 15th planting, where as in die-back incidence no signicant difference was found among four dates of planting and four varieties. Among four varieties Byadgi Dabbi recorded highest fruit rot incidence (28.09 %) and severity (36.08 PDI).

Table 23a: Multiple regression analysis between fruit rot incidence with spore load and weather parameters during *kharif* 2012 and 2013

Parameter	X_1 (Spore load)			X_2 (Max. Temp.)			X_3 (Min. Temp.)			X_4 (Morn. RH)			X_5 (Even. RH)			X_6 (Cumulative Rainfall)		
	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled
β -value (RC)	0.41	0.35	0.38	3.69	4.07	3.88	-6.40	-5.95	-6.18	0.73	0.81	0.77	0.52	0.57	0.55	0.01	0.02	0.02
SE of β (r)	1.44	1.68	1.56	3.03	3.54	3.29	6.76	7.89	7.33	1.12	1.30	1.21	0.37	0.43	0.40	0.03	0.03	0.03
t value of β	0.28	0.21	0.25	1.21	1.15	1.18	-0.94	-0.75	-0.85	0.65	0.62	0.64	1.40	1.30	1.35	0.45	0.59	0.52
	2012						2013						Pooled					
Intercept (α)	-75.79						-106.48						-91.14					
R^2 value	0.88						0.85						0.87					
2012	$Y_1 = 75.79+0.41X_1+3.69X_2-6.40X_3+0.73X_4+0.52X_5+0.01X_6$																	
2013	$Y_2= -106.48+0.35X_1+4.07X_2-5.95X_3+0.81X_4+0.57X_5+0.02X_6$																	
Pooled	$Y_P = -91.14+0.38X_1+3.88X_2-6.18X_3+0.77X_4+0.55X_5+0.02X_6$																	

Table 23b: Observed and predicted fruit rot incidence with spore load and weather parameters during *kharif* 2012 and 2013

Standard weeks	2012			2013			Pooled		
	Observed	Predicted	Difference	Observed	Predicted	Difference	Observed	Predicted	Difference
30	0	-2.80	2.80	2.82	3.68	-0.86	1.41	0.44	0.97
31	3.33	2.12	1.21	5.00	8.31	-3.31	4.17	5.22	-1.05
32	4.67	3.71	0.96	5.67	13.88	-8.21	5.17	8.80	-3.63
33	7.67	3.99	3.68	9.00	9.76	-0.76	8.34	6.88	1.46
34	9.33	4.03	5.30	11.00	13.71	-2.71	10.17	8.87	1.30
35	10.67	8.34	2.33	12.13	17.90	-5.77	11.40	13.12	-1.72
36	11.67	7.10	4.57	13.17	19.05	-5.88	12.42	13.08	-0.66
37	13.00	11.31	1.69	15.43	13.55	1.88	14.22	12.43	1.79
38	11.71	12.84	-1.13	14.00	15.47	-1.47	14.67	12.67	2.00
39	17.67	14.24	3.43	19.27	17.75	1.52	18.47	16.00	2.48
40	5.67	6.10	-0.43	6.31	15.18	-8.87	5.99	10.64	-4.65
41	8.33	6.56	1.77	8.19	17.05	-8.86	8.26	11.81	-3.55
42	10.32	7.05	3.27	9.96	14.12	-4.16	10.14	10.59	-0.45
43	15.33	9.86	5.47	11.53	17.32	-5.79	11.62	15.08	-3.46
44	13.10	10.69	2.41	12.83	27.37	-14.54	12.97	19.03	-6.07

Table 24a : Effect of date of planting on development chilli fruit rot and die-back disease during *kharif* 2012-13

Date of planting	Genotypes														
	Fruit rot Incidence %					Fruit rot PDI					Die-back Incidence %				
	Byadgi Dabbi	Byadgi kaddi	Sankeshwar	Guntur	Mean	Byadgi Dabbi	Byadgi kaddi	Sankeshwar	Guntur	Mean	Byadgi Dabbi	Byadgi kaddi	Sankeshwar	Guntur	Mean
June 15th	27.72 (31.75)	24.86 (29.89)	26.32 (30.86)	24.94 (29.94)	25.96 (30.61)	33.76 (35.51)	21.80 (27.84)	26.48 (30.96)	37.79 (32.72)	**29.2 (33.06)**	7.48 (15.87)	6.84 (15.16)	7.64 (16.04)	8.94 (17.39)	**7.73** (16.11)
July 1st	26.48 (30.97)	22.83 (28.53)	27.29 (30.36)	26.43 (30.92)	25.76 (30.20)	38.29 (38.22)	17.89 (25.01)	27.34 (30.87)	31.71 (37.92)	**28.81 (32.09)**	8.24 (16.67)	6.49 (14.75)	7.82 (16.23)	6.82 (15.13)	**7.34** (15.70)
July 15th	28.37 (32.18)	26.32 (30.86)	24.95 (29.95)	28.94 (32.53)	27.15 (31.38)	35.34 (36.53)	19.34 (26.08)	28.46 (32.23)	33.81 (34.27)	**29.24 (32.59)**	6.96 (15.29)	7.46 (15.84)	6.94 (15.27)	7.14 (15.49)	**7.13** (15.47)
August 1st	29.80 (33.02)	23.70 (29.18)	28.34 (32.16)	25.83 (30.52)	26.92 (31.22)	36.93 (37.42)	16.92 (24.27)	29.20 (32.72)	21.48 (35.55)	**28.13 (30.50)**	7.00 (15.34)	8.20 (16.63)	8.46 (16.90)	6.94 (15.27)	**7.65** (16.03)
Mean	**28.09** (31.98)	**24.43** (29.61)	**26.73** (30.83)	**26.53 (30.98)**		**36.08** (36.92)	**18.99** (25.80)	**27.87** (31.69)	**32.45** (33.83)		**7.42** (15.79)	**7.25** (15.60)	**7.72** (16.11)	**7.46** (15.82)	
	DOP		Variety	DOP X Variety		DOP		Variety	DOP X Variety			DOP	Variety	DOP X Variety	
S.Em.±	0.37		0.43	0.43		0.10		0.12	0.25			0.42	0.49	0.99	
CD at 0.05	NS		1.28	1.28		0.30		0.36	0.74			NS	NS	NS	

Date of planting	Die-back PDI					Yield (q/ha)				
	Byadgi Dabbi	**Byadgi kaddi**	**Sankeshwar**	**Guntur**	**Mean**	**Byadgi Dabbi**	**Byadgi kaddi**	**Sankeshwar**	**Guntur**	**Mean**
June 15th	36.30 (37.03)	38.94 (38.59)	41.27 (39.96)	38.74 (38.48)	38.81 (38.52)	9.30	9.40	9.40	8.40	9.13
July 1st	33.89 (35.59)	35.15 (36.35)	35.78 (36.72)	34.98 (36.24)	34.95 (36.23)	8.00	8.14	8.35	7.20	7.92
July 15th	34.87 (36.18)	39.84 (39.12)	38.39 (38.27)	39.40 (38.86)	38.13 (38.11)	7.82	7.95	8.12	6.90	7.70
August 1st	40.48 (39.50)	42.49 (40.66)	34.80 (36.14)	41.30 (39.97)	39.77 (39.07)	7.65	7.80	7.28	6.48	7.30
Mean	36.39 (37.07)	39.11 (38.68)	37.56 37.77	38.61 (38.39)		8.19	8.32	8.29	7.25	8.01
	DOP	Variety	DOP X Variety			DOP	Variety	DOP X Variety		
S.Em.±	0.43	0.49	0.99			0.60	0.69	1.38		
CD at 0.05	1.28	1.46	2.94			1.78	2.05	4.10		

DOP: Date of Planting

Table 24b: Effect of date of planting on development chilli fruit rot and die-back disease during *kharif* 2013-14

Date of planting	Fruit rot Incidence %				Fruit rot PDI				Die-back Incidence %				Die-back PDI				Yield (q/ha)			
	BD	BK	SK	Mean	BD	BK	SK	Mean	BD	BK	SK	Mean	BD	Q	SK	Mean	BD	BK	SK	Mean
June 15th	25.52	22.66	24.12	24.10	31.56	19.6	24.28	25.15	7.30	5.55	6.88	6.58	35.06	37.7	40.03	37.60	7.21	7.53	7.89	7.54
July 1st	24.28	20.63	25.09	23.33	36.09	15.69	25.14	25.64	6.54	5.90	6.70	6.38	32.65	33.91	34.54	33.70	7.04	7.89	7.74	7.56
July 15th	26.17	24.12	22.75	24.35	33.14	17.14	26.26	25.51	6.02	6.52	6.00	6.18	33.63	38.6	37.15	36.46	7.79	7.34	6.67	7.27
Mean	**25.32**	**22.47**	**23.99**	**23.93**	**33.60**	**17.48**	**25.23**	**25.43**	**6.62**	**5.99**	**6.53**	**6.38**	**33.78**	**36.74**	**37.24**	**35.92**	**7.35**	**7.59**	**7.43**	**7.46**

BD - Byadagi Dabbi BK – Byadagi Kaddi SK – Sankeshwar

In 2013-14 *kharif* with three different dates of planting was carried out at the Main Agricultural Research Station, Dharwad, with three different dates, starting from 15th June to 15th July at fortnightly intervals with three genotypes Byadgi Kaddi, Byadgi Dabbi and Sankeshwar. Disease incidence and severity of both fruit rot and die-back was recorded and presented in Table 24b. The highest fruit rot incidence 24.35 per cent with 25.51 PDI was observed in July 15th planting, where as highest die-back incidence 6.58 per cent with 37.60 PDI was observed in June 15th planting. The highest yield (7.56q/ha) was recorded in July 1st planting.

4.4 Development of IDM strategies for disease

4.4.1 Field evaluation of chilli genotypes

A total of 343 chilli genotypes were screened in natural endemic condition in MARS Dharwad during *kharif* 2012 and *kharif* 2013. These genotypes were grouped as per the scale and data is presented in the Table 25a and 25b, Plate 32.

Among 343 genotypes screened under natural endemic field condition during *kharif* season of 2012, none of them were found immune, while 15 genotypes showed resistant reaction, 39 genotypes were found moderately resistant with grade scale of 3. However, 199 genotypes were moderately susceptible, 86 genotypes were found susceptible and the remaining 4 genotypes were highly susceptible with infection of >75 per cent.

During *kharif* 2013 out of 343 genotypes screened, none of them were found immune, while eight genotypes were found resistant, 30 genotypes were moderately resistant. However, 168 genotypes were moderately susceptible, 131 genotype were susceptible and six genotypes were highly susceptible with infection of >75 per cent.

For both years of investigation *kharif* 2012-13 and 2013-14 eight genotypes were found resistant where as 21 genotypes were recorded as moderately resistant.

4.4.1.1 *In vitro* screening of genotypes

To identify the resistant sources to fruit rot severity, a total of 38 chilli genotypes were screened against *Colletotrichum* spp. (*C.capsici, C. gloeosporioides* and *C.*

Table 25a: Grouping of chilli genotypes based on resistance against fruit rot disease under field condition during *kharif* 2012-13

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune		0
1	1-10	Resistant	*Capsicum baccatum,* DC – 1001, DC – 1002, DCA-101, DH-10-1, DH-12-1, VN-2, Tiwan-17, Nooji-2, IC-119559, Jin's Joy, Susan's Joy, Moor/Perenni, Gift from Maldov, VN_2 X B. Dabbi,	15
3	11-25	Moderately resistant	Byadgi Kaddi, DC – 1006, DC – 1007, DCA-102-2, DCA-106-1, DCA-107-1, DCA-109-2, DCA-118, DCA-118-1, KDSC-210-10-4, LCA-312, SNK, SIC-11-179, SIC-10-166-1, Pant C-1-1, Pant C-1-2, Pant C-1-3, Cochin, Cochin-2 UFM-2-1, DH-2, DH-12, DH-11, LCA-206, LCA-206-1, VN-2-1, SKAU- SC-618-2, SKAU- SC-231, DCA-241, Tiwan-8, Tiwan-5, Tiwan-4, Tiwan-15, Tiwan-19, IC-119756, Punjab Guchedar, CCA-3288, CCA-3468, CCA-3336	39
5	26-50	Moderately susceptible	*C. chinense,* DC – 1003, DC – 1008, DCA-101-1, DCA-102, DCA-102-3, DCA-103-1, DCA-106, DCA-106-2, DCA-107, DCA-108, DCA-108-1, DCA-108-2, DCA-108-3, DCA-109-1, DCA-110, DCA-110-1, DCA-112, DCA-112-1, DCA-113, DCA-114-1, DCA-115-1, DCA115-2, DCA-115-3, DCA-116, DCA-120, DCA-121, DCA-122-2, KDSC-210-10-1, DCA-123-2, DCA-124-1, DCA-125-1, DCA-126, DCA-127-1, DCA-129, DCA-131, DCA-132, DCA-132-1, DCA-133, DCA-135-1 KDSC-210-10, DCA-123-1KDSC-21010-2, KDSC-210-10-3, KDSC-510-10-1, KDSC-510-10-2, CO-3, Arka Lohith, PMR-5, PMR-5-1, LCA-305, LCA-206, LCA-283, LCA-283-1, LCA-312-1, LCA-312-2, LCA-324, Hissar Shakthi,Hissar Shakthi-1, Hissar Shakthi-2, G-3-1, LCA-310 (2-3 pods/node), LCA-310-1, LCA-310-2, Hissar Vijay, LCA-304-1, DCA- 155, DH-9-6-6, GPC-82-1, AR-75, GPC-82-1-1, S-32, SIC-10-166, Serano, Cochin-1, Button ,,UFM-2, Buttom-1, Button-2, DH-5, DH-5-1, DH-5-2, DH-10, DH-1, Mosac-27, 1701 F4, GPM-60, GPM-50, GPM-50-1, PBC-460, PMR-21, Pant C-2 , Paprika-2, CO-3, Phule-5, JJK-2000-114, JJK-2000-114-1, K-1, JCA-283, JCA-283-1, CO-1, AR-75, D3-46, S-32, Pant C-1-1, LCA-304, LCA-304-2 SKAU- SC-105-4, SKAU- SC-305, SKAU- SC-1003-2, SKAU- SC-23-1, SKAU- SC-101-1, SKAU- SC-502-1, SKAU- SC-885, SKAU- SC-97, SKAU- SC-3, SKAU- SC-107, SKAU-Agnirekha-Sel-1, SKAU-Wonder hot- Sel -1, SKAU-PS-1 (Payorika-Sel-1), SKAU-PS-4 (Payorika-Sel-4), SKAU-PS-2, SKAU-PS-3, SKAU- SC-105, SKAU-SC-115, S-32-1, DCA-237, DCA-238, DCA-239, DCA-240, Tiwan-1, Tiwan-2, Tiwan-3, Tiwan-7,Tiwan-9, Tiwan-10, Tiwan-11, Tiwan-12, Tiwan-13, Tiwan-14, Tiwan-16, Tiwan-18, China-1, China-2, China-3, Sankeshwar-1, Ornamental, Nooji-1 , Lokal Capcicum-red, Tomato Chilli (Warangal Sapota), Kadrolli Local, Chikballapur Local, Phule Jyothi, Phule Sai, X-235, IC-92109, IC-119243, IC-119264, IC-119267, IC-119546, IC-119578, IC-119581, IC-119594, IC-119614, IC-119736, IC-208595, IC-20416, IC-20901, Horti Local, S-2530 (PAV), Mr. Lee No. 3, MSH-1, PBC-308, PBC-396, PBC-788,, CCA-1349 , CCA-3106, CCA-3331, Mr. Lee No. 3, MSH-1, PBC-308, PBC-396, PBC-788, CCA-1349 , CCA-3106, CCA-3331, CCA-3743, CCA-260, CCA-4-0, CCA-2340-2, CCA-321, CCA-323, CCA-984-A, CCA-982-A, CCA-1410-A , CCA-42-A, CCA-48-A, US- 170, US- 344, US- 341, US- 611, US- 720, US- 1055	199

Grade	PDI	Reaction	Genotype	No. of genotypes
7	51-75	Susceptible	Sankeshwar, DC – 1004, DC – 1005, DC - 1009 , DCA-101-2, DCA-101-3, DCA-103, DCA-104, DCA-104-1, DCA-105, DCA-109, DCA-113-1, DCA-114, DCA-115, DCA-117, DCA-119, DCA-122, DCA-123, DCA-124, DCA-125, DCA-127, DCA-128, DCA-130, DCA-130-1, DCA-134, DCA-134-1, DCA-135, DCA-135-2, KDSC-510-10, GPC-69, GPC-69-1, GPC-80, CO-1, Arka asir, LCA-206-1, LCA-324-1, LCA-324-2, Hissar Shakthi-3, G-3, LCA-304, DH-9-6-6-1, G-4, Yellow, Jwala-UR, Phule-5, Phule-5-1, Pant C-1, UNFM-1, Button-1, JJK -2000-114, Button, DH-8, GPM-56, Paprika-1, Co-3-1, Hissar Vijay, PBC-460, LCA-310, LCA-304-1, SKAU- SC-578-1, SKAU- SC-101, DCA-236, SKAU- SC-814-2, SKAU- SC-1003, DCC – 201, B.Dabbi(Kusugal), IC-119561, IC-119592, IC-119598, IC-119608, IC-119622, IC-119696, IC-119701, 96 TH 1101, PBC-142 , PBC-535, CCA-3619, CCA-4-1, CCA-750, CCA-3636, CCA-191-A, CCA-215-A, US- 113, US- 918	86
9	> 75	Highly susceptible	Byadgi Dabbi, GPM-64, Pant C-1, Punjab Surkha	4

Table 25b: Grouping of chilli genotypes based on resistance against fruit rot disease under field condition during *kharif* 2013-14

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune	-	0
1	1-10	Resistant	*Capsicum baccatum*, DC – 1001, DCA-101, DH-10-1, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X B. dabbi	8
3	11-25	Moderately resistant	Byadgi Kaddi, DC – 1002, DC – 1003, DC – 1006, DC – 1007, DCA-109-2, KDSC-210-10-4, LCA-312, SNK SIC-10-166-1, Pant C-1-2, Cochin, Cochin-2, DH-2, DH-11, DH-12-1, VN-2, SKAU- SC-618-2, Tiwan-5 Tiwan-8, Tiwan-17, Nooji-2, Kadrolli Local, IC-119559, IC-208595, Punjab Guchedar , Moor/Perenni CCA-3288, CCA-3336, CCA-3468	30
5	26- 50	Moderately susceptible	Sankeshwar, *C. chinense*, DC – 1004, DC – 1005, DC – 1009, DC – 1008, DCA-102-2, DCA-106-1, DCA-107-1, DCA-101-2, DCA-101-3, DCA-102, DCA-103, DCA-104, DCA-104-1, DCA-105, DCA-106-2, DCA-108-1, DCA-109, DCA-108-3, DCA-109-1, DCA-110, DCA-110-1, DCA-113-1, DCA115-2, DCA-115-3, DCA-117, DCA-118-1, DCA-119,, DCA-121, DCA-122, DCA-123, DCA-125, DCA-126, DCA-129, DCA-132, DCA-132-1, DCA-133, DCA-135-1, DCA-135-2, KDSC-210-10-2, KDSC-210-10-3, KDSC-510-10, KDSC-510-10-1, KDSC-510-10-2, GPC-69, GPC-69-1, GPC-80, CO-3, LCA-312-1, Arka asir, LCA-305, LCA-206, LCA-206-1, LCA-283, Arka Lohith, LCA-324, LCA-324-1, Hissar Shakthi-1, Hissar Shakthi-2, G-3, G-3-1, LCA-310 (2-3 pods/node), LCA-310-2, Hissar Vijay, LCA-304-1, DH-9-6-6, DH-9-6-6-1, GPC-82-1-1, Jwala-UR, Pant C-1, Pant C-1-1, Pant C-1-3, Cochin-1, Button-1, UFM-2, UFM-2-1, Button, Button-2, DH-5, DH-5-1, DH-8, DH-10, DH-12, DH-1, 1701 F4, GPM-56 PBC-460, Paprika , JJK-2000-114-1, K-1, JCA-283, JCA-283-1, CO-1, LCA-206-1, LCA-206, VN-2-1, PBC-460, LCA-310, S-32-1, LCA-304, LCA-304-2, LCA-312, SKAU- SC-965-5, SKAU- SC-105, SKAU- SC-814-2, SKAU- SC-105-4, SKAU- SC-1003-2, SKAU- SC-502-1, SKAU- SC-231, SKAU- SC-107, SKAU-Agnirekha-Sel-1SKAU-Wonder hot- Sel -1, SKAU-PS-4 (Payorika-Sel-4, SKAU-PS-3, DCA-240, DCA-241, Tiwan-1, Tiwan-4, Tiwan-7, Tiwan-9, Tiwan-13, Tiwan-15, Tiwan-16, Tiwan-18, Tiwan-19, China-1, China-3, Nooji-1 , Lokal Capcicum-red, Tomato Chilli , Spice Paprica, Phule Sai, Chikballapur Local, Phule Jyothi, IC-119243, IC-119267, IC-119546, IC-119561, IC-119581, IC-119594, IC-119614, IC-119736, IC-208595, IC-20416, IC-20901, PBC-612, 96 TH 1101, Mr. Lee No. 3, MSH-1, PBC-142 , PBC-535, CCA-1349 , CCA-3106, CCA-3331, CCA-3619, CCA-3743, CCA-260, CCA-321, CCA-982-A, CCA-191-A, CCA-215-A, CCA-48-A , US- 113, US-611, US- 720, US- 918, US- 1055	168

Grade	PDI	Reaction	Genotype	No. of genotypes
7	51 - 75	Susceptible	DCA-101-1, DCA-102-3, DCA-103-1, DCA-106, DCA-107, DCA-108-2, DCA-112, DCA-112-1, DCA-113, DCA-114, DCA-114-1, DCA-115, DCA-115-1, DCA-116, DCA-118, DCA-120, DCA-122-2, DCA-123-1, DCA-123-2, DCA-124, DCA-124-1, DCA-125-1, DCA-127, DCA-127-1, DCA-128, DCA-130, DCA-130-1, DCA-131, DCA-134, DCA-134-1, DCA-135, KDSC-210-10, KDSC-210-10-1, CO-1, PMR-5, PMR-5-1, LCA-283-1, LCA-312-2, LCA-324-2, Hissar Shakthi, Hissar Shakthi-3, LCA-310-1, LCA-304, DCA- 155, GPC-82-1, AR-75, S-32, Yellow, SIC-11-179, SIC-10-166, Serano, Phule-5 UNFM-1, Button , JJK -2000-114, Buttom-1, DH-5-2, Mosac-27, GPM-60, GPM-50, GPM-50-1, PMR-21, Pant C-2 , Paprika-1, Paprika-2, Co-3-1, Phule-5, Hissar Vijay, JJK-2000-114, AR-75, D3-46, S-32, Pant C-1, Pant C-1-1, LCA-304-1, SKAU-SC-304-1, SKAU- SC-578-1, SKAU-SC-1003, DCC – 201, SKAU- SC-305, SKAU- SC-23-1, SKAU- SC-101, SKAU- SC-101-1, SKAU- SC-885, SKAU- SC-97, SKAU- SC-3, SKAU-PS-1 (Payorika-Sel-1), DCA-237, DCA-238, DCA-239, Tiwan-2, Tiwan-3, Tiwan-10, Tiwan-11, Tiwan-12, Tiwan-14, Tiwan-17,, B.Dabbi(Kusugal), China-2, Sankeshwar-1, Ornamental, X-235, IC-92109, IC-119264, IC-119578, IC-119592, IC-119598, IC-119608, IC-119622, IC-119696, IC-119701, Horti Local, S-2530 (PAV), Punjab Surkha, PBC-308, PBC-396, PBC-788, CCA-4-0, CCA-4-1, CCA-2340-2, CCA-750, CCA-323, CCA-3636, CCA-984-A, CCA-1410-A, CCA-42-A, US- 170, US- 341, US- 344	130
9	> 75	Highly susceptible	Byadgi Dabbi, DCA-108, G-4, Phule-5-1, GPM-64, SKAU-PS-2, DCA-236	7

Table 25c: Grouping of resistant and moderately resistant chilli genotypes against fruit rot disease under field condition during *kharif* 2012-13 and 2013-14

Grade	PDI	Reaction	Genotype	No. of genotypes
1	1-10	Resistant	*Capsicum baccatum*, DC – 1001, DCA-101, DH-10-1, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X B. dabbi	8
3	11-25	Moderately resistant	Byadgi Kaddi, DC – 1006, DC – 1007, DCA-109-2, KDSC-210-10-4, LCA-312, SNK, SIC-10-166-1, Pant C-1-2, Cochin, Cochin-2, DH-2, DH-11, SKAU-SC-618-2, Tiwan-5 Tiwan-8, IC-119756, Punjab Guchedar , CCA-3288, CCA-3336, CCA-3468	21

a. Overview of genotypes screening

b. DC – 1001

c. Vn_2 X Byadgi Dabbi

d. *Capsicum baccatum*

e. CCA-3468

f. Tiwan-18

g. Byadgi Dabbi

Plate 32a Screening of chilli genotypes for resistance against fruit rot disease under field condition

Table 26a: Reaction of chilli genotypes against *Colletotrichum* spp. under *in vitro* condition

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune		0
1	1-10	Resistant		0
3	11 – 25	Moderately resistant	*Capsicum baccatum,* DC – 1001, DC – 1002, DC – 1003 ,DC – 1006, DC – 1007, DCA-101, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X Byadgi Dabbi, DH-10-1, Punjab Guchedar, LCA-312, Tiwan-17, Nooji-2, Moor/Perenni	17
5	26 – 50	Moderately susceptible	Byadgi Kaddi , DCA-109-2, KDSC-210-10-4, SNK, SIC-10-166-1, Pant C-1-2, Cochin Cochin-2, DH-2, DH-11	10
7	51 - 75	Susceptible	IC-119756, Tiwan-8, DCA-236, DH-12-1 VN-2, SKAU- SC-618-2	6
9	> 75	Highly susceptible	Byadgi Dabbi, Kadrolli Local, IC-119559, CCA-3288, CCA-3336, CCA-3468	6

Table 26b: Reaction of chilli genotypes against *A. alternata* under *in vitro* condition

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune		0
1	1-10	Resistant		0
3	11 – 25	Moderately resistant	*Capsicum baccatum,* DC – 1001, DC – 1002, DC – 1003 ,DC – 1006, DC – 1007, DCA-101, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X Byadgi Dabbi, DH-10-1 Punjab Guchedar, DCA-109-2, DH-11, LCA-312, Tiwan-17, Nooji-2, Moor/Perenni	19
5	26 – 50	Moderately susceptible	Byadgi Kaddi , DCA-109-2, KDSC-210-10-4, SNK, SIC-10-166-1, Pant C-1-2, Cochin, Cochin-2, DH-2	9
7	51 - 75	Susceptible	IC-119756, Tiwan-8, DCA-236, DH-12-1 VN-2, SKAU- SC-618-2	6
9	> 75	Highly susceptible	Byadgi Dabbi, Kadrolli Local, IC-119559, CCA-3288, CCA-3336, CCA-3468	6

Table 26c: Reaction of chilli genotypes against *Fusarium* spp. under *in vitro* condition

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune	0	0
1	1-10	Resistant	0	0
3	11 – 25	Moderately resistant	*Capsicum baccatum,* DC – 1001, DC – 1002, DC – 1003 ,DC – 1006, DC – 1007, DCA-101, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X Byadgi Dabbi, DH-10-1 Punjab Guchedar, DCA-109-2, DH-11, LCA-312, Tiwan-17, Nooji-2, Moor/Perenni, DH-2	20
5	26 – 50	Moderately susceptible	Byadgi Kaddi , KDSC-210-10-4, SNK, Pant C-1-2, Cochin, Cochin-2, DH-2	7
7	51 - 75	Susceptible	SIC-10-166-1, IC-119756, Tiwan-8, DCA-236, VN-2, SKAU- SC-618-2	6
9	> 75	Highly susceptible	Byadgi Dabbi, Kadrolli Local, IC-119559, DCA-236, CCA-3336, CCA-3468	6

Table 26d: Reaction of chilli genotypes against *Colletortrichum* spp*. A. alternata, Fusarium* spp. under *in vitro* condition

Grade	PDI	Reaction	Genotype	No. of genotypes
0	0	Immune		0
1	1-10	Resistant		0
3	11 – 25	Moderately resistant	*Capsicum baccatum,* DC – 1001, DC – 1002, DC – 1003 ,DC – 1006, DC – 1007, DCA-101, Jin's Joy, Susan's Joy, Gift from Maldov, VN_2 X Byadgi Dabbi, DH-10-1 Punjab Guchedar, LCA-312, Tiwan-17, Nooji-2, Moor/Perenni	17
5	26 – 50	Moderately susceptible	Byadgi Kaddi , KDSC-210-10-4, SNK, SIC-10-166-1, Pant C-1-2, Cochin, Cochin-2, DH-2	7
7	51 - 75	Susceptible	IC-119756, Tiwan-8, DCA-236, DH-12-1 VN-2, SKAU- SC-618-2	6
9	> 75	Highly susceptible	Byadgi Dabbi, Kadrolli Local, IC-119559, CCA-3288, CCA-3336, CCA-3468	6

a. Diversity of chilli genotypes used for screening

b. Inoculation by pin prick method

c. Incubation in moist chamber

d. Symptoms on fruits

Plate 33: In vitro screening of chilli genotypes

acutatum) *A.alternata*, *F. oxysporum, F. sporotrichioides* in laboratory condition by pin prick method and the reactions of all these genotypes are furnished in the Table 26a, 26b and 26c (Plate 33).

Results indicated that the genotypes have diverse degree of reaction against *Colletotrichum* spp. (*C.capsici, C. gloeosporioides* and *C. acutatum*) *A.alternata*, *F. oxysporum, F. sporotrichioides.* Among 38 genotypes, none of them showed immune and resistant reaction. However, moderately resistant reaction was observed in seventeen genotypes, ten genotypes showed moderately susceptible reaction against *C.capsici, C. gloeosporioides, C. acutatum*. 19 genotypes showed moderately resistant, eight showed moderately susceptible reaction against *A.alternata* and 20 genotypes showed moderately resistant, seven showed moderately susceptible reaction against *F. oxysporum* and *F. sporotrichioides*.

4.4.2 Seed health management

4.4.2.1 Standard Blotter Method

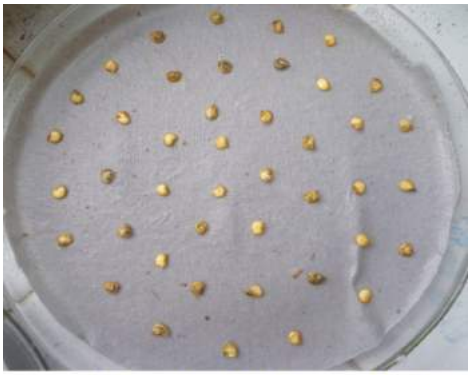
The seeds which were showing fungal colonies were observed under stereoscopic-binocular microscope, morphology of mycelium, asexual fruiting body and conidia revealed the presence of *Colletotrichum capsici* (72.85%), *C. gloeosporioides* (9.26%) and *C. acutatum* (4.76%)*, Alternaria alternata* (5.20%) and *Fusarium sporotrichioides* (3.45%) and *F. oxysporum* (4.30%) (Table 27, Plate 34).

4.4.2.2 Seed treatment with chemical fungicides

Evaluation of seed treatment fungicides (Table28) revealed that among three systemic fungicides evaluated at 0.2% concentration, pyraclostrobin 20WG showed least infection (11.63%) with highest vigour index (861.17). Between two non systemic fungicides captan 75WP showed least infection (12.28%) with highest vigour index (754.64). Among six combi product fungicides, carboxin 37.5% + thiram 37.5% WS showed least infection (7.25%) with highest vigour index (932.02) followed by metalaxyl 4%+mancozeb64% (10.09%, 871.70). Highest infection (43.26%) with least vigour index (351.77) was observed in untreated control.

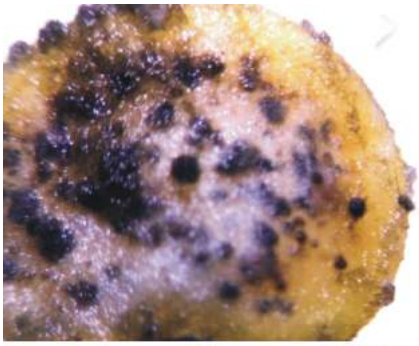
Table 27: Chilli seed mycoflora under stereo binocular microscope

Fungi	Frequency (%)
Colletotrichum capsici	72.85
C. gloeosporioides	9.26
C. acutatum	4.76
Alternaria alternata	5.20
Fusarium sporotrichioides	3.45
F. oxysporum	4.30

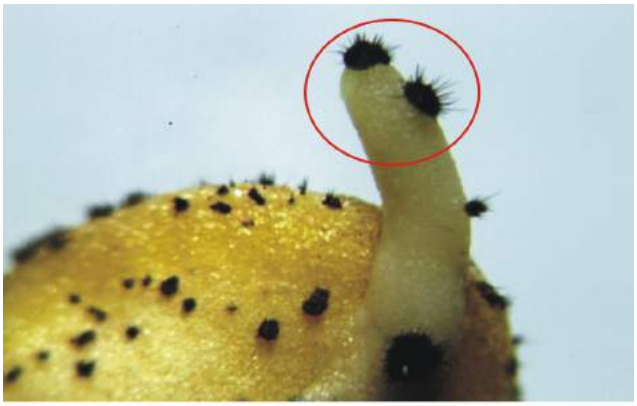


a. Standard blotter method

b. Fungal growth on seed



c. Acervulii on seed (50X)



d. Acervulii on plumule (50X)

e. Acervulii on radicle (50X)

Plate 34 Seed health study

Table 28: Effect of fungicide seed treatment on per cent seedling infection and vigour index in chilli

Common name	a.i. and formulation	Trade name	Per cent seedling infection	Vigour index
Systemic fungicides @ 0.2%				
Carbendazim	50 WP	Bavistin	12.28 (20.50)*	825.62
Pyraclostrobin	20 WG	Headline	11.63 (19.93)	861.17
Tebuconazole	2 DS	Raxil	13.40 (21.46)	772.35
Nonsystemic fungicides @ 0.2%				
Captan	75 WP	Captaf	19.99 (26.54)	754.64
Mancozeb	75 WP	Indofil-M45	20.09 (26.61)	660.03
Combi product fungicides @ 0.2%				
Carboxin 37.5% + Thiram 37.5%	75 WS	Vitavax power	7.25 (15.60)	932.02
Carbendazim 25% + Mancozeb 50%	75 WS	Sprint	16.67 (24.08)	744.22
Carbendazim 25% + Iprodione 25%	50 WP	Quintal	13.12 (21.23)	808.90
Hexaconazole 4 % + Zineb 68 %	72 WP	Avtar	14.11 (22.05)	762.30
Metalaxyl 4% + Mancozeb 64%	68WP	Ridomil-Gold	10.09 (18.51)	871.70
Tricyclazole 18% + Mancozeb 62%	80 WP	Merger	11.17 (19.51)	864.15
Control	-	-	43.26 (41.10)	351.77
S.Em. ±			0.17	5.87
CD @ 5%			0.49	17.22

* Arc sine values

4.4.2.2 Seed treatment with bio-fungicides

Results of four bio fungicides (Table29) alone (@ 10.0 g/kg) and in combination (5.0 +5.0 g/kg) seed treatment revealed that *T. harzianum* 5.0g + *P. fluorescens* 5.0g showed least infection (14.89%) with highest vigour index (930.74) followed by *P. fluorescens* (10.0 g/kg) 14.94% infection with 915.27 vigour index. Highest seedling infection (42.99%) with least vigour index (361.87) was observed in untreated control.

4.4.3 Field efficacy of chemicals for the management of fruit rot and die-back disease of chilli during *kharif* 2012 and 2013

A field experiment was conducted during *kharif* 2012 and 2013 at MARS Farm, Dharwad for management of fruit rot and die-back disease of chilli using four systemic and four combi-product fungicides along with untreated control. Insect management was done as per package of practice. Data are furnished in Table 30 to 32.

Kharif 2012

Evaluation of fungicides revealed that among four systemic fungicides evaluated at 0.1% concentration difenconazole 25EC showed least incidence of die back (1.33 %) with 12.31 PDI which is on par with pyraclostrobin 20WG (2.0 per cent, 16.49PDI) and propiconazole 25EC (2.66 per cent, 19.89 PDI). Least fruit rot incidence (8.31 %) was observed in difenconazole 25EC followed by pyraclostrobin 20WG (12.26 %), whereas least fruit rot severity (7.33 PDI) observed in pyraclostrobin 20WG (Table 30).

Among four combi product fungicides tested pyraclostrobin 5% + metiram 55% WG showed the least incidence (1.66 %) of die back with least severity (13.83 PDI) which is on par with tricyclazole 18% + mancozeb 62% WP (1.68 per cent, 14.31 PDI). Least fruit rot incidence (10.49 %) was observed in tricyclazole 18% + mancozeb 62% WP, whereas least fruit rot severity (9.00 PDI) observed in pyraclostrobin 5% + metiram 55% WG. Highest yield was observed in difenconazole 25EC (9.15 q/ha) with cost benfit ratio 2.66 which is on par with tricyclazole 18% + mancozeb 62% WP (8.75 q/ha, C:B 2.44) and pyraclostrobin 5% + metiram 55% (8.65 q/ha C:B 2.48).

Table 29: Effect of bio fungicide seed treatment on per cent seedling infection and vigour index in chilli

Treatments (10g/kg)	Rate per kg seed	Per cent seedling infection	Vigour index
Trichoderma harzianum	10g	16.66 (24.07)*	804.90
Pseudomonas fluorescens	10g	14.94 (22.72)	915.27
Bacillus subtilis	10g	17.44 (24.67)	804.29
T. harzianum + *P. fluorescens*	5g+5g	14.89 (22.68)	930.74
T. harzianum + *B. subtilis*	5g+5g	16.16 (23.69)	833.14
P. fluorescens + *B. subtilis*	5g+5g	15.39 (23.08)	900.99
T. harzianum + *Verticillium lecanii*	5g+5g	16.35 (23.84)	831.53
P. fluorescens + *Verticillium lecanii*	5g+5g	15.58 (23.23)	836.00
B. subtilis + *Verticilium lecanii*	5g+5g	16.64 (24.06)	815.12
Control	-	42.99 (41.10)	361.87
S.Em. ±		0.20	4.94
CD @ 5%		0.59	14.68

* Arc sine values

Highest die back incidence (6.33 %), die back severity (33.33 PDI), fruit rot incidence (20.83 %) and fruit rot severity (52.30 PDI) with lowest yield 3.81 q/ha was observed in control (Table 30).

kharif 2013

Evaluation of fungicides revealed that among four systemic fungicides evaluated at 0.1% concentration difenconazole 25EC showed the least incidence of die back (2.47 %) with 13.47 PDI which is on par with propiconazole 25EC (3.67 per cent, 20.29PDI) and pyraclostrobin 20WG (3.80 per cent, 17.67 PDI). Least fruit rot incidence (9.67 %) was observed in difenconazole 25EC followed by pyraclostrobin 20WG (12.23 %), whereas least fruit rot severity (8.50 PDI) observed in pyraclostrobin 20WG which is on par with difenconazole 25EC (8.67 PDI) (Table 31).

Among four combi product fungicides, pyraclostrobin 5% + metiram 55% WG showed the least incidence (1.66 %) of die back with least severity (13.83 PDI) which is on par with tricyclazole 18% + mancozeb 62% WP (2.67 per cent, 13.51 PDI). Least fruit rot incidence (11.67 %) was observed in tricyclazole 18% + mancozeb 62% WP, whereas least fruit rot severity (10.17 PDI) observed in pyraclostrobin 5% + metiram 55% WG. Highest yield was observed in difenconazole 25EC (8.66 q/ha) with cost benefit ratio 2.52, which was on par with pyraclostrobin 5% + metiram 55% (8.10 q/ha C:B 2.32) and tricyclazole 18% + mancozeb 62% WP (7.66 q/ha C:B 2.14).

Highest die back incidence (7.67 %), die back severity (35.33 PDI), fruit rot incidence (22.67 %) and fruit rot severity (55.33 PDI) with lowest yield 3.30 q/ha was observed in control (Table 31).

The pooled results of *kharif* 2012 and 2013 indicated that at 0.1% concentration difenconazole 25EC shown least incidence of die-back (1.93 %) which was on par with propiconazole, pyraclostrobin and also with all combi product fungicides. Highest die-back incidence (7.00 %) in control followed by tebuconazole (5.00 %). Least die-back severity (12.88 PDI) was observed in difenconazole which was on par with tricyclazole 18% + mancozeb 62% WP (15.41PDI) and pyraclostrobin 5% + metiram 55% (13.50 PDI) followed by pyraclostrobin 20WG (17.67 PDI), whereas highest die-back severity (35.38 PDI) was observed in control followed by tebuconazole (23.65 PDI).

Table 30: Chemical management of fruit rot and dieback disease during *kharif* 2012-13

Treatment	Trade Name	a.i.	Formulation	Concentration %	Dieback Incidence (%)	Dieback Severity (%)	Fruit rot Incidence (%)	Fruit rot Severity (%)	Dry Fruit Yield q/ha	C: B
Difenconazole	Score	25	EC	0.1	1.33 (6.53)*	12.31 (20.31)	8.31 (16.72)	7.67 (16.02)	9.15	2.66
Propiconazole	Tilt	25	EC	0.1	2.66 (9.08)	19.89 (26.47)	13.12 (21.20)	11.00 (19.32)	7.65	2.21
Pyraclostrobin	Headline	20	WG	0.1	2.0 (7.94)	16.49 (23.93)	12.26 (20.48)	7.33 (15.48)	8.30	2.31
Tebuconazole	Folicur	25.9	EC	0.1	4.66 (12.35)	22.90 (28.55)	15.31 (23.03)	12.00 (20.22)	7.05	2.02
Hexaconazole 4% + Zineb 68%	Avatar	72	WP	0.25	2.33 (8.74)	18.99 (25.81)	12.56 (20.74)	9.33 (17.63)	8.05	2.27
Tricyclazole 18% + Mancozeb62%	Merger	80	WP	0.25	1.68 (7.33)	14.31 (22.22)	10.49 (18.89)	10.00 (18.37)	8.75	2.44
Carbendazim 12%+ Mancozeb 63%	Saaf	75	WP	0.25	3.33 (10.49)	21.41 (27.49)	13.43 (19.71)	12.33 (20.49)	7.9	2.26
Pyraclostrobin 5% + Metiram 55%	Cabriotop	60	WG	0.25	1.66 (7.15)	13.83 (21.80)	11.39 (21.49)	9.00 (17.30)	8.65	2.48
Control					6.33 (16.77)	33.33 (35.25)	20.83 (27.14)	52.30 (46.30)	3.81	1.27
S.Em.±					1.63	1.71	0.84	1.50	0.72	
CD @0.05					3.39	3.63	1.80	3.20	2.2	

* Arc sine values

Table 31: Chemical management of fruit rot and dieback disease during *kharif* 2013-14

Treatment	Trade Name	a.i.	Formulation	Concentration %	Dieback Incidence (%)	Dieback Severity (%)	Fruit rot Incidence (%)	Fruit rot Severity (%)	Dry Fruit Yield q/ha	C: B
Difenconazole	Score	25	EC	0.1	2.47 (9.03)*	13.47 (21.52)	9.67 (18.11)	8.67 (17.11)	8.66	2.52
Propiconazole	Tilt	25	EC	0.1	3.67 (11.04)	20.29 (26.76)	14.28 (22.19)	12.45 (20.65)	6.33	1.83
Pyraclostrobin	Headline	20	WG	0.1	3.80 (11.24)	17.67 (24.84)	12.23 (20.46)	8.50 (16.94)	7.16	2.00
Tebuconazole	Folicur	25.9	EC	0.1	5.33 (13.35)	23.67 (29.10)	16.67 (24.09)	13.83 (21.82)	6.83	1.96
Hexaconazole 4% + Zineb 68%	Avatar	72	WP	0.25	3.87 (11.34)	19.33 (26.07)	14.41 (22.30)	10.28 (18.69)	7.16	2.02
Tricyclazole 18% + Mancozeb62%	Merger	80	WP	0.25	3.93 (11.43)	15.44 (23.13)	11.67 (19.96)	12.35 (20.57)	7.66	2.14
Carbendazim 12%+ Mancozeb 63%	Saaf	75	WP	0.25	4.77 (12.61)	22.40 (28.24)	14.33 (22.24)	13.90 (21.88)	7.12	2.04
Pyraclostrobin 5% + Metiram 55%	Cabriotop	60	WG	0.25	2.67 (9.39)	13.51 (21.56)	12.00 (20.26)	10.17 (18.59)	8.10	2.32
Control					7.67 (16.07)	35.33 (36.46)	22.67 (28.42)	55.33 (48.04)	3.30	1.10
S.Em.±					0.99	0.68	1.13	1.23	0.93	
CD @0.05					2.96	2.03	3.38	3.70	2.78	

* Arc sine values

Table 32: Pooled analysis of chemical management of fruit rot and dieback disease during 2012-13 and 2013-14

Treatment	Trade Name	a.i.	Formulation	Concentration %	Dieback Incidence (%)	Dieback Severity (%)	Fruit rot Incidence (%)	Fruit rot Severity (%)	Dry Fruit Yield q/ha	C: B
Difenconazole	Score	25	EC	0.1	1.93 (7.99)*	12.88 (20.98)	8.99 (17.44)	8.18 (16.62)	8.86	2.59
Propiconazole	Tilt	25	EC	0.1	3.13 (10.18)	20.23 (26.68)	13.73 (21.74)	11.77 (20.05)	6.95	2.02
Pyraclostrobin	Headline	20	WG	0.1	2.93 (9.86)	17.67 (24.79)	12.25 (20.48)	7.91 (16.32)	7.74	2.16
Tebuconazole	Folicur	25.9	EC	0.1	5.00 (12.92)	23.65 (29.06)	15.96 (23.540	12.95 (21.08)	6.93	1.99
Hexaconazole 4% + Zineb 68%	Avatar	72	WP	0.25	3.13 (10.19)	19.33 (26.05)	13.42 (21.48)	9.82 (18.26)	7.60	2.15
Tricyclazole 18% + Mancozeb62%	Merger	80	WP	0.25	2.80 (9.63)	15.41 (23.10)	11.08 (19.44)	11.18 (19.53)	8.21	2.29
Carbendazim 12%+ Mancozeb 63%	Saaf	75	WP	0.25	4.03 (11.58)	22.42 (28.16)	13.00 (21.13)	13.13 (21.24)	7.53	2.15
Pyraclostrobin 5% + Metiram 55%	Cabriotop	60	WG	0.25	2.23 (8.59)	13.50 (21.53)	11.70 (19.99)	9.55 (17.99)	8.33	2.40
Control					7.00 (15.34)	35.38 (36.48)	21.79 (27.82)	53.83 (47.18)	3.58	
S.Em.±					1.33	1.02	0.85	0.77	0.90	
CD @0.05					3.92	3.07	3.07	2.30	2.69	

* Arc sine values

In difenconazole 25EC least fruit rot incidence (8.99 %) was observed which was on par with tricyclazole 18% + mancozeb 62% WP (11.08 %) and pyraclostrobin 5% + metiram 55% (11.70 %) and pyraclostrobin 20WG (12.25 %), whereas highest fruit rot incidence (21.79 %) was observed in control. Least fruit rot severity (7.91 PDI) was observed in pyraclostrobin 20WG which was on par with difenconazole 25EC (8.18 PDI) pyraclostrobin 5% + metiram 55% (9.55PDI), whereas highest fruit rot severity (53.83 PDI) was observed in control.

Highest yield was observed in difenconazole 25EC (8.86 q/ha) with cost benefit ratio 2.59 which was on par with pyraclostrobin 5% + metiram 55% (8.33 q/ha, C:B 2.40) and tricyclazole 18% + mancozeb 62% WP (8.21 q/ha C:B 2.29), whereas lowest yield (3.58 q/ha) was observed in control.

4.4.4 Integrated management of fruit rot disease of chilli

Field experiment was conducted during *kharif* 2012 and 2013 at Dharwad with four modules namely bio intensive module for both disease and insect pests (M_1), bio-intensive module for disease with chemical pesticides for insect pests (M_2), Adoptive module (M_3), chemical intensive module (M_4) to develop best disease management module for chilli fruit rot disease, details of treatments were explained in material methods 3.4.5. Data are presented in Table 33a, 33b, 34a, 34b and 35 Plate 35and 36.

Kharif 2012

The results of *kharif* 2012 indicated that least seedling rot infection (7.31 %) was recorded in chemical module which was on par with adoptive module (7.33 %).

At 93 DAT (days after transplanting) M_3 (Adoptive module) recorded the least fruit rot incidence (1.60 %) which is on par with M_4 (Chemical intensive module) (1.72%), M_2 (Bio intensive module for disease) (2.04 %) and M_1 (Biointensive module for both disease and insects) (2.31 %). The least fruit rot severity (1.20 PDI) was recorded in M_3 (Adoptive module) which is also on par with M_4 (Chemical intensive module), M_2 (Bio intensive module for disease) and M_1 (Biointensive module for both disease and insects).

a. At green fruit stage

b. Red fruit stage

Plate 35: Field view of management modules at MARS Dharwad

Table 33a: Management modules for chilli fruit rot disease during *kharif* 2012-13

Module	Fruit rot incidence (%) DAT								Fruit rot severity (%) DAT								Yield q/ha
	93	100	107	114	121	128	135	Mean	93	100	107	114	121	128	135	Mean	
Biointensive module for both disease and insects. (M_1)	2.31 (8.73)*	9.26 (17.71)	13.03 (21.14)	13.32 (21.3)	9.40 (17.84)	10.07 (18.48)	12.67 (20.81)	9.93 (17.96)	1.80 (7.54)	6.72 (14.98)	7.45 (15.79)	7.93 (16.33)	6.28 (14.49)	6.12 (14.29)	6.93 (15.13)	6.14 (14.08)	5.53
Bio intensive module for disease (M_2)	2.04 (8.10)	8.30 (16.74)	12.65 (20.79)	12.83 (20.97)	8.59 (16.97)	9.57 (17.96)	10.22 (18.6)	9.24 (17.28)	1.60 (7.17)	6.39 (14.55)	6.51 (14.77)	6.83 (15.08)	5.77 (13.80)	5.98 (14.11)	7.15 (15.46)	5.71 (13.56)	6.10
Adoptive module (M_3)	1.60 (7.21)	4.84 (12.62)	5.05 (12.82)	7.38 (15.73)	3.52 (10.79)	4.21 (11.68)	4.58 (12.29)	4.45 (11.96)	1.20 (6.21)	2.64 (9.260	2.76 (9.54)	3.24 (10.35)	2.83 (9.61)	3.25 (10.31)	3.69 (10.95)	2.80 (9.53)	9.02
Chemical intensive module (M_4)	1.72 (7.46)	6.06 (14.22)	8.36 (16.77)	10.04 (18.45)	5.24 (13.11)	5.50 (13.54)	6.42 (14.48)	6.19 (14.07)	1.40 (6.69)	3.07 (10.01)	3.24 (10.32)	3.57 (10.82)	3.26 (10.36)	3.13 (10.10)	4.23 (11.81)	3.18 (10.21)	8.80
S.Em. ±	0.73	0.52	0.40	0.67	0.65	1.13	0.39	2.12	0.96	0.87	0.65	0.60	0.84	0.85	1.16	2.75	0.61
CD @ 0.05	1.55	1.60	1.23	2.06	2.00	3.48	1.20	3.70	2.04	1.85	1.38	1.28	1.79	1.81	2.47	3.47	1.82

* Arc sine values DAT: Days after transplanting

Table 33b: Economics of disease management modules against chilli fruit rot and dieback disease during 2012-13.

Module	Seedling rot Incidence (%)	Fruit rot Incidence (%)	Fruit rot Severity (%)	Dieback incidence	Dieback severity	Yield q/ha	Treatment cost (Rs/ha)	Treatment cost + cost of cultivation (Rs/ha)	Net income* (Rs/ha)	C: B ratio
Biointensive module for both disease and insects. (M_1)	16.16 (23.68)*	9.93 (17.96)	6.14 (14.08)	2.00 (8.13)	19.0 (25.82)	5.53	3028	33028	55300	1.67
Bio intensive module for disease (M_2)	16.12 (23.62)	9.24 (17.28)	5.71 (13.56)	2.00 (8.13)	18.60 (25.54)	6.10	6559	36559	61000	1.66
Adoptive module (M_3)	7.33 (15.67)	4.45 (11.96)	2.80 (9.53)	1.20 (6.21)	10.40 (18.79)	9.02	6514	36514	90200	2.47
Chemical intensive module (M_4)	7.31 (15.67)	6.19 (14.07)	3.18 (10.21)	1.40 (6.69)	12.80 (20.95)	8.80	7503	37503	88000	2.34
S.Em. $\pm$	0.77	2.12	2.75	0.79	0.63	0.61				
CD @ 0.05	1.65	3.70	3.47	1.69	1.35	1.82				

Rs. 10000/q., fixed cost: Rs. 30,000/ha.

* Arc sine values

Table 34a: Management modules for chilli fruit rot disease during *kharif* 2013-14

Module	Fruit rot incidence (%) DAT								Fruit rot severity (%) DAT								Yield q/ha
	93	100	107	114	121	128	135	Mean	93	100	107	114	121	128	135	Mean	
Biointensive module for both disease and insects. (M_1)	2.37 (8.83)*	9.42 (17.85)	9.47 (17.92)	9.65 (17.84)	8.07 (16.41)	9.29 (17.68)	9.36 (17.80)	8.09 (16.25)	1.60 (7.17)	5.90 (14.01)	7.08 (15.38)	7.48 (15.85)	5.80 (13.88)	6.12 (14.25)	7.00 (15.30)	5.83 (13.72)	5.20
Bio intensive module for disease (M_2)	1.98 (7.99)	9.00 (17.45)	8.92 (17.28)	9.23 (17.61)	7.91 (16.33)	8.48 (16.85)	8.87 (17.27)	7.41 (15.50)	1.40 (6.69)	5.81 (13.84)	6.02 (14.15)	6.36 (14.56)	5.46 (13.44)	5.66 (13.69)	6.86 (15.12)	5.38 (13.16)	5.90
Adoptive module (M_3)	1.48 (6.90)	5.05 (12.88)	5.41 (12.90)	5.57 (13.46)	5.43 (13.35)	4.12 11.70	4.40 (11.97)	4.49 (12.05)	1.00 (5.73)	2.28 (8.50)	2.60 (9.25)	2.68 (9.34)	3.00 (9.86)	3.06 (9.98)	3.40 (10.41)	2.57 (9.11)	8.80
Chemical intensive module (M_4)	1.60 (7.20)	5.87 (14.00)	6.85 (14.54)	7.67 (15.95)	6.57 (14.71)	6.13 14.33	6.39 (14.45)	5.86 (13.76)	1.20 (6.21)	2.90 (9.76)	2.76 (9.37)	2.90 (9.72)	2.80 (9.54)	3.08 (10.03)	3.90 (11.32)	2.79 (9.51)	8.60
S.Em. ±	0.64	1.82	1.45	1.08	1.32	1.35	0.80	0.77	0.78	0.92	0.88	0.61	1.42	1.09	1.10	2.28	0.65
CD @ 0.05	1.37	3.86	3.09	2.29	2.81	2.88	1.71	1.34	1.67	1.97	1.87	1.30	3.03	2.32	2.35	3.98	1.94

* Arc sine values DAT: Days after transplanting

At 100 DAT M_3 (Adoptive module) recorded the least fruit rot incidence (4.84 %) which is on par with M_4 (Chemical intensive module) (6.06 %) followed by M_2 (Bio intensive module for disease) (8.30 per cent. The least fruit rot severity (2.64 PDI) recorded in M_3(Adoptive module) which is also on par with M_4 (Chemical intensive module) (3.07 PDI).

At 135 DAT M_3 (Adoptive module) recorded the least fruit rot incidence (4.58 %) followed by M_4 (Chemical intensive module) (6.42 %). The least fruit rot severity (3.69 PDI) recorded in M_3 (Adoptive module) which is on par with M_4 (Chemical intensive module) (4.23 PDI).

The least die-back incidence (1.20 %) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical intensive module) (1.40 %). The least die-back severity (10.40 PDI) was recorded in M_3 (Adoptive module) followed by M_4 (Chemical intensive module) (12.80 PDI).

The yield was significantly superior in M_3 (Adoptive module) (9.02 q/ha) with 2.47 cost benefit ratio, which was on par with M_4 (Chemical intensive module) (8.80 q/ha, 2.34 C:B ratio), whereas the least yield (5.53 q/ha, 1.67 C:B ratio) was recorded in M_1 (Bio intensive module for both disease and insects).

Kharif 2013

The results of *kharif* 2013 indicated that least seedling rot infection (6.78 %) was recorded in adoptive module which was on par with chemical module (6.93 %)

At 93 DAT M_3 (Adoptive module) recorded the least fruit rot incidence (1.48 %) which was on par with M_4 (Chemical intensive module) (1.60 %) and M_2 (Bio intensive module for disease)(1.98 %). The least fruit rot severity (1.00 PDI) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical intensive module), M_2 (Bio intensive module for disease) and M_3 (Biointensive module for both disease and insects).

At 100 DAT M_3 (Adoptive module) recorded the least fruit rot incidence (5.05 %) which was on par with M_4 (Chemical intensive module) (5.87 %) followed by M_2 (Bio intensive module for disease) (9.00 %). The least fruit rot severity (2.28 PDI) recorded

Table 34b: Economics of disease management modules against chilli fruit rot and dieback disease during *kharif* 2013-14.

Module	Seedling rot Incidence (%)	Fruit rot Incidence (%)	Fruit rot Severity (%)	Dieback incidence	Dieback severity	Yield q/ha	Treatment cost (Rs/ha)	Treatment cost + cost of cultivation (Rs/ha)	Net income* (Rs/ha)	C: B ratio
Biointensive module for both disease and insects. (M_1)	16.38 (23.85)*	8.09 (16.25)	5.83 (13.72)	2.20 (8.38)	18.00 (25.06)	5.20	3028	33028	52000	1.57
Bio intensive module for disease (M_2)	16.00 (23.51)	7.41 (15.50)	5.38 (13.16)	2.10 (8.33)	17.60 (24.77)	5.90	6559	36559	59000	1.61
Adoptive module (M_3)	6.78 (15.07)	4.49 (12.05)	2.57 (9.11)	1.20 (6.21)	8.20 (16.51)	8.80	6514	36514	88000	2.41
Chemical intensive module (M_4)	6.93 (15.24)	5.86 (13.76)	2.79 (9.51)	1.00 (5.43)	9.40 (17.82)	8.60	7503	37503	86000	2.29
S.Em. $\pm$	1.11	0.77	2.28	1.19	0.98	0.65				
CD @ 0.05	2.36	1.34	3.98	2.53	2.87	1.94				

Rs. 10000/q., fixed cost: Rs. 30,000/ha.

* Arc sine values

Table 35: Pooled analysis management modules for chilli fruit rot disease during *kharif* 2012-13 and 2013-14

Module	Seedling rot Incidence (%)			Fruit rot Incidence (%)			Fruit rot Severity (%)			Dieback incidence			Dieback severity			Yield q/ha			C: B ratio
	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	2012	2013	Pooled	Pooled
Biointensive module for both disease and insects. (M_1)	16.16 (23.68)*	16.38 (23.85)	16.27 (23.77)	9.93 (17.96)	8.09 (16.25)	9.01 (17.43)	6.14 14.08	5.83 (13.72)	5.98 14.07	2.00 (8.13)	2.20 (8.38)	2.10 8.25	19.0 (25.82)	18.00 (25.06)	18.54 25.48	5.53	5.20	5.36	1.62
Bio intensive module for disease (M_2)	16.12 (23.62)	16.00 (23.51)	16.06 (23.59)	9.24 (17.28)	7.41 (15.50)	8.33 (16.70)	5.71 13.56	5.38 (13.16)	5.54 13.50	2.00 (8.13)	2.10 (8.33)	2.05 8.23	18.60 (25.54)	17.60 (24.77)	18.10 25.16	6.10	5.90	6.00	1.64
Adoptive module (M_3)	7.33 (15.67)	6.78 (15.07)	7.06 (15.33)	4.45 (11.96)	4.49 (12.05)	4.47 (14.73)	2.80 9.538	2.57 (9.11)	2.68 9.35	1.20 (6.21)	1.20 (6.21)	1.20 6.21	10.40 (18.79)	8.20 (16.51)	9.30 17.71	9.02	8.80	8.92	2.44
Chemical intensive module (M_4)	7.31 (15.67)	6.93 (15.24)	7.12 (16.10)	6.19 (14.07)	5.86 (13.76)	6.02 (12.87)	3.18 10.21	2.79 (9.51)	2.98 9.90	1.40 (6.69)	1.00 (5.43)	1.20 6.21	12.80 (20.95)	9.40 (17.82)	11.11 19.45	8.80	8.60	8.71	2.32
S.Em. $\pm$	0.77	1.11	0.76	2.12	0.77	0.84	2.75	2.28	0.86	0.79	1.19	0.79	0.63	0.98	0.75	0.61	0.65	0.94	
CD @ 0.05	1.65	2.36	1.63	3.70	1.34	1.80	3.47	3.98	1.84	1.69	2.53	1.68	1.35	2.87	1.61	1.82	1.94	2.89	

in M_3 (Adoptive module) which was on par with M_4 (Chemical intensive module) (2.90 PDI).

At 135 DAT M_3 (Adoptive module) recorded the least fruit rot incidence (4.40 %) which was on par with M_4 (Chemical intensive module) (6.39 %) followed by M_2 (Bio intensive module for disease) (8.87 %). The least fruit rot severity (3.40 PDI) recorded in M_3(Adoptive module) which was on par with M_4 (Chemical intensive module) (3.90 PDI) followed by M_2 (Bio intensive module for disease) (6.86 PDI).

The least die-back incidence (1.00 %) was recorded in M_4 (Chemical intensive module) which was on par with M_3 (Adoptive module) (1.20 %) followed by M_2 (Bio intensive module for disease) (2.10 %). The least die-back severity (8.20 PDI) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical intensive module) (9.40 PDI).

The yield was significantly superior in M_3 (Adoptive module) (8.80 q/ha) with 2.41 cost benefit ratio, which was on par with M_4 (Chemical intensive module) (8.60 q/ha, 2.29 C:B ratio) followed by M_2 (Bio intensive module for disease) (5.90 q/ha, 1.61 C:B ratio).

The pooled results of *kharif* 2012 and 2013 indicated that least seedling rot incidence (7.06 %) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical intensive module) (7.12 %) followed by M_2 (Bio intensive module for disease) (16.06 %).

In M_3 (Adoptive module) least fruit rot incidence (4.47 %) was recorded which was on par with M_4 (Chemical intensive module) (6.02 %) followed by M_2 (Bio intensive module for disease) (8.33 %). The least fruit rot severity (2.68 PDI) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical module) (2.98 PDI) followed by M_2 (Bio intensive module for disease) (5.54 PDI).

The least die-back incidence (1.21 %) was recorded in both M_3 (Adoptive module) and M_4 (Chemical intensive module) followed by M_2 (Bio intensive module for disease) (2.05 %). The least die-back severity (9.30 PDI) was recorded in M_3 (Adoptive module) which was on par with M_4 (Chemical module) (11.11 PDI) followed by M_2 (Bio intensive module for disease) (18.10 PDI).

a. Adoptive module M_3 (green fruit stage)

b. Biointensive module M_1 (green fruit stage)

c. Adoptive module M_3 (red fruit stage)

d. Chemical intensive module (M_4)

e. Biointensive module M_1 (red fruit stage)

Plate 36: Fruit rot disease management modules at MARS Dharwad

The yield was significantly superior in M_3 (Adoptive module) (8.92 q/ha) with 1.25 cost benefit ratio, which was on par with M_4 (Chemical intensive module) (8.71 q/ha, 2.32 C:B ratio) followed by M_2 (Bio intensive module for disease) (6.0 q/ha, 1.64 C:B ratio), whereas least yield (5.36 q/ha, 1.62 C:B ratio) was recorded in M_1 (Bio intensive module for disease and insects.).

5. DISCUSSION

Chilli (*Capsicum annuum* L.) is a very remunerative, widely grown indispensable spice crop in the world and is cultivated in almost all the states of India. Chilli is suffering from several economically important diseases like damping off, die back, fruit rot, leaf spots, leaf curl, wilt etc. which pose a serious threat to the successful large-scale cultivation. The fruit rot disease caused by fungi *Colletotrichum* (namely *C. capsici*, *C. gloeosporioides* and *C. acutatum*), *A. alternata*. and *Fusarium* spp. is a major yield limiting factor.

The disease is more severe in India because of its complex nature and symptoms vary in different stages of crop. In the present situation of climate change there are lot of variations and fluctuations in environmental conditions which may lead into variability in pathogen population and disease epidemics in different regions. Therefore to throw light on many questions, experiments were conducted on various aspects of chilli fruit rot and die-back disease with reference to prevalence and distribution of disease, pathogen diversity, severity of the disease in various geographical regions of South India, isolation, identification, morphological, and molecular variability of pathogens and their quick detection by molecular method to know the complexity of causal organisms.

Role of weather parameters on disease incidence and survival ability of pathogens, host range and cross inoculations were studied. Further, seed health management and integrated disease management strategies comprising screening of genotypes for resistance, evaluation of chemicals under field conditions and various disease management modules were studied for identification of the best management module with maximum C:B ratio which helps the farming community to a greater extent. The experiments were conducted in the laboratory as well as in the field during 2012 and 2013 the results obtained on these aspects are discussed here under.

5.1 Survey, isolation and identification of pathogen/s to study the distribution in different geographical regions of South India

Survey on the incidence and severity of disease helps to gather information on the prevalence, severity and distribution of disease, pathogen diversity in particular

agro-climatic zone. It reveals the magnitude of the problem on hand and serves as a precursor for evolving the management strategies.

Survey and surveillance form the basis for any successful plant protection that depends on early detection of disease followed by timely adoption of management measures. In the present investigation roving survey was undertaken for two years in major chilli growing areas of Karnataka, Maharashtra and Andhra Pradesh to assess the incidence and severity of fruit rot. During the survey it was generally observed that disease incidence on red colored fruits was more than other parts of plant in most of the areas surveyed.

The survey also supplements the information about intensity and existence of biotypes in particular geographical locations. Hence, an attempt was made to assess the incidence and severity of fruit rot disease of chilli. The severity of fruit rot of chilli expressed as disease incidence and per cent disease index. The survey also revealed that the severity of fruit rot and dieback disease from location to location and also varietal performance differed from place to place, obviously due to various factors like temperature, relative humidity, pattern of rainfall and even it could also be attributed to existence of variability of pathogen/s, cropping pattern and genotype grown.

From the pooled results of two years survey (2012-13 and 2013-14) it was observed that among the three states the highest fruit rot incidence (19.97%) with 13.77 PDI was observed in Maharashtra followed by Andhra Pradesh (19.82%, 13.07 PDI) whereas the highest die-back incidence (11.23%) with 42.79 PDI was observed in Andhra Pradesh followed by Karnataka (9.06%, 38.14 PDI) (Fig.2).

Among eight districts of Karnataka, the highest fruit rot incidence (22.18%) with 14.75 PDI was observed in Bellary, whereas the highest die-back incidence (11.18%) with 43.92 PDI was observed in Gadag (Fig.3 and Fig. 4). In Guntur district of Andhra Pradesh the highest fruit rot incidence (21.84%) with 12.98 PDI was recorded. Shivakumara (2006) reported that maximum fruit rot severity (11.56 PDI) was recorded in Gulbarga district followed by Raichur (11.17 PDI) district. Rajput (2011) reported that highest severity of fruit rot was noticed in Nalvadi and Sanshi villages of Dharwad district.

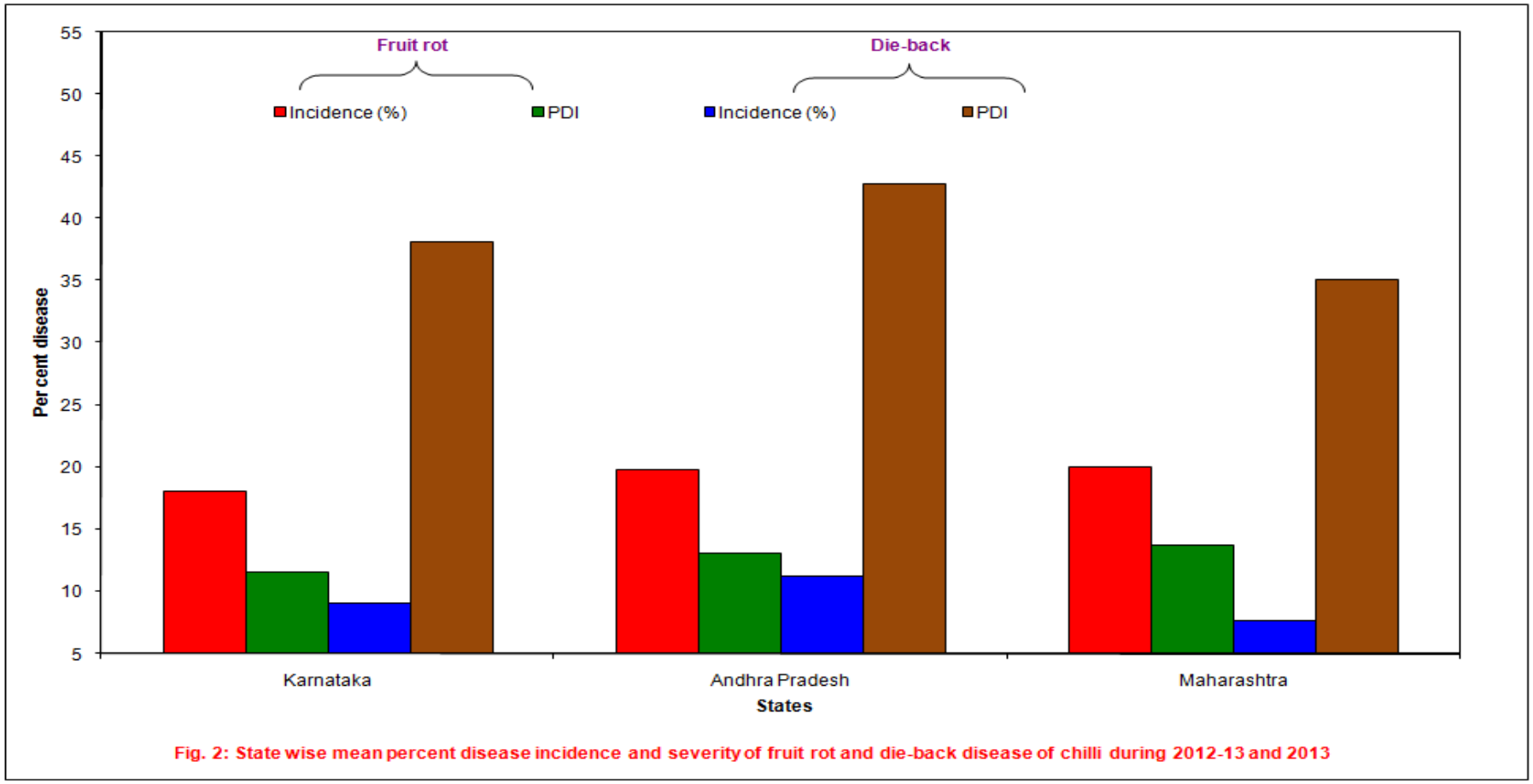


Fig. 2: State wise mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2012-13 and 2013

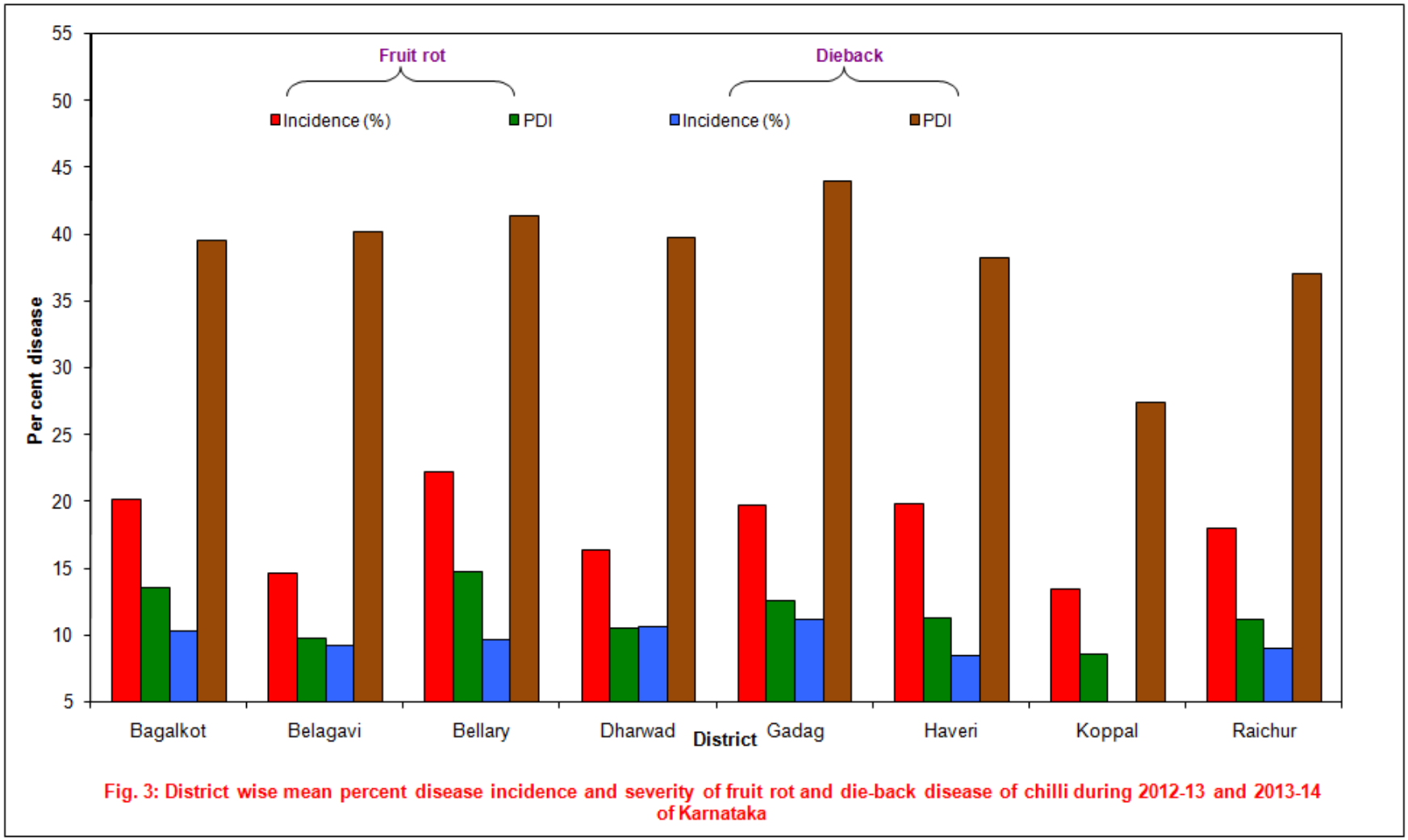


Fig. 3: District wise mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2012-13 and 2013-14 of Karnataka

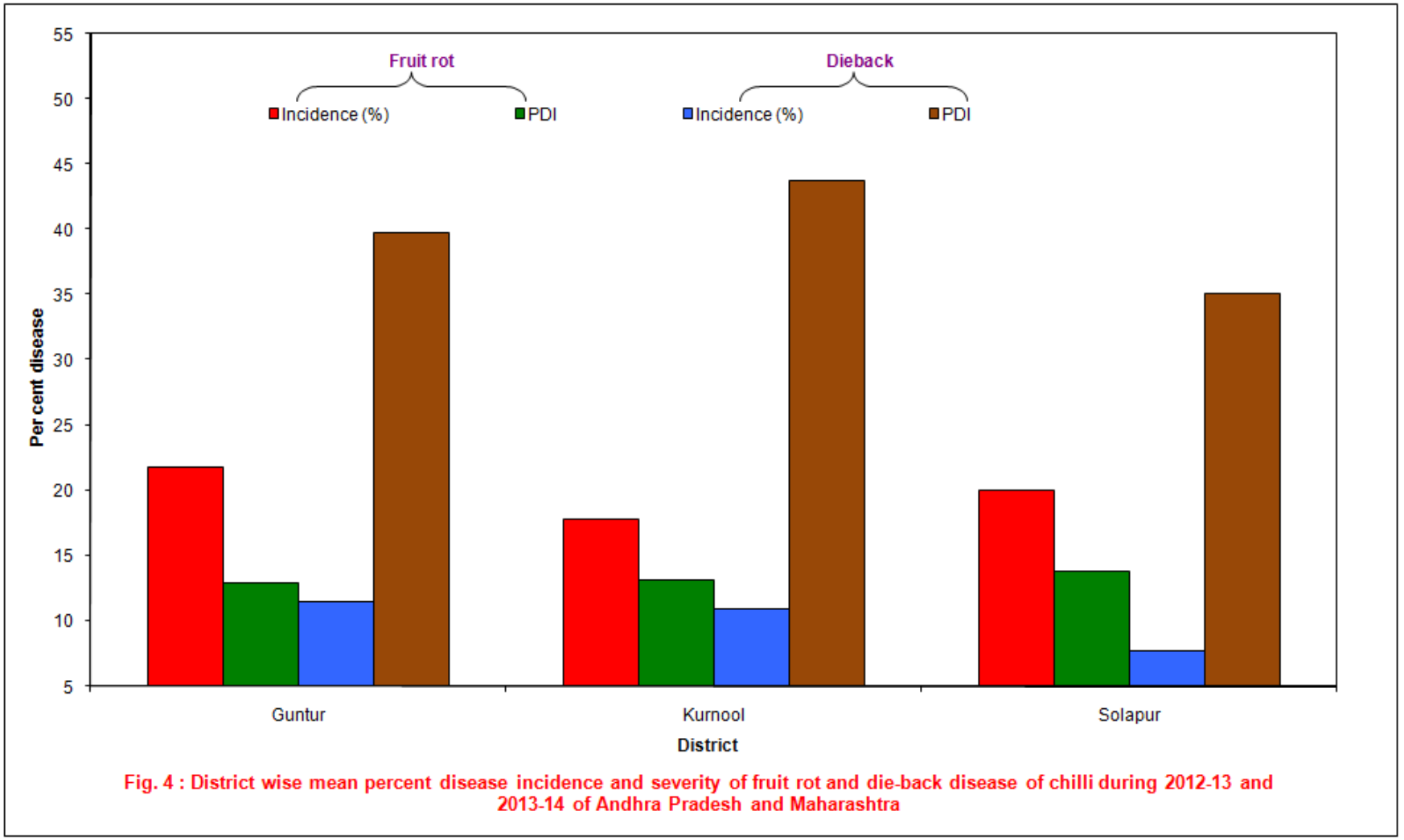


Fig. 4 : District wise mean percent disease incidence and severity of fruit rot and die-back disease of chilli during 2012-13 and 2013-14 of Andhra Pradesh and Maharashtra

In the present study maximum fruit rot incidence and severity observed in Maharashtra and Andhra Pradesh is mainly due to irrigated condition with temperature of 25-30°C which is ideal for disease development. The same trend of temperature and irrigation is also followed in Bellary district. In these regions, chilli is grown in large area and also continuously year after year which leads to increase in inoculum of pathogens in seeds, plant debris and in soil. Use of untreated seeds which were produced locally is also one of the main reason for increase in disease incidence and severity of fruit rot.

In the present survey it is observed that in both rainfed (17.66%, 11.34PDI) and irrigated (18.96%, 12.23 PDI) conditions disease was equally distributed in severe form (Fig.5). Soil type (red and black) has no distinct differentiation for fruit rot disease. If the congenial weather condition and sufficient amount of inoculum is available then it leads to disease development in all these situations on commonly cultivated susceptible genotype like Byadgi Dabbi (Fig. 6). It is observed that in both sole crop (18.58%, 11.95 PDI) and inter crop (17.52%, 11.36 PDI) disease was equally distributed in severe form, indicating that inter crop has never helped in reducing the disease (Fig. 7).

With reference to genotypes observed during survey, fruit rot and die-back disease (15.87 to 21.88%, 9.77 to 10.84% respectively) was equally severe in all genotypes. It is indicating the susceptible nature of commonly cultivated genotypes *viz.,* Byadgi Dabbi, Byadgi Kaddi and Guntur (Shivakumara, 2006) (Fig. 8).

Predominance of various pathogens was observed during survey. Frequency of occurrence of single pathogen was always less compared to combination of pathogens. The combination of *C. capsici* and *Fusarium* spp. was 28.37 per cent, *C. capsici* with *A. alternata* 11.35 per cent, combination of *C. capsici, C. gloeosporioides* and *A. alternata* was 10.64 per cent. *C. capsici* as a predominant fungus causing fruit rot of chilli was reported by Thind and Jhooty (1985). Ramachandran *et al.* (2007) conducted survey and collected 92 isolates from different chilli growing areas in Andhra Pradesh and Karnataka. Among them 53 were identified as *C.capsici*, 38 as *C. gloeosporioides* and one was *C. acutatum*. Chilli fruit samples collected from Tamil Nadu, revealed that *C. capsici* was the most commonly isolated (69%) followed by *C. gloeosporioides* (19%) and *A. alternata* (Madhvan *et al.,* 2010). Association of

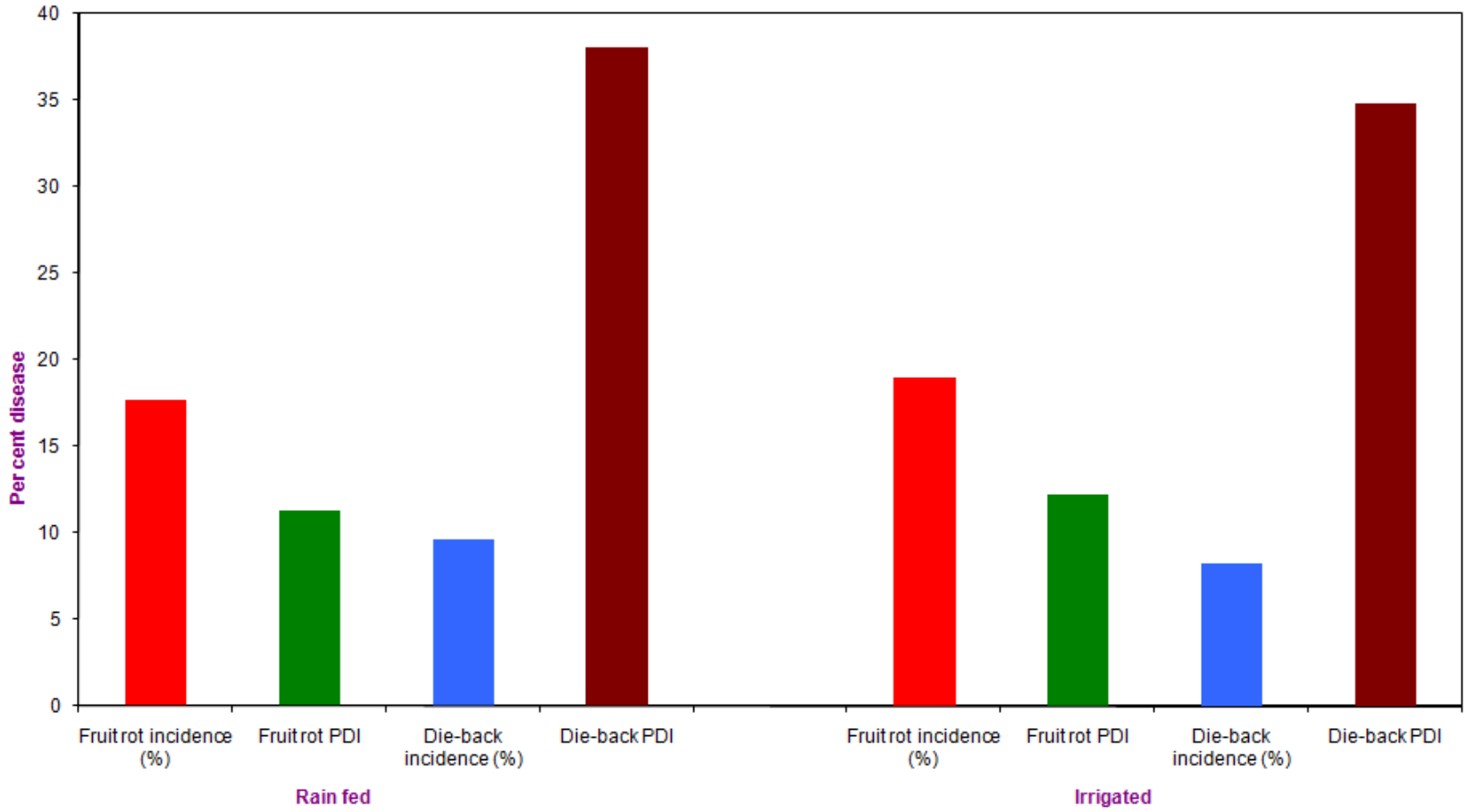


Fig. 5: Fruit rot and die-back incidence and severity under rainfed and irrigated condition in the survey during 2012-13 and 2013-14

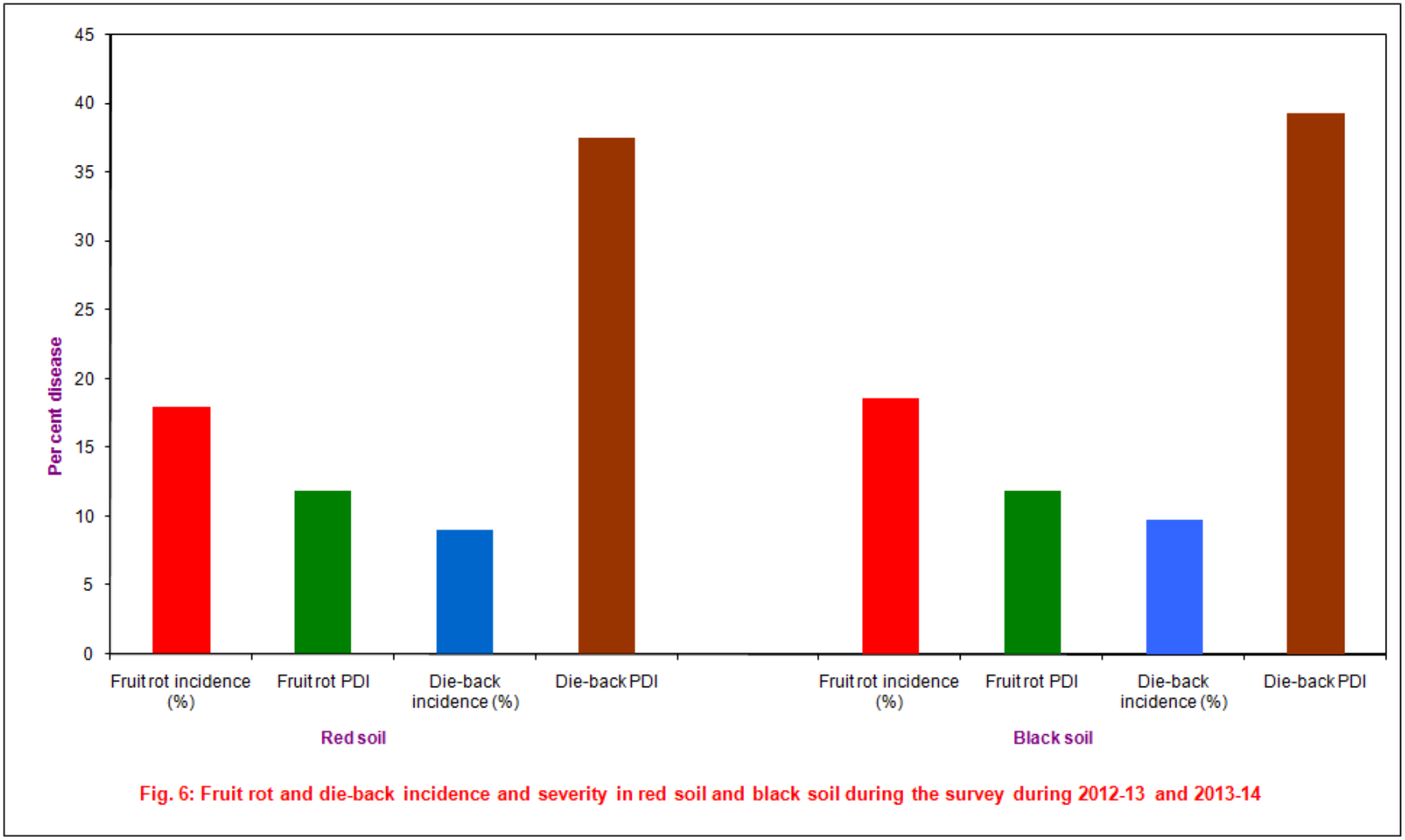


Fig. 6: Fruit rot and die-back incidence and severity in red soil and black soil during the survey during 2012-13 and 2013-14

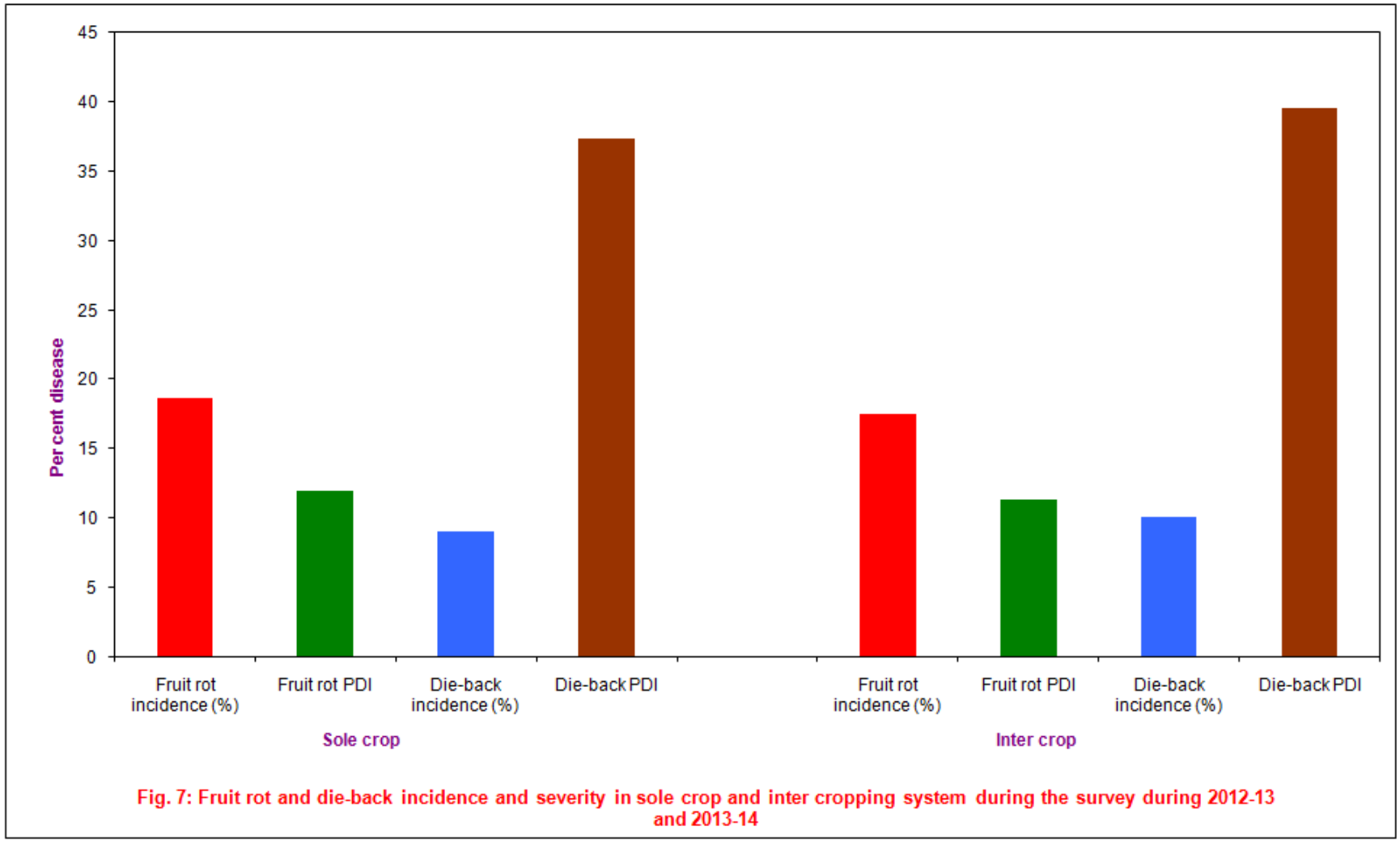


Fig. 7: Fruit rot and die-back incidence and severity in sole crop and inter cropping system during the survey during 2012-13 and 2013-14

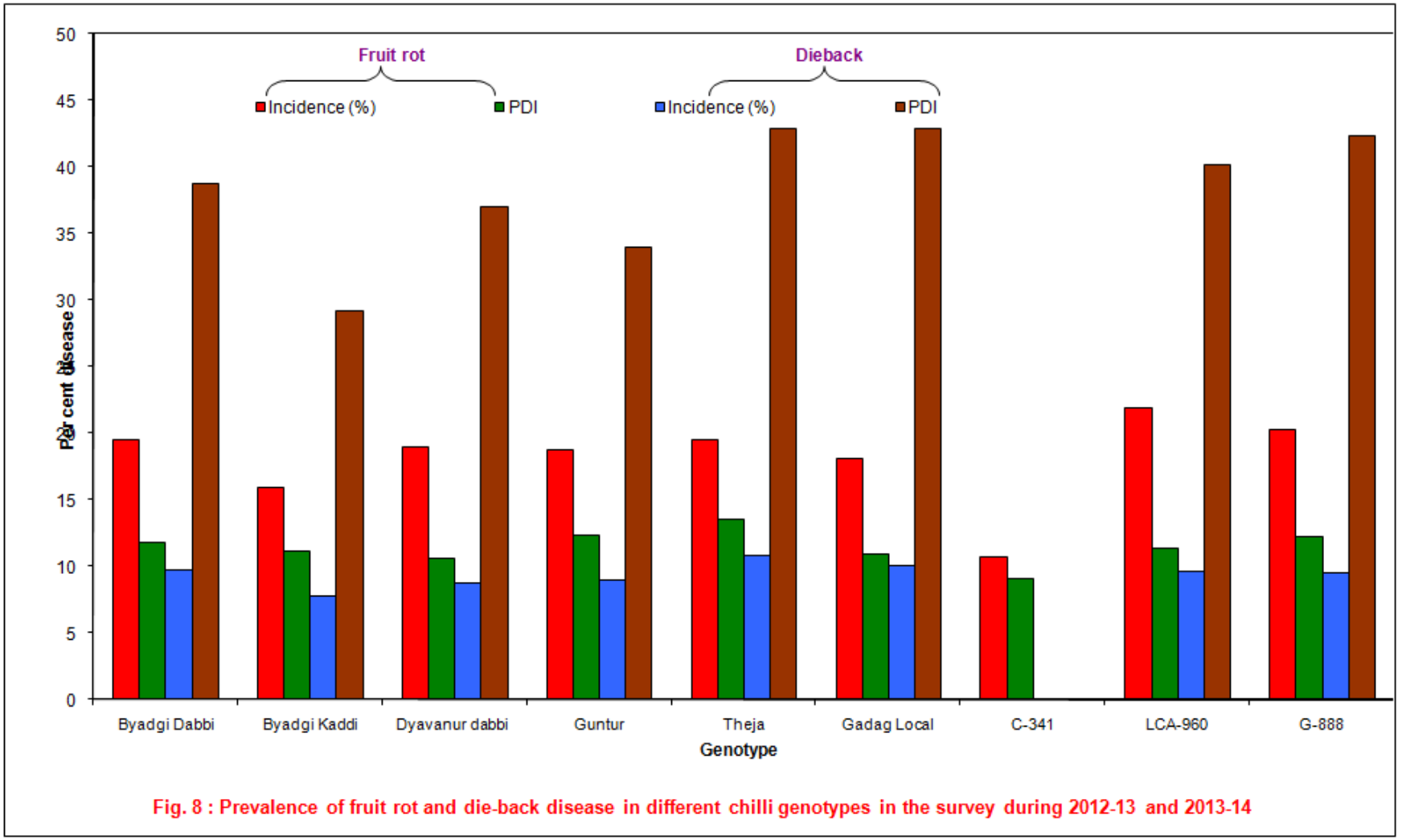


Fig. 8 : Prevalence of fruit rot and die-back disease in different chilli genotypes in the survey during 2012-13 and 2013-14

Fusarium spp. in the present study is supported by the work of Parey *et al.* (2013) who reported different *Fusarium* spp. were involved in fruit rot in Jammu and Kashmir.

Mild to severe form of fruit rot and die-back disease was observed irrespective of varieties during the field survey under taken. During 2012-13 and 2013 -14 such variation in disease incidence in different locations is quite often attributed to environmental conditions. However, the variations may also be attributed to the presence of variability in pathogenic fungi. The mean frequency of pathogens isolated from samples collected during survey recorded as the highest frequency (38.56%) was observed in *C. capsici* followed by *A. alternata* (18.98%) and *C. gloeosporioides* (14.89%) (Fig. 9). Shivakumara (2006) isolated *Colletotrichum* spp. (25%) followed by *A. alternata* (21%) from fruit infected chilli from northern Karnataka.

The present results are well supported by the reports of Hegde and Kulkarni (2001a), Bagri *et al.* (2004) and Das *et al.* (2004) wherein they reported the maximum prevalence of *Colletotrichum capsici*. In fruit rot disease of chilli, multiple infections were quite common. Many workers have also reported the prevalence of more than two fungal pathogens in fruit rot disease of chilli (Prabhavathy and Reddy, 1995; Basak *et al.,* 1996b; Bagri *et al.,* 2004).

5.2 Morphological characterization and molecular variability of pathogen/s

5.2.1 Morphological characterization

Accurate identification of *Colletotrichum* species along with the knowledge of populations responsible for epidemics are essential for developing and implementing effective disease management strategies (Freeman *et al.,* 1998). Traditionally, identification and characterization of *Colletotrichum* species have been based on morphological characters, such as size and shape of conidia and appressoria; existence of setae; the teleomorph state and cultural characters such as colony colour, growth rate and texture (Von Arx, 1957; Smith and Black, 1990). In the present investigation 25 isolates of *C. capsici* , 20 of *C. gloeosporioides ,* 12 of *C. acutatum,* 10 of *A. alternata,* 9 of *F. oxysporum* and 7 of *F. sporotrichioides* were selected for morphological variations and results are discussed here.

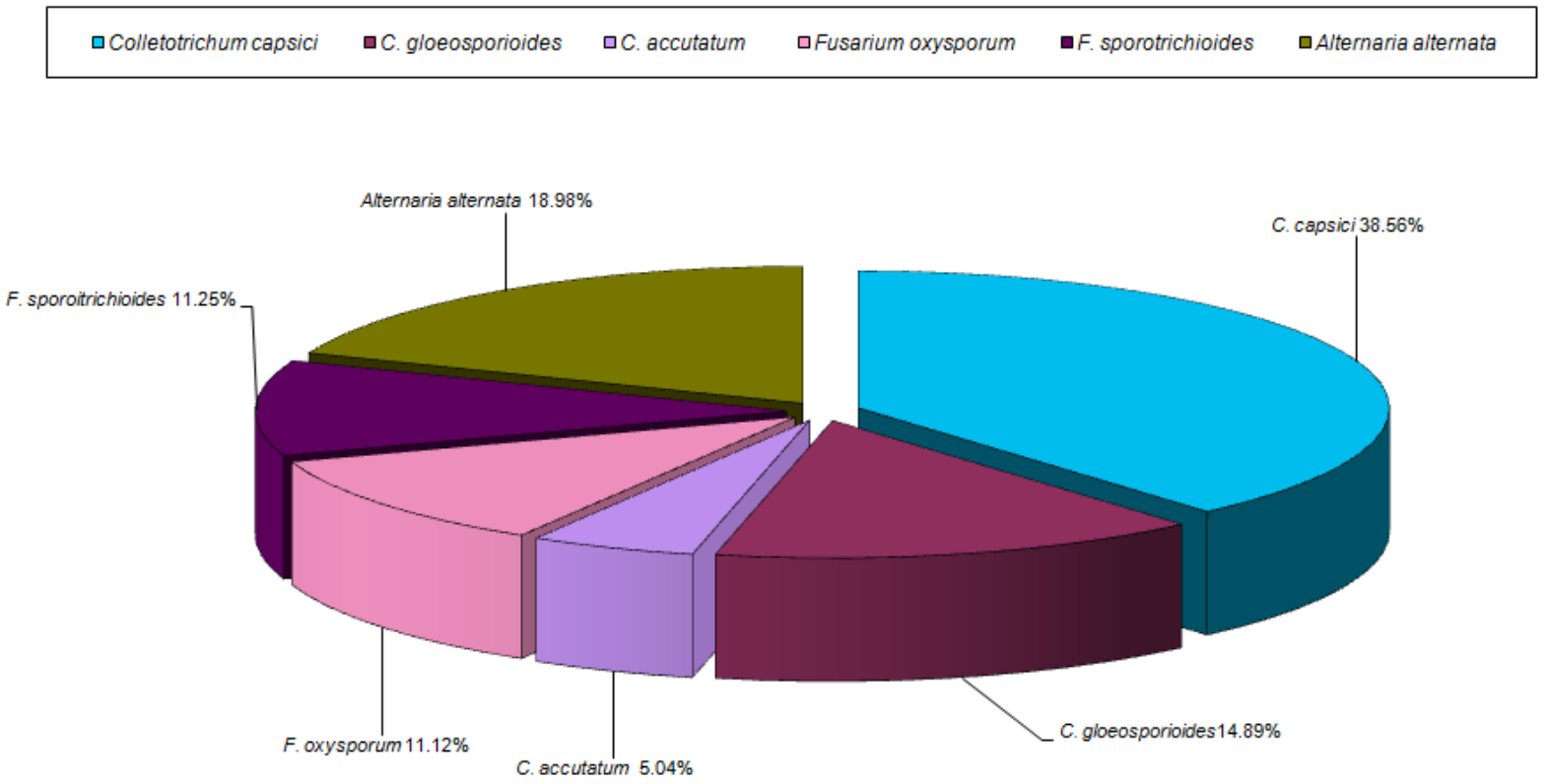


Fig. 9: Frequency of pathogen/s isolated chilli fruit rot disease

C. capsici

The colony varied from white to grey color, flat to raised fluffy and smooth regular to coarse irregular margin. Acervuli size varied between 130.01 to 162.60 µm with setae length 145.40 to 179.10 µm, medium to good sporulation, falcate shaped spores with size between 13.5 - 21.2 X 3.2 - 4.8 µm. These findings are in agreement with the findings of earlier workers (Sydow, 1913; Butler, 1918). Whitish aerial mycelial growth and concentric rings of growth were visible along with light rose colored spore masses. Conidia were single celled curved with smooth margin and hyaline (Hegde, 1998; Jeyalakshmi and Seetharaman, 1999; Rohana *et al.* 2005; Shivakumara, 2006; Rajput , 2011; Sangdee *et al.,* 2011; Christopher *et al.,* 2013).

Akhtar and Singh (2007) collected five isolates of *C. capsici* from Uttaranchal which showed variation in culture color (white grey to blackish grey), colony morphology (smooth to wavy margin growth) on PDA media, conidial size (varied between 25.27 to 26.15 µm length, 3.17 to 3.66 µm width). These observations were similar to present investigation but differed slightly with conidial size. Variation in colony and spore morphology is supported by the work of (Masoodi *et al.,* 2013). Parey *et al.* (2013) observed *C. capsici* isolates varied in mycelial color fairly white to light grey, circular to irregular margin with fluffy to flat growth, conidial size varied between 21.4 to 25.3 µm length, 3.7 to 4.3 µm width.

C. gloeosporioides

The colony varied from white to grey color, where as in three isolates Cg-9, Cg-10 and Cg-12 whitish saffron color was observed. Flat to raised fluffy and smooth regular to coarse irregular margin and sectoring was observed in three isolates, Cg-4, Cg-12 and Cg-20. Medium to excellent sporulation of cylindrical shaped spores with oil globules with size between 12.5 - 16.7 X 1.6 - 2.8 µm was recorded. These findings are in agreement with the findings of earlier workers (Simmondes, 1965; Mordue, 1971; Irwin and Camerson, 1978; Holiday, 1980; Jeffries *et al.,* 1990; Ekbote., 1994; Sudhakar 2000; Prasannakumar 2001; Venkataravanappa and Nargund 2002 and Prashanth, 2007 Than *et al.,* 2008a; Jayalakshmi, 2010; Biju *et al.,* 2012; Chandramani, 2012; Patil and Nargund, 2013). The present results are well supported by the earlier reports, wherein they reported the colony of *C. gloeosporioides* varied

from light orange to pale grey colour, conidia were cylindrical in shape and measured about 13.5 X 4.5 µm.

C. gloeosporioides isolated from chilli was distinct from *C. capsici* showing fast, fluffy, dull white mycelium and within the isolates also found distinct characteristics with respect to growth, colour of mycelia and sporulation (Shivakumara, 2006). Venkataravanappa and Nargund (2007) revealed that conidia size of six isolates of *C. gloeosporioides* from mango anthracnose samples, varied between 10.9-20.6 µm in length and 4.39 – 6.65 µm in width.

C. acutatum

The colony was varied from whitish pink to brownish pink color with flat to fluffy and smooth regular to coarse irregular margin. Medium to good sporulation of fusiform shaped spores with size varied between 11.4 - 14.1 X 1.1 - 2.3 µm was recorded. These findings are in agreement with the findings of earlier workers (Simmonds, 1965; Wharton and Uribeonodo, 2004; Than *et al.,* 2008a; Zivkovic *et al.,* 2010; Patil and Nargund, 2013), wherein they reported *C. acutatum* conidia were single septate, fusiform in shape and conidia size varies between 8 -16 X 2.5 – 4.0 µm.

A. alternata

The colony varied from ash to dark ash color, medium fluffy to raised fluffy and smooth regular to coarse irregular margin. Medium to excellent sporulation of muriform spores with beak with 3 – 5 horizontal septa 1 – 2 vertical septa, spore size varied between 14.1 - 21.8 X 6.1 - 8.4 µm was observed.

A. alternata isolates from chilli showed ash colour to black coloured mycelium with medium to fast growth and moderate to excellent sporulation, spore size varied between 18.1 - 30.1 X 5.8 – 6.7 µm (Shivakumara, 2006; Amitkumar *et al.,* 2012; Parey *et al.,* 2013)

F. oxysporum

The colony was varied from white to whitish purple color, flat, smooth and regular margin. Medium to excellent sporulation of falcate macro conidia with 3 – 5 horizontal septa and size varied between 22.01 - 32.10 X 3.2- 5.2µm.

The fungus produced microconidia, which were oval-ellipsoid, cylindrical, straight to curved, variable and found abundantly. Macro conidia, sparse and thin walled, having 3-5 septate, fusoid and subfulcate measures 26 - 42 X 2.8 – 4.5 µm. Culture of fungus on potato dextrose agar was whitish to peach purple coloured with woolly, aerial mycelium (Booth, 1971; Joffe, 1986; Bagri *et al.,* 2012; Patil and Nargund, 2013).

F. sporotrichioides

The colony varied from light brown to white rose colour, fluffy, smooth to coarse and regular to irregular margin. Good to excellent sporulation of falcate macro conidia with 3 – 5 horizontal septa and size varies between 32.1 - 42.0 X 3.4 -5.2 µm, globose microconidia were observed. These observations were also found similar to Booth (1971) and Joffe (1986) wherein they reported that mycelium varied from white rose to light brown, red colour, aerial growth, microconidia were globose to lemon shape, macroconidia were curved, falcate elongated with 3 – 5 septate measures 22-45 X 3.6 -5.4 µm.

5.2.2 Molecular characterization and variability of pathogen/s

Morphological characterization alone, are not always adequate for species identification due to overlap in morphological characters and phenotypic variation among species under different environmental conditions. Conidial shape has been applied as a reliable means of discriminating certain species; for example, conidial shape has differentiated *Colletotrichum* species pathogenic to strawberry (Denoyes and Baudry, 1995). However, in other cases, identification can be complicated because of overlapping ranges of conidial morphology and variation in colony characteristics (Adaskaveg and Hartin, 1997). Correct taxonomic identification is important in disease management such as choosing appropriate fungicides (Whitelaw-Weckert *et al.,* 2007).

To overcome the inadequacies of traditional morphology based identification schemes, DNA sequence analyses have been used to characterize and analyze the taxonomic complexity of fungal pathogens. Cannon *et al.* (2000) stated that data derived from nucleic acid analyses should provide the most reliable framework to build a classification of *Colletotrichum*, as DNA characters were not directly influenced by

environmental factors. Assessment of molecular variability by using microsatellite markers were used in differentiation species of *Fusarium* (Prasad *et al.,* 2004). Genetic differentiation of *C. gloeosporioides* isolates from cultivated strawberry plants and non-cultivated hosts was done by using boot strap analysis and constructed a dendrogram using RAPD markers (Xiao *et al.,* 2004). Though RAPD differentiated *C. capsici* and *C. gloeosporioides* and also the strainal variations among these species but in recent years RAPD technique has its own limitation. Most fungal phylogenetic studies utilized sequences from the ribosomal gene cluster, since they were present in large numbers as tandem repeats and evolved as a single unit. In particular, sequence analysis of the internal transcribed spacer (ITS) regions which lie between the 18S and 5.8S genes and the 5.8S and 28S genes, has proved useful in studying phylogenetic relationships of *Colletotrichum* species because of their comparative variability (Sreenivasaprasad *et al.,* 1994; Moriwaki *et al.,* 2002; Photita *et al.,* 2005).

A combined application of morphological characters, molecular diagnostic tools and pathogenicity helps in identification and to study variability among species. To understand existence of variation among the isolates of pathogens, PCR based technique *i.e.*, ITS was used in the present investigation. Ramachandran *et al.* (2007) identified 92 isolates from different chilli growing areas of India, among them 53 were *C.capsici* 38 as *C. gloeosporioides* and one was found to be *C. acutatum* based on ITS sequence analysis. Phylogenetic analyses from DNA sequence data of ITS rDNA region revealed three major clusters representing these three species of *Colletotrichum* spp. in chilli (Than *et al.,* 2008b).

The genera *Colletotrichum* spp. *Alternaria* spp. and *Fusarium* spp. pose a major challenge for systematics because of the phylogenetic relationships of many of their members still are unclear. DNA sequences of selected six isolates were compared using bioinformatics tool like NCBI BLAST programme. Based on sequence comparison these isolates were identified as *C.capsici, C. gloeosporioides, C. acutatum*, *A. alternata, F. sporotrichioides* and *F. oxysporum* and were markedly similar to the reference strain of NCBI BLAST Genbank. The ITS region of onion twisting disease causing fungal pathogen isolates were amplified by using the NCBI BLAST program, they confirmed these isolates as *C.gloeosporioides, C.acutatum* and *F. oxysporum* (Patil and Nargund, 2013).

Pongpisutta *et al.* (2013) reported that effects of environmental manipulation on the morphological stability makes identification between *Colletotrichum* species difficult. ITS RFLP and ITS sequence analysis are considered to be essential tools to solve the problems of species differentiation and specific identification of the chilli anthracnose causal agents. After ITS rDNA region identification of pathogens *C. capsici, C.gloeosporioides, C.acutatum* , *Alternaria alternata, F. sporotrichioides* and *F. oxysporum* further studies were carried out for specific DNA amplification which was observed with fairly consistent band for *C. capsici* (25 isolates) at 450 bp, for *C. gloeosporioides* (20 isolates) fairly consistent band was observed with CgInt region at 450 bp and *C. acutatum* (12 isolates) at 490 bp with concentration of 437 µg/µl. Whereas, *Alternaria alternata* amplification was observed at 390 bp and for *Fusarium* spp approximately at 550-570 bp. Fungal isolates from chilli fruits in Thailand that showed typical anthracnose symptoms were identified as *C. acutatum, C. capsici* and *C. gloeosporioides* by ITS sequence study (Than *et al.,* 2008a). Morphology and pathogenecity are not enough to distinguish between *Colletotrichum* spp. diversity. Studies include internal transcribed spacer (ITS) regions (Freeman *et al.,* 2001; Moriwaki *et al.,* 2002; Sanders and Korsten*,* 2003; Lee *et al.,* 2007) as well as restriction fragment length polymorphism (RFLP) (Balardin *et al.,* 1999; Martin and Garcia-Figueres 1999; Saha *et al.,* 2002 ; Weir *et al.,* 2012).

The products of the PCR ITS rDNA digestion with *Hind III* revealed that no restriction sites were present. The digestion with *HaeIII,* resulted in a characteristic pattern of three fragments in all the isolates. *C. capsici* isolates showed four clusters (Fig. 10), in cluster-I (six isolates), cluster – II (12 isolates), cluster – III (six isolates), cluster – IV (one isolate). *C. gloeosporioides* isolates showed five clusters (Fig. 11), in cluster-I (five isolates), cluster – II (one isolate), cluster – III (nine isolates), cluster – IV (three isolates) and cluster –V (two isolates). *C. acutatum* isolates showed three clusters (Fig. 12), in cluster-I (five isolates), cluster – II (five isolates) and cluster – III (two isolates). The digestion with *Taq I,* resulted in a characteristic pattern of three fragments in *Alternaria* and *Fusarium* isolates. *A. alternata* isolates showed two clusters (Fig. 13) cluster-I (seven isolates), cluster – II (three isolates). *Fusarium* isolates shown five clusters (Fig. 14), in cluster-I (five isolates), cluster – II (six isolates), cluster – III (one isolate) cluster – IV (three isolates) and cluster – V (one

LEGEND

Isolates	Source
1	Koluru
2	Siraguppa
3	Salahalli
4	UAS Dharwad
5	Kundgol
6	Byalal
7	Hulkoti
8	Byadgi
9	Basapur
10	Chikkatembinahal
11	Nelhal
12	Panchamukhi
13	Belgammanadoddi
14	Emmiganur
15	Dharmapuram
16	Mantralya
17	Mugathi
18	Madire
19	Paaladagu
20	Kattavaripalem
21	Bayyavaram
22	Mangalveda
23	Sangola
24	Aurangabad
25	Coimbatore

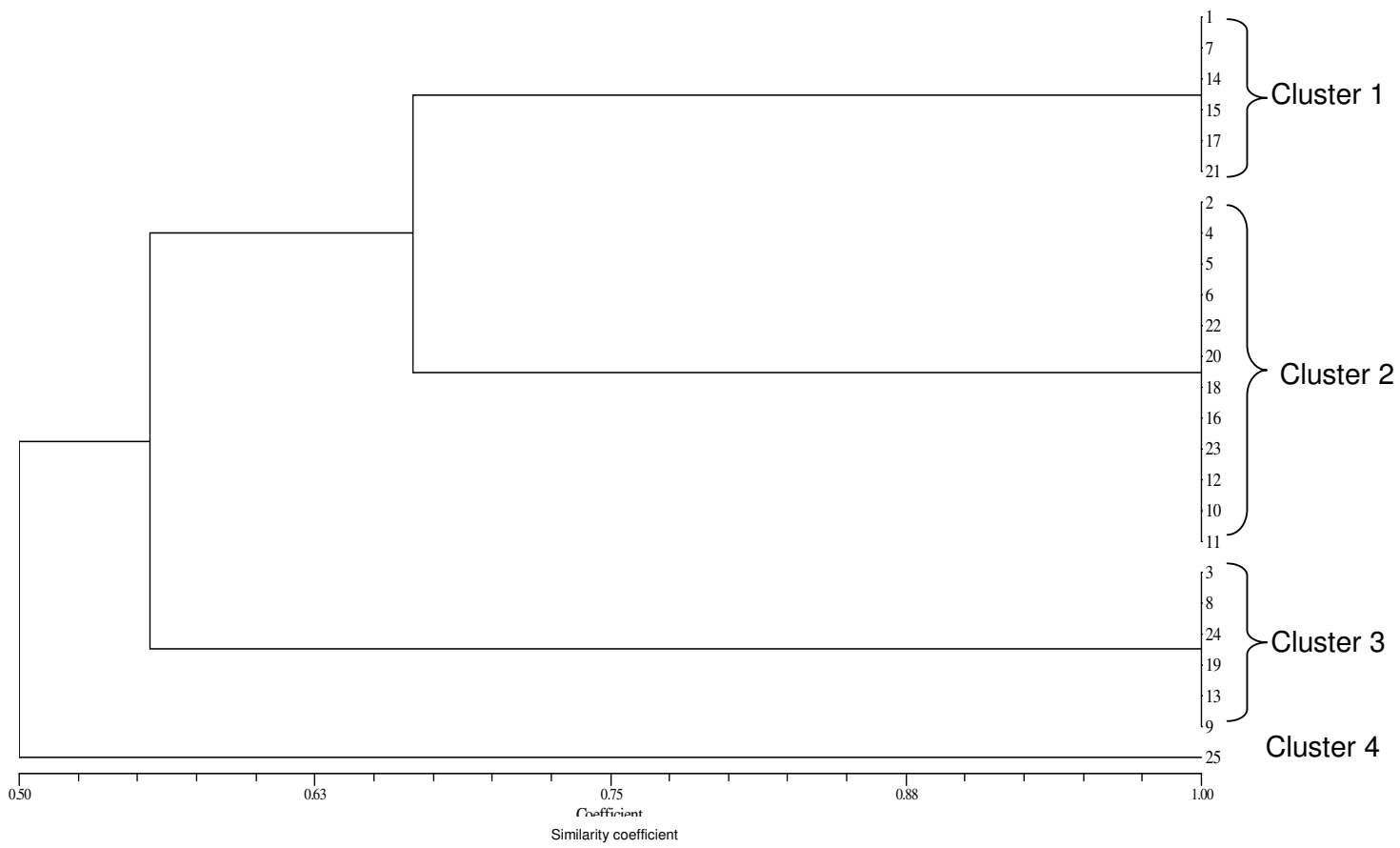


Fig. 10: PCR-RFLP diversity profile of *C. capsici* by *HaeIII*

LEGEND

Isolates	Source
1	Kagalgombe
2	Shanvaspura
3	Inamhongal
4	Byahatti
5	UAS Dharwad
6	Shirguppi
7	Binkadkatti
8	Guttal
9	Kanakapur
10	Beluru
11	Mandapur
12	Raladoddi
13	Hanumapuram
14	Alur
15	Kalludevarakunta
16	Mangalaveda
17	Medikonduru
18	Percherela
19	Ananthapuram
20	Coimbatore

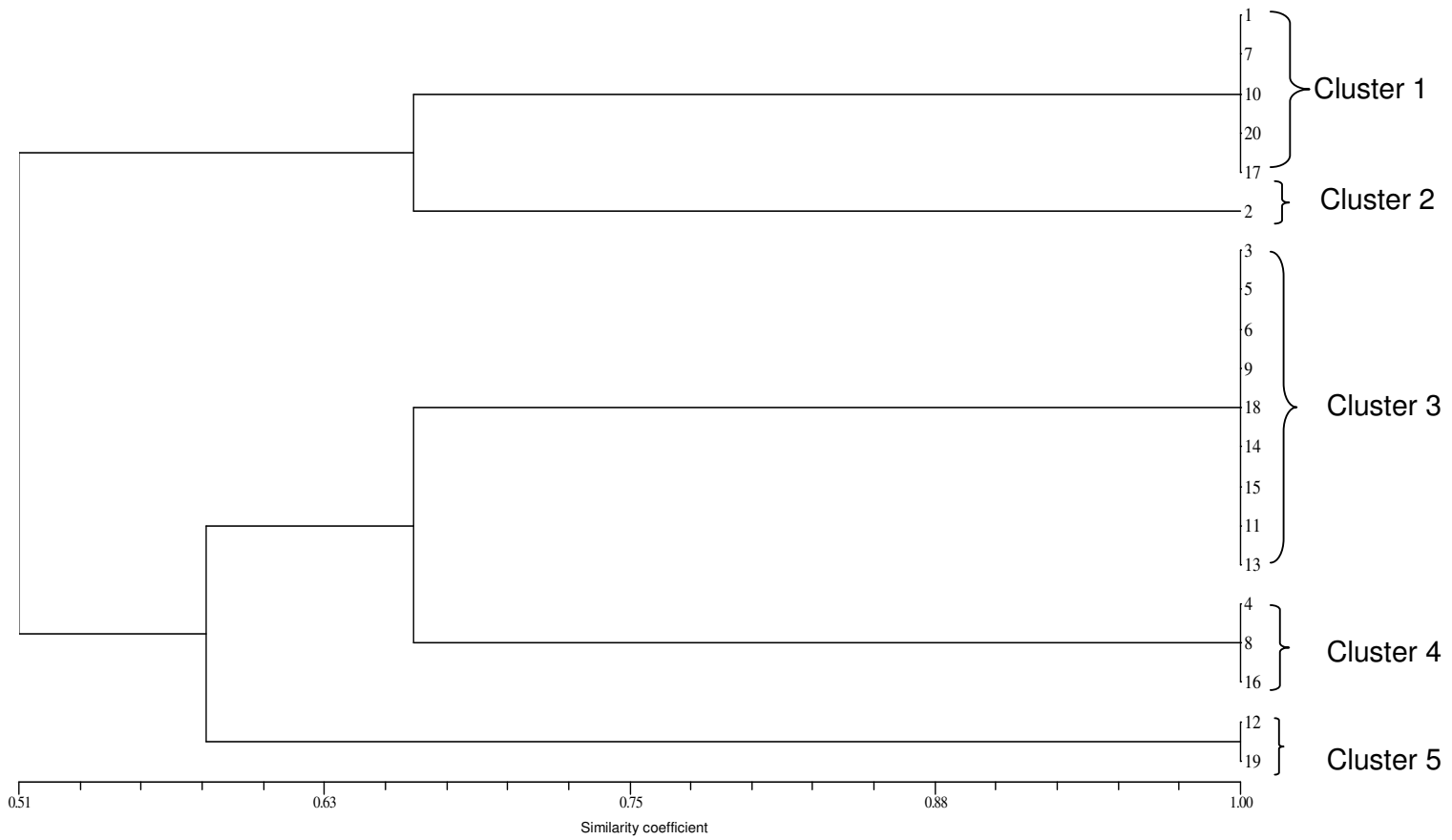


Fig. 11 : PCR-RFLP diversity profile of *C. gloeosporioides* by Hae III

LEGEND

Isolates	Source
1	Raravi
2	Govanakoppa
3	UAS Dharwad
4	Binkadakatti
5	Byadgi
6	Devihosur
7	Lingadahalli
8	Budugumpa
9	Belgammanadoddi
10	Mantralaya
11	Marakattu
12	Pedakurpadu

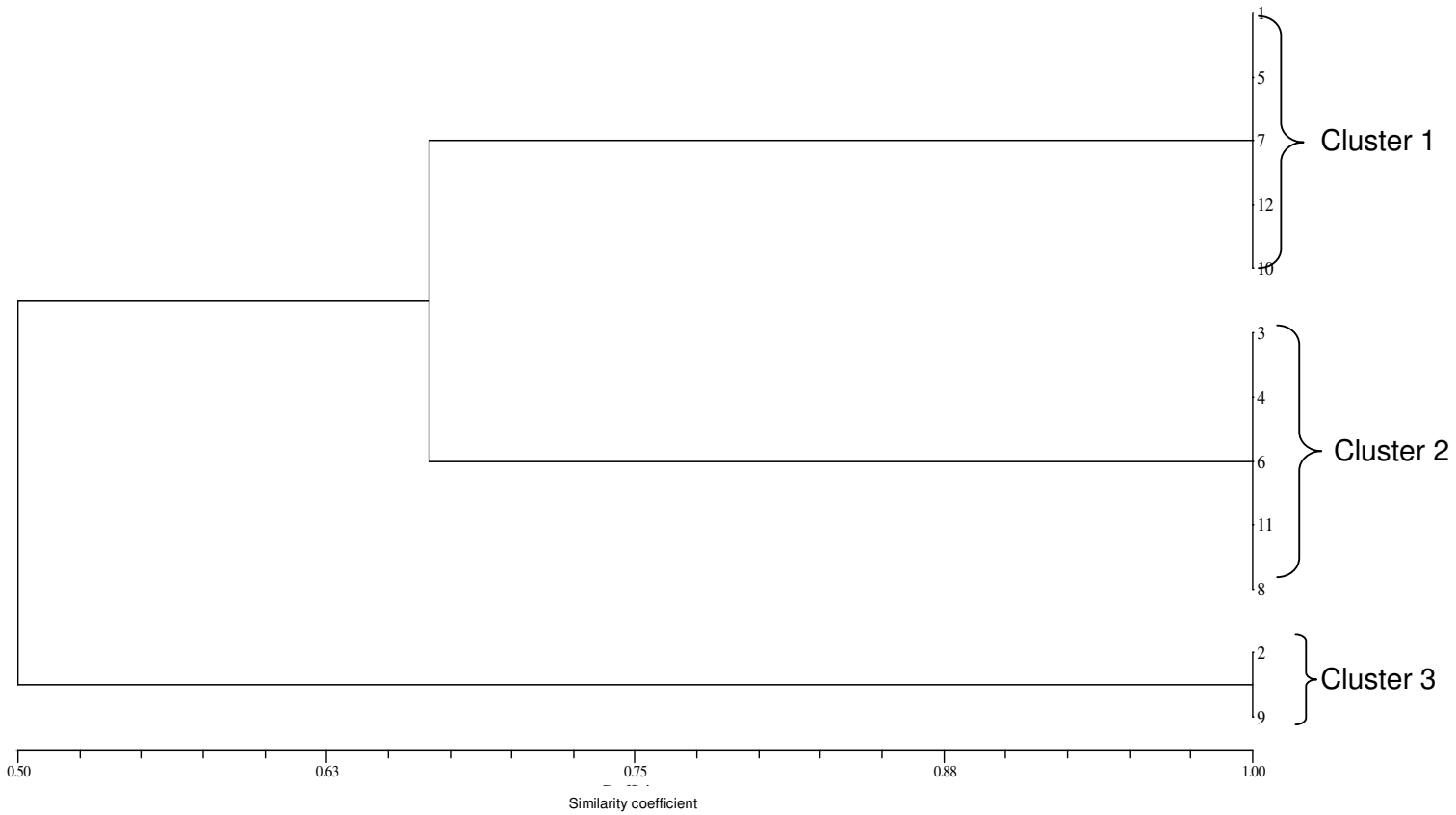


Fig. 12 : PCR-RFLP diversity profile of *C.acutatum* by *Hae III*

LEGEND

Isolates	Source
1	Koluru
2	UAS Dharwad
3	Kundgol
4	Hulkoti
5	Guttal
6	Talakall
7	Raichur
8	Paldaagu
9	Mandapura
10	Kalludevarakunta

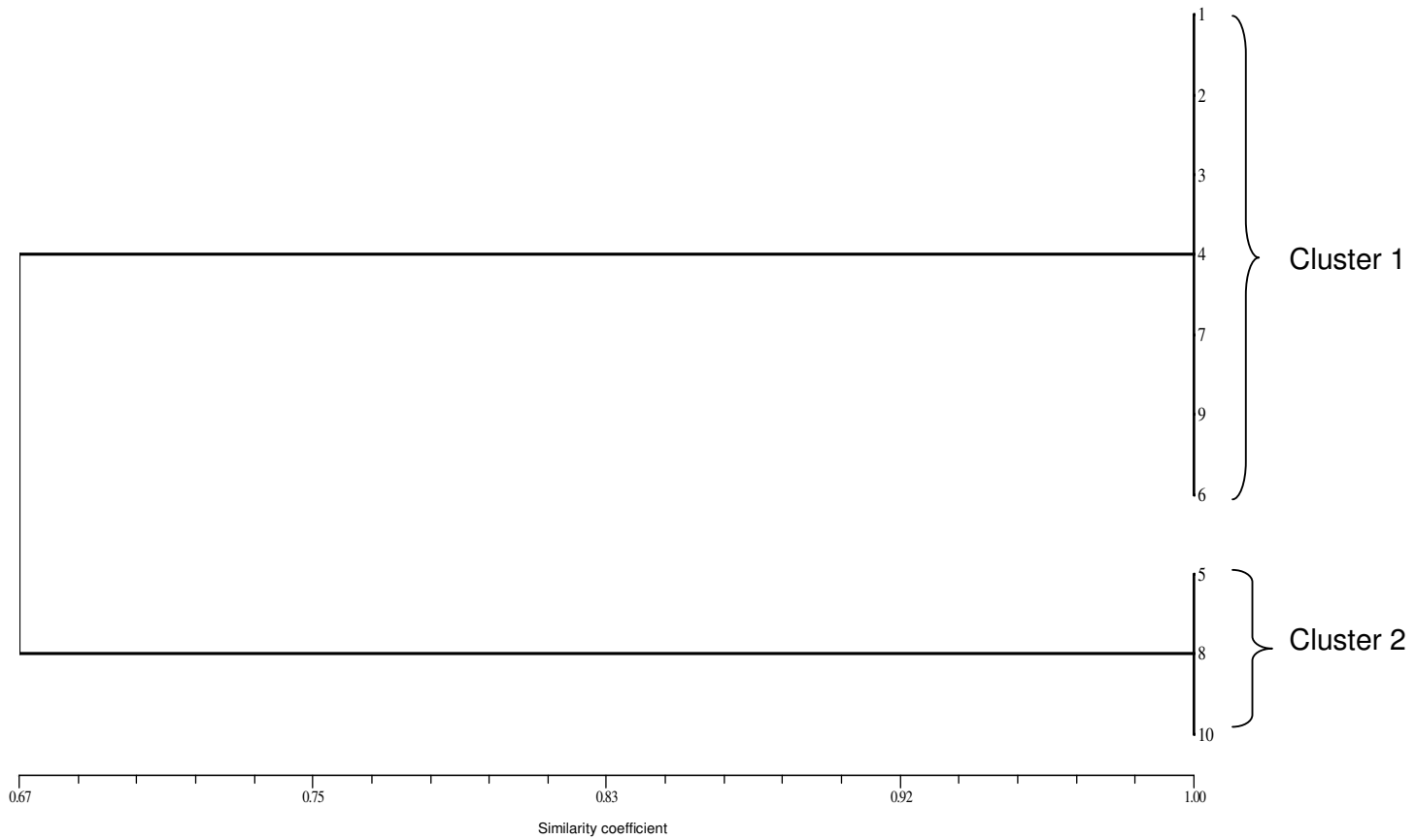


Fig. 13: PCR-RFLP diversity profile of *A. alternata by TaqI*

LEGEND

Isolates	Source
1	Raravi
2	UAS Dharwad
3	Sharewad
4	Byalal
5	Ranebennur
6	Nelhal
7	Alur
8	Emmiganur
9	Mangalaveda
10	Lokapur
11	Kumbapur farm
12	Badrapur
13	Bommanal
14	Raladoddi
15	Mantralaya
16	Perecherla

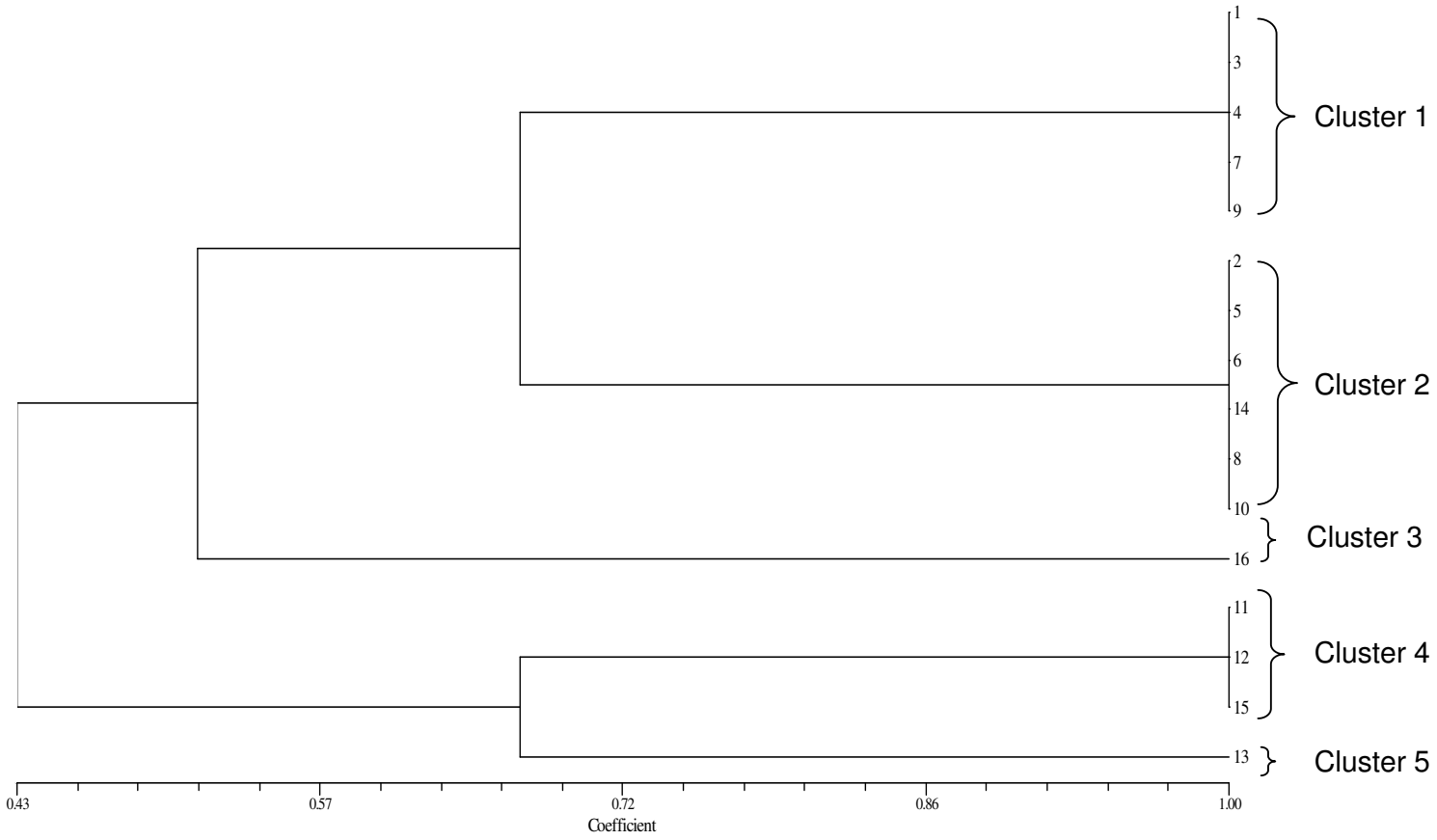


Fig. 14: PCR-RFLP diversity profile of *Fusarium* spp. *Taq I*

isolate). ITS-RFLP technique is an efficient method for rapid diagnosis of *Colletotrichum* species from chilli. Similar type of observations were made by Sheu *et al.* (2007) where in they collected a total of 412 Taiwan isolates from chilli production areas analyzed through ITS-RFLP fingerprinting. Among them, 245 *C. acutatum*, 34 *C. boninense*, 52 *C. capsici* and 69 *C. gleosporioides* were identified. Other *Colletotrichum* isolates (3%) were not distinguishable, which inferred to the various inter- and intra-species variations in *Colletotrichum* members.

Imjit *et al.* (2013) reported that PCR- based molecular method provided improved early detection and diagnosis system of fruit rot disease of chilli. In the present study detection of pathogens from different parts of plant like seeds, fruits, infected twig/stem by PCR-based method was done by using specific primers. specific amplification with specific primers of DNA extracted directly from infected host tissues i.e., seed, fruit, pedicel and dieback stem revealed that *C. capsici* was amplified by species specific primer (C.cap-F and C.cap-R) as single band at 450bp. *C. gloeosporioides, C. acutatum,* amplified by species specific primers (CgInt and CaInt) at 450 and 490bp respectively, *Alternaria alternata* amplified by species specific primer at 390bp and *Fusarium spp.* were amplified at 550 – 570bp. Quick detection and diagnosis will help in plant quarantine laboratories to obtain fast and accurate test results. Present results are well supported by the reports of Zivkovic *et al.* (2010) Chowdappa and Chethana (2012) and Pongpisutta *et al.* (2013).

5.3 Epidemiology of the fruit rot disease in relation to climatic factors

5.3.1 Survival ability of *C. capsici*, *C. gloeosporioides, A. alternata* and *F. oxysporum* in plant debris

During the absence of an active host plant, pathogen/s may survive themselves to maintain continuity of the disease cycle and to provide primary inoculum for infection in the next season. Dormant mycelium plays an important role in the perpetuation, dissemination and inciting of disease from one season to another. The study was initiated to know the survival ability of the pathogen at different ecological conditions *viz*., laboratory conditions, soil surface and 10 cm depth of soil.

The present study revealed that *Colletotrichum* spp. remained viable up to 165 days under laboratory conditions, 120 days on soil surface and 60 days under 10cm depth of soil condition. *A. alternata* remained viable up to 120 days under laboratory conditions, 90 days on soil surface and 45 days under 10cm depth of soil condition. *F. oxysporum* remained viable up to 150 days under laboratory conditions, 135 days on soil surface and 60 days under 10cm depth of soil condition.

The present results were slightly different from earlier reports in which Ahmed (1982) found that, *C. capsici* causing fruit rot of chilli survived up to eight months in both seed and culture. *C. capsici* could survive up to 225 days on infected seeds of chilli stored under room conditions where as on pedicel and fruit rind it survived for 195 days (Sanathakumar, 1999). *F. oxysporum* remained viable up to 120 days under laboratory, 255 days on pot soil surface and 270 days under refrigerator condition, whereas *Colletotrichum* spp. remained viable up to 165 days under laboratory, 120, 210 days in pot soil surface and refrigerator condition respectively. These pathogens survived in the infected debris and it served as primary source of infection during the favorable conditions in next season (Patil and Nargund, 2013)

5.3.2 Host range of chilli fruit rot pathogens

C. capsici can overwinter on alternative hosts such as solanaceous vegetables and legume crops, plant debris and rotten fruits in the field (Pring *et al.,* 1995). In the present study two solanaceous vegetables and seven legume hosts were tested. On solanaceous vegetables, tomato and brinjal chlorotic lesions were produced on 4^{th} day after inoculation. These lesions turned to brown color leading to necrosis after seven days of inoculation. In legume crops like cowpea, green gram and black gram brown color horse shoe type lesions were observed after eight days after inoculation. *C. capsici* which causes fruit rot of chilli also infects soybean, tomato, potato, and brinjal (Sundararaman, 1927; Hegde, 1998). Pandey (2006) showed on the basis of morphological, pathological and molecular characterization that *C. capsici* from chilli causes fruit rot, seed and seedling mortality in tomato.

5.3.3.1 Cross inoculation of *C. capsici*

Colletotrichum species were generally able to survive in or on seeds and one of the ways that anthracnose was introduced to the chilli field is through infected transplants. *C. capsici* infection of chilli was shown to have two pathways: invasion through the seed coat and invasion through the openings of the testa (Jewsakun, 1978). *C. capsici* caused seed rot and root rot of seedlings (Bhale *et al.,* 1999a; Shivakumara, 2006; Hemannavar, 2008; Chauhan *et al.,* 2010a) and also it causes die-back of chilli (Hegde, 1998; Shivakumara 2006; Akhtar *et al.,* 2008; Rajput, 2011). Hence, to know whether the same pathogen will cause all these symptoms, in the present investigation cross inoculation of *C. capsici* between seed, twig, fruit pedicel and fruit was carried out, the results revealed that *C. capsici* can cause seed rot, die-back of twigs, pedicel discoloration and fruit rot from all tested parts of chilli plant.

5.3.3.2 Pathogen interaction

Fruit rot of chilli is caused by more than one pathogen i.e., different species of *Colletotrichum*, (*C. capsici*, *C. gloeosporioides, C. acutatum*), *A. alternata* and *Fusarium spp*. (Simmonds, 1965; Thind and Jhooty 1985; Datar, 1995; Mesta, 1996; Shivakumara, 2006; Santoshreddy *et al.,* 2012; Parey *et al.,* 2013). Hence to know about the symptoms caused by these pathogens in combination, an experiment was conducted in this aspect. It revealed that symptoms caused by combination of *C. capsici*, *C. gloeosporioides, C. acutatum* appear on one day after inoculation as water soaked lesion of 0.5 -1.0 cm diameter. After seven days of inoculation sunken lesion with salmon color spore mass produced on 1.5 – 2.0 cm diameter lesion. Symptoms caused by combination of *C. capsici, A.alternata* and *F. oxysporum* appear on one day after inoculation as water soaked lesion of 0.5 – 1.0 cm diameter, after four days of inoculation grayish mycelial growth observed on 2.0 – 2.5 cm diameter, six days after inoculation concentric rings with grayish salmon color spore mass produced on these lesions.

5.3.4.1 Effect of weather parameters on spore load of *Colletotrichum* spp.

Environmental factors play a major role in the development of disease epidemics. The relationships among rainfall intensity, duration and crop geometry and

the dispersal of inoculum possibly lead to different levels of disease severity. The effects of temperature often interact with other factors, such as leaf surface wetness, humidity, light or competitive microbiota. The duration of the surface wetness, however, appears to have the most direct influence on the germination, infection and growth of the pathogen on the host. In the two consecutive years of investigation, the simple correlation and multiple regression analysis was worked out to understand relationship between weather parameters and spore load of *Colletotrichum* spp.

In the pooled data of two consecutive years (2012 and 2013), cumulative rainfall recorded highly significant positive correlation (r = 0.84) with maximum temperature (r = 0.34). Whereas, other weather parameters *viz*., relative humidity of evening and morning were negatively correlated.

It indicates that among weather parameters selected for correlation on the spore load of *Colletotrichum* spp. cumulative rainfall and maximum temperature showed significantly positive correlation.

The coefficient of determinative value (R^2) was found to be 90 and 83 per cent in 2012 and 2013 respectively. The difference between observed and predicted spore load of *Colletotrichum* spp. varied from -4.28 to +1.19 (Fig. 15)

There was variation in the spore load progression which was accounted by the linear functions of the independent variables such as maximum and minimum temperature, morning and evening relative humidity, rainfall and number of rainy days and dependent variable was spore load trapped by aeroscope. Influence of weather factors on the development of spore load of *C. truncatum* indicated that more conidial counts were observed during last week of July and first week of August, which coincided with the critical stages of infection in green gram anthracnose disease (Kulkurni, 2009).

5.3.4.2 Effect of *Colletotrichum* spp. spore load and weather parameters on fruit rot disease:-In the two consecutive years of investigation, the simple correlation and multiple regression analysis was worked out to understand relationship between weather parameters, *Colletotrichum* spp. spore load and fruit rot incidence.

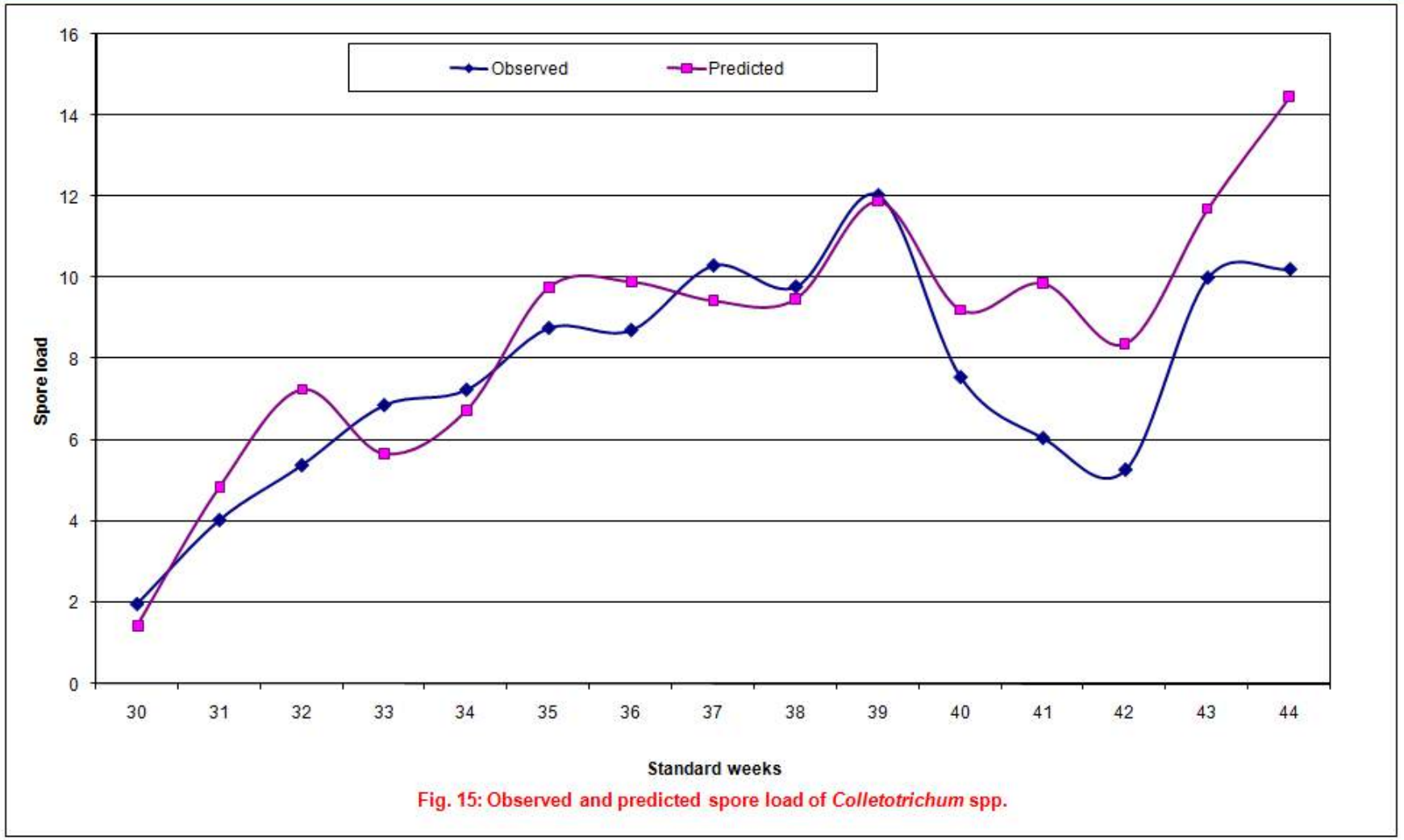


Fig. 15: Observed and predicted spore load of *Colletotrichum* spp.

In the pooled data of two consecutive years (2012 and 2013), spore load recorded highly significant positive correlation (r = 0.94) followed by cumulative rainfall (r = 0.80), and maximum temperature (r = 0.41). It indicates that spore load of *Colletotrichum* spp. and among weather parameters cumulative rainfall and maximum temperature showed significantly positive correlation on fruit rot incidence in chilli.

The coefficient of determinative value (R^2) was found to be 88 and 85 per cent in 2012 and 2013 respectively. The difference between observed and predicted fruit rot incidence *Colletotrichum* spp. varied from -0.66 to + 2.48 (Fig. 16)

Cumulative rainfall contributed maximum (R^2 = 0.97) to development of onion twister disease severity caused by *C. gleosporioides, C. acutatum* and *F. oxysporum* (Patil *et al.,* 2013a).

5.3.5 Effect of date of planting on fruit rot and die-back disease incidence and severity

A considerable variation on incidence of twister disease of onion caused by *C. gleosporioides, C. acutatum* and *F. oxysporum* with respect to date of planting, in which planting at 15th July was found ideal for obtaining maximum severity of disease (Patil *et al.,* 2013a). In present investigation a field trial was carried out to assess the effect of planting time on fruit rot and die-back disease development which revealed that highest fruit rot incidence was observed in July 15th planting, where as highest die-back incidence was observed in June 15th planting. Byadgi Dabbi recorded highest fruit rot incidence and severity where as therer was no significant difference in die back disease incidence in date of planting and varieties.

5.4 Development of IDM strategies for disease

No single specific management program could eliminate chilli fruit rot complex. Effective management of such complex diseases usually involves the integrated management strategies to reduce the use of fungicides, to enforce eco friendly low cost and effective management by combination of cultural, biological, chemical management with intrinsic resistance strategies. Hence, in the present investigation emphasis was given on identification of resistance genotypes, evaluation of seed

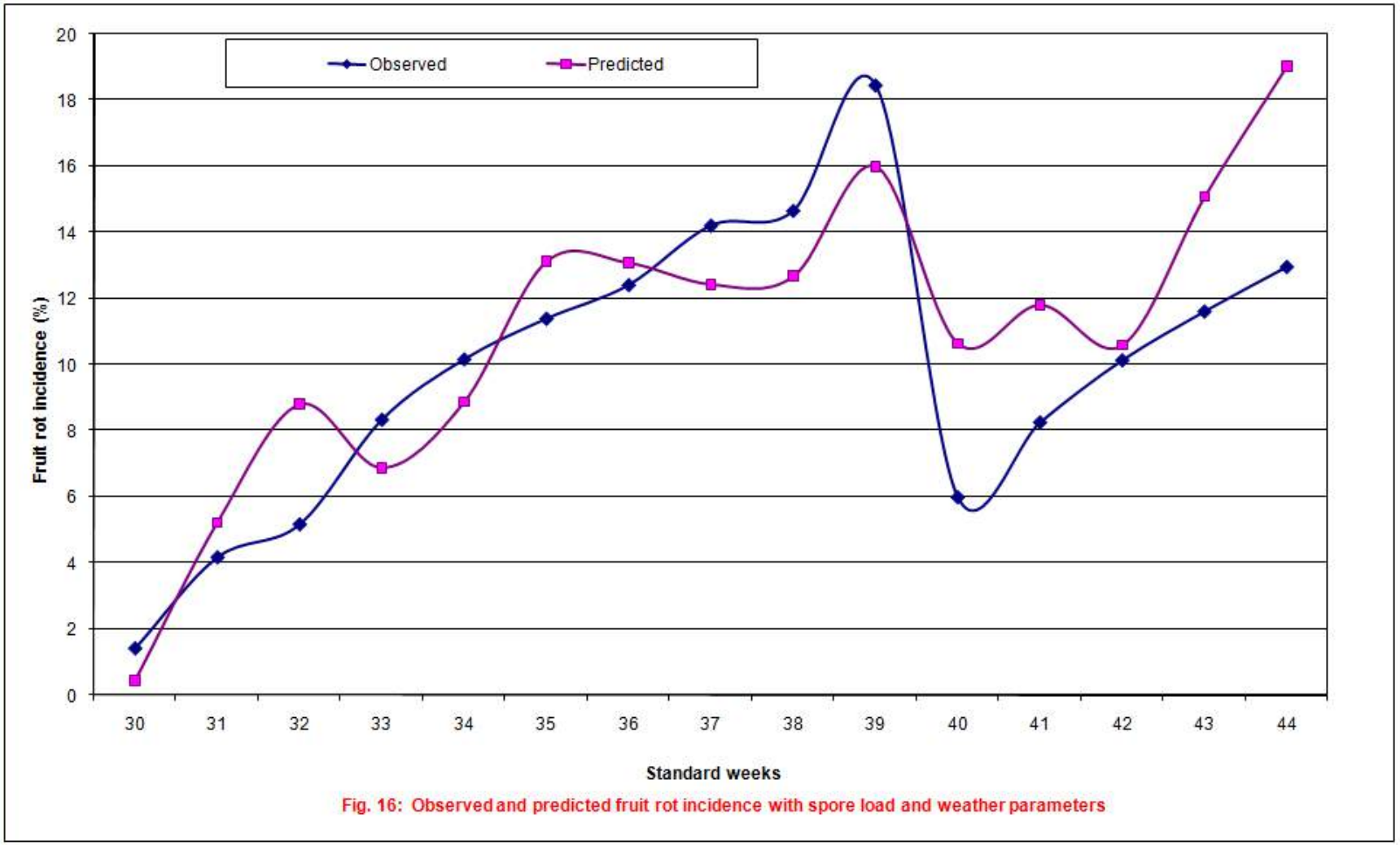


Fig. 16: Observed and predicted fruit rot incidence with spore load and weather parameters

treatment chemical and bio fungicides to eliminate primary inoculum , chemical management and also evaluated four management modules which include bio-intensive, chemical and adoptive by combination of both biological and chemical management which are discussed in following paragraph.

5.4.1 Evaluation of chilli genotypes

Among disease management strategies the use of resistant cultivars is the cheapest, easiest, safest and most effective means of controlling the disease. This is not only to eliminate losses from the disease but also decrease the cost of chemical and mechanical control, as well as reduce contamination of the environment from the use of toxic chemicals. This is an important choice in all crop improvement programme. Besides, the resistant cultivars conserve natural resources and reduce the cost, time and energy when compared to other methods of disease management. Increase in use of fungicides to control the fruit rot has led to consciousness of their persistence and development of new strains of pathogen. To avoid this situation, identifying the resistant cultivars against chilli fruit rot is most significant one.

Earlier reports indicated varied degree of reaction of genotypes against fruit rot fungus, *C. capsici* under natural endemic condition. LCA-301, LCA-324, K-1 and Byadagi Kaddi were found resistant. Whereas KDSC-210-10 and S-32 were found highly susceptible (Hegde and Anahosur 2001b). The genotypes Arka Lohit, Pepper Hot, CA 97, KDC 1, CC 4, CA 95, CA 115 and CA 59 were found to be moderately resistant to anthracnose and a high yielding moderately resistant to fruit rot disease chilli hybrid CCH1(Sln 1 x CA 97) was identified (Pugalendhi *et al.,* 2010).

Among 343 genotypes screened under natural endemic field condition during *kharif* season of 2012 and 2013, none were immune, eight found resistant, 21 genotypes were moderatly resistant.

Under *In vitro* screening by pin prick method none of the genotype showed immune and resistant reaction. However, moderately resistant reaction was observed in seventeen genotypes, ten genotypes showed moderately susceptible reaction against *C.capsici, C. gloeosporioides, C. acutatum*. Ninteen genotypes showed moderately resistant, eight showed moderately susceptible reaction against *A.alternata*

and 20 genotypes showed moderately resistant, seven showed moderately susceptible reaction against *F. oxysporum* and *F. sporotrichioides*. These results are well supported by Parey *et al.,* (2013), wherein they revealed that evaluation of genotypes against *C. capsici* none was resistant, however, DC-4, Arka Lohit, LCA-235, LCA-333, LCA-301 exhibited moderately resistant reaction under both field and pot culture conditions and minimum lesion size was also observed under *in vitro* by pin prick method in these genotypes. In particular, some lines of *C. baccatum* showed resistance to the pathogen, and pathogen inoculation resulted in limited lesions on the chilli fruits (Yoon, 2003). However, to date, no resistance has been found in *Capsicum annuum*, which is the only species grown worldwide (Park, 2007).

5.4.2 Seed health management

5.4.2.1 Standard Blotter Method

The seeds showing fungal colonies under stereo-binocular microscope revealed the presence of *C. capsici* (72.85%), *C. gloeosporioides* (9.26%) and *C. acutatum* (4.76%), *A. alternata* (5.20%) and *F. sporotrichioides* (3.45%) and *F. oxysporum* (4.30%) (Fig. 17). The present studies are in conformity with Solanke *et al.* (2001) who reported the presence of *C. capsic*i, *F. moniliformae*, *A. alternata* from chilli seed samples. *C. capsici,* species of *Alternaria* and *Fusarium* were observed in fruit rot affected chilli seed samples of northern Karnataka (Shivakumara, 2006; Hemannavar *et al.,* 2009). *C. dematium* and *A. alternata* were associated with chilli seeds and found responsible for severe seed rot and seedling rot was reported by Bhale *et al.,* (1999a).

5.4.2.2 Evaluation of chemical fungicides

Simple seed treatment is known to reduce the seed-borne infections and subsequently protect seed from deterioration. In absence of resistant cultivars the use of fungicides has become inevitable method in the management of seed borne fruit rot fungi in chilli. Evaluation of seed treatment fungicides revealed that among three systemic fungicides evaluated at 0.2% concentration pyraclostrobin 20WG had shown least infection (11.63%) with highest vigour index (861.17). Between two non systemic fungicides captan 75WP showed least infection (12.28%) with highest vigour index (754.64). Similar results were reported by Arunkumar and Vyas (2003). Among six

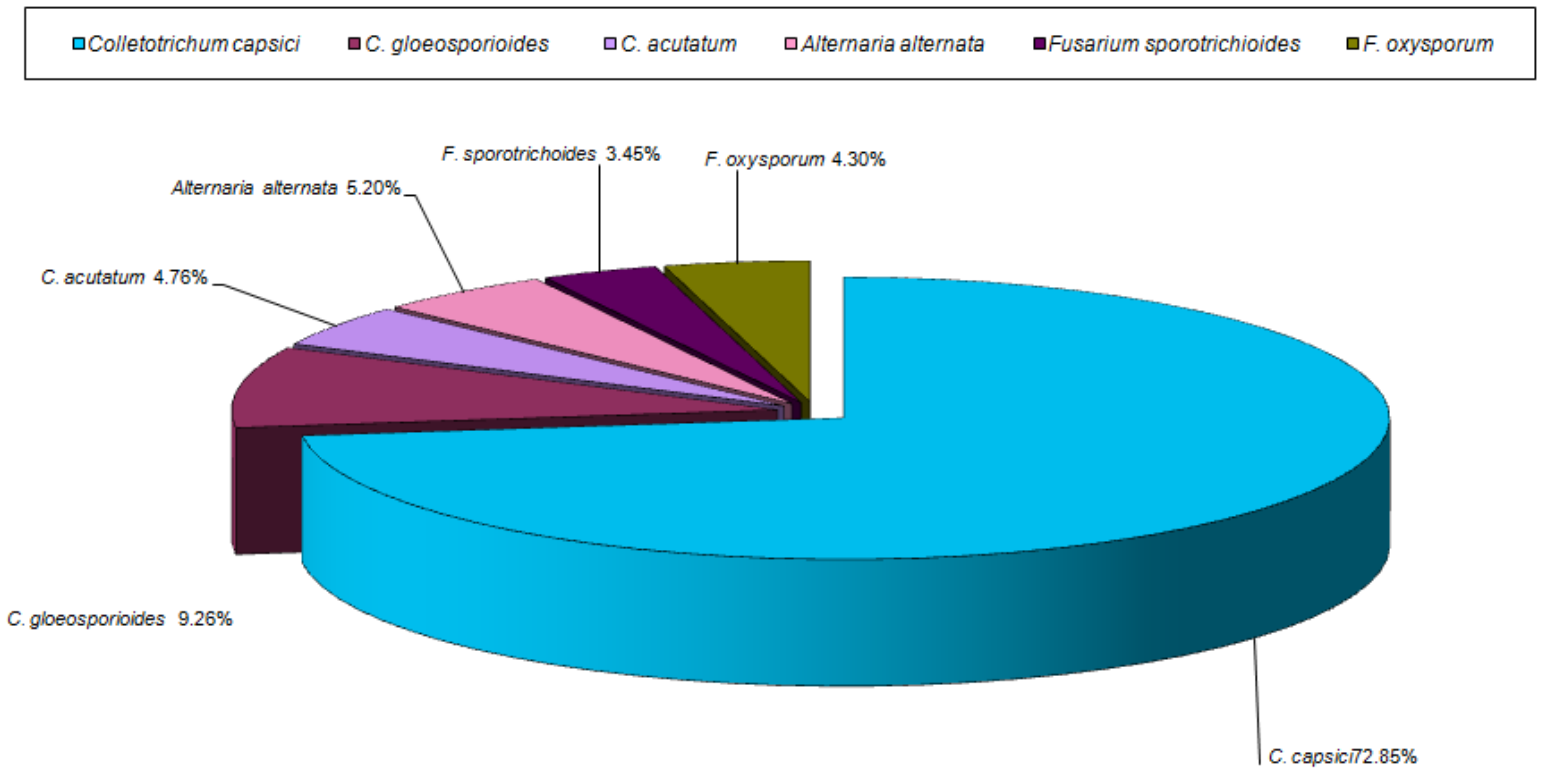


Fig. 17: Frequency of chilli seed mycoflora

combi product fungicides, carboxin 37.5% + thiram 37.5% WS showed least infection (7.25%) with highest vigour index (932.02) followed by metalaxyl 4%+mancozeb64% (10.09%, 871.70) (Fig. 18). Among fungicides, carboxin + thiram (Vitavax power) at 0.2% was most effective seed treatment fungicide for chilli seed health management in nursery conditions. Similar results were reported by Hemannavar (2008) under laboratory conditions. In combi product carboxin 37.5% + thiram 37.5% WS, carboxin inhibits the mitochondrial electron transport of fungi which act on target site succinate dehydrogenase enzyme. The other compound thiram increases the efficacy of carboxin by reacting with protein SH group and also it acts on multi sites and effectively acts against seed and soil borne fungal pathogens.

5.4.2.3 Evaluation of bio fungicides

Seed treatment with biofungicides is the oldest practice in plant protection which provide economical and relatively nonpolluting and now, this is an attractive delivery system for either fungal or bacterial bioprotectants compared to other field application systems. The uses and expectations of seed treatment are greater today due to the impact of environmental regulations that have either banned or restricted use of organic mercurial fungicides because of their residual toxicity. Bioprotectants applied to seeds may not only protect seeds but also may colonize and protect roots and increase plant growth. *Trichoderma* spp. and *Pseudomonas fluorescens* have been considered as good model of biological control because of their ubiquitous nature, easy to isolate, rapid growth on many substrates, affect wild range of plant pathogens, acts as mycoparasite, competes well for food and site, have enzyme system capable of attacking many plant pathogens and easy in application.

Results of four bio fungicides alone (@ 10.0 g/kg) and in combination (5.0 +5.0 g/kg) seed treatment revealed that *T. harzianum* 5.0g + *P. fluorescens* 5.0g showed least infection (14.89%) with highest vigour index (930.74) followed by *P. fluorescens* (10.0 g/kg) 14.94% infection with 915.27 vigour index. The highest seedling infection (42.99%) with least vigour index (361.87) was observed in untreated control. Suthinraj and John (2009) reported that seed treatment with *P. fluorescens* (5g/kg) and *T. harzianum* (10g/kg) reduces 25% and 24.10% incidence of *C. capsici* and increased seedling vigour of chilli by 13.70% and 12.10% respectively (Fig. 19). *P. fluorescens*

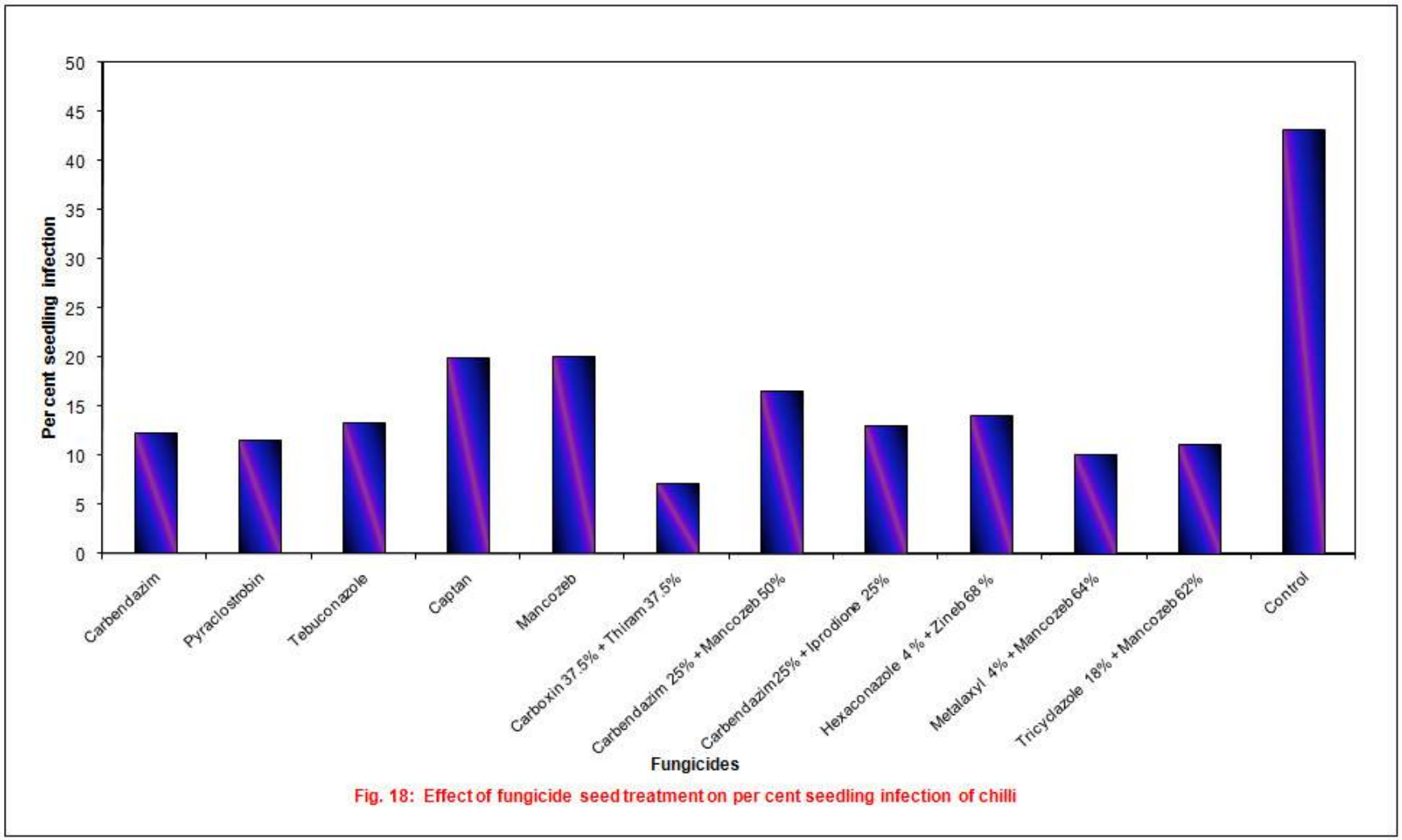


Fig. 18: Effect of fungicide seed treatment on per cent seedling infection of chilli

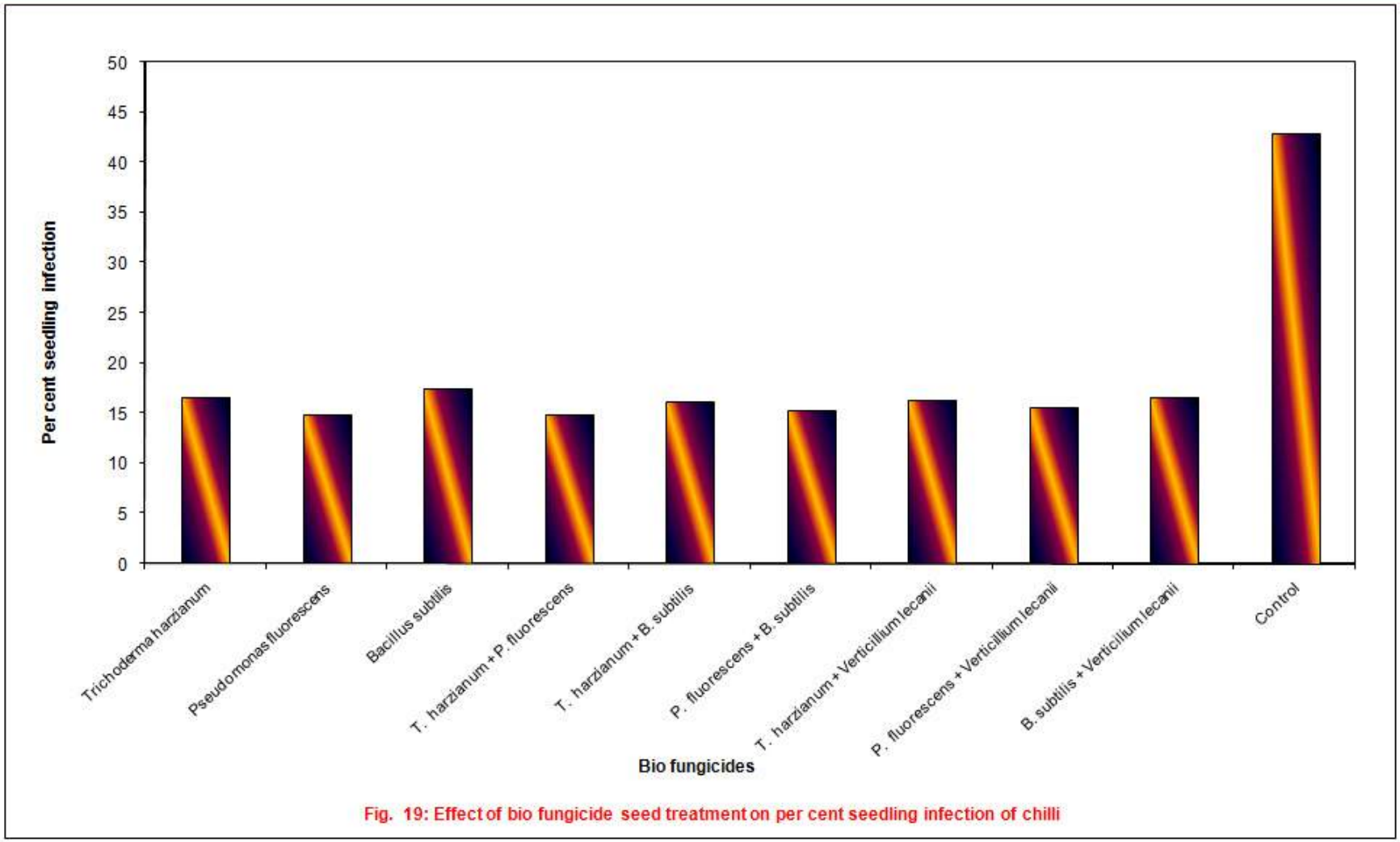


Fig. 19: Effect of bio fungicide seed treatment on per cent seedling infection of chilli

showed higher antagonistic activity against *C. capsici* under *in vitro* conditions and also less seedling rot was obtained in *P. fluorescens* treated seeds compared to *T. harzianum* (Hegde *et al.,* 2001b*,* Srinivas *et al.,* 2006; Azad *et al.,* 2013). Seed treatment with *Trichoderma harzianum* recorded least damping off incidence followed by *T.viride* and *Pseudomonas fluorescence* compared to untreated control in chilli (Deshmukh *et al.,* 2012). Choudhary *et al.,* (2013) reported that seed treatment with carbendazim, thiram and *T. viride* effectively managed seedling rot caused by *C. capsici*.

5.4.3 Field efficacy of chemicals for the management of fruit rot and die-back disease of chilli during *kharif* 2012 and 2013

Chemicals are the most common and practical method to control anthracnose diseases. However, fungicide tolerance often arises quickly, if a single compound is relied upon too heavily. The disease can be managed under normal weather conditions with a reasonable spray program. However, there are numerous reports of negative effects of using chemicals on farmers' income and health, and toxic contamination to the environment, particularly in developing countries (Voorrips *et al.,* 2004). A field experiment was conducted during *kharif* 2012 and 2013 at MARS Farm, Dharwad for management of fruit rot and die-back disease of chilli using four systemic and four combi-product fungicides along with a control where only insect management was done as per package of practices. The pooled results indicated that at 0.1% concentration difenconazole 25EC and pyraclostrobin 20WG had shown least incidence of die-back (1.93 and 2.93% respectively) and fruit rot (8.99% and 12.25% respectively). Among combi-products tricyclazole 18% + mancozeb 62% WP and pyraclostrobin 5% + metiram 55% had shown least incidence of die-back (2.80% and 2.23% respectively) and fruit rot (11.08% and 11.70% respectively) (Fig. 20). Similar observations were reported by Alexander and Waldenmaier, 2002; Lewis and Miller, 2003, wherein they reported the strobilurin fungicides azoxystrobin (Quadris), trifloxystrobin (Flint), and pyraclostrobin (Cabrio) have recently been labeled for the effective management of chilli fruit rot. Difenconazole, propiconazole and tricyclazole at 0.1% effectively manages the fruit rot diseases caused by *Colletotrichum* spp. in fruits and vegetables (Hegde *et al.,* 2002b; Jamadar and Patil 2007; Benagi *et al.,* 2009; Biju *et al.,* 2011; Nargund *et al.,* 2011; Nargund *et al.,* 2013b). These triazoles are sterol

inhibiting fungicides affect cytochrome P-450 enzymes inhibitors of sterol C-14 demethylation by this they act against most of the Ascomycota group fungal pathogens, whereas strobulirins act through inhibition of respiration by binding to the Q_o center of the cytochrome b. These strobulirins are very broad and balanced spectrum of activity on the foliage and have very favorable toxicological profile rapidly dissipating from soil and surface water which are unlikely to cause hazard to non target organisms and they have both protective and curative effect.

Use of combi product fungicides avoids the development of resistance of fungi to systemic fungicides because these systemic fungicides interfere with only one or sometimes two functions in physiology of fungus which it easily overcomes by either a single mutation or by selection of resistant individuals in a population. Wherein non-systemic protectant fungicides affect too many functions in fungus physiology and to develop resistance the fungus will have to make too many gene changes. Hence the combination of both systemic and non-systemic fungicides provides better management of plant fungal disease for long duration

Highest yield was observed in difenconazole 25EC (8.86 q/ha) with cost benefit ratio 2.59 which was on par with pyraclostrobin 5% + metiram 55% (8.33 q/ha, C:B 2.40) and tricyclazole 18% + mancozeb 62% WP (8.21 q/ha C:B 2.29), whereas lowest yield (3.58 q/ha) was observed in control.

5.4.4 Integrated management of fruit rot disease of chilli

Field experiment was conducted during *kharif* 2012 and 2013 at Dharwad with four modules namely bio intensive module for both disease and insect pests (M_1), bio-intensive module for disease with chemical pesticides for insect pests (M_2), adoptive module (M_3), chemical intensive module (M_4) to develop best disease management module for chilli fruit rot disease.

This study found that adoptive module is a cost-effective and eco-friendly approach in the chilli fruit rot management. The result of two years experimentation revealed that adoptive module showed least seedling infection (7.06 %), die-back incidence(1.21 %) and severity(9.30 PDI), fruit rot incidence (4.47 %), severity (2.68 PDI) and recorded high yield 8.92 q/ha with 2.44 cost benefit ratio which was also on

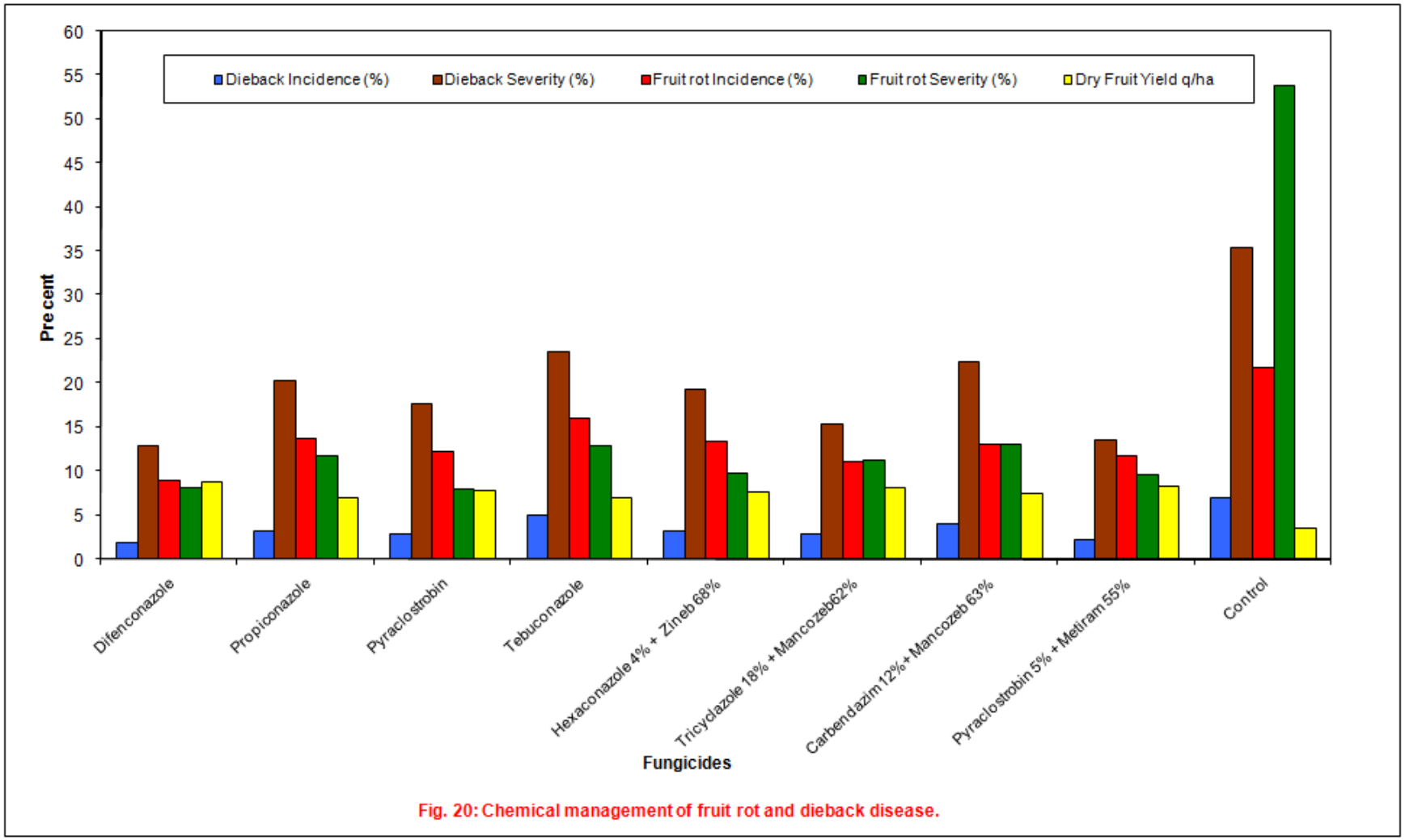


Fig. 20: Chemical management of fruit rot and dieback disease.

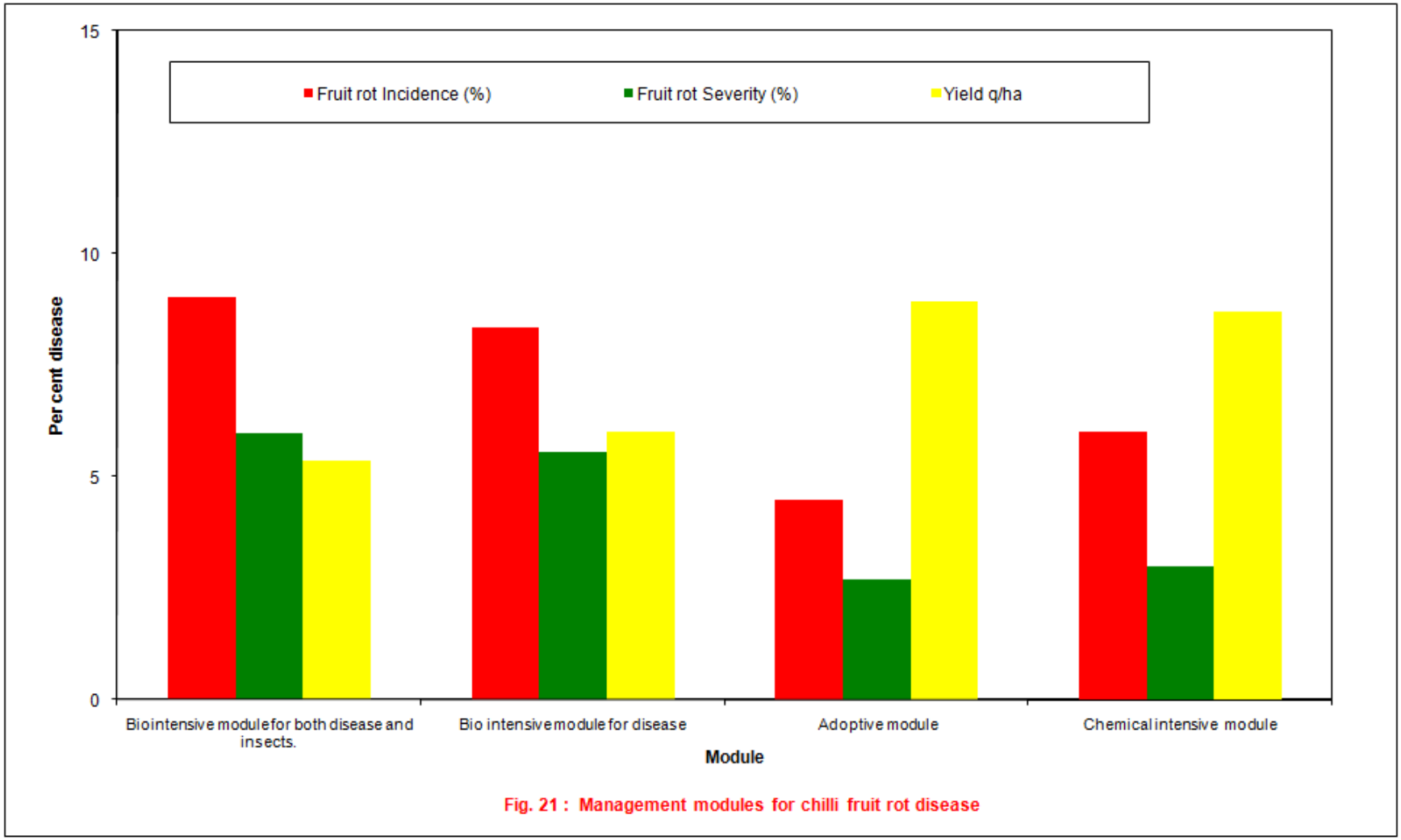


Fig. 21 : Management modules for chilli fruit rot disease

par with chemical intensive module with 8.71 q/ha 2.32 C:B ratio (Fig. 21). The present results were also supported by (Sharma *et al.,* 2004; Lydia and Zachariah, 2012; Patil and Nargund, 2013) where in they reported among management modules, biological, chemical and IDM. IDM module was superior to biological and chemical modules. As no single specific management practice could eliminate chilli fruit rot complex here adoptive module involves the integrated management strategies at right time application reduces the use of fungicides, and it enforces eco friendly low cost and effective management of chilli fruit rot.

Future line of work

- An extensive and continuous survey in intensive manner to see the diversity of pathogens is needed.
- Identification of susceptible stage for die-back disease.
- Apart from ITS region, sequence analysis of protein coding genes such as partial β-tubulin gene is needed to resolve phylogenetic relationships among the *Colletotrichum* species.
- Marker Assisted Selection for identification and development of multiple disease resistance genotypes is needed.
- IDM module (adoptive) needs to be demonstrated in farmer's fields for popularization of cost effective and eco-friendly management systems to farming community.

6. SUMMARY AND CONCLUSIONS

Chilli (*Capsicum annuum* L.) is one of the very popular spice/ vegetable crop grown worldwide known for its medicinal and health benefiting properties. This crop is suffering from several economically important diseases. Fruit rot disease caused by fungi *Colletotrichum* spp. (namely *C. capsici*, *C. gloeosporioides* and *C. acutatum*), *A. alternata*. and *Fusarium* spp. is major yield limiting factor in all chilli growing areas. In view of the destructive nature of disease the present investigation was executed.

The investigations included various aspects of chilli fruit rot and die-back disease with reference to prevalence and distribution of disease, pathogen diversity, severity of the disease in various geographical regions of South India, isolation, identification, morphological and molecular variability of pathogens and their quick detection by molecular method. Epidemiology and integrated disease management strategies comprising screening for resistance, evaluation of chemicals, various disease management modules to find out the best management module with maximum C:B ratio which helps the farming community to a greater extent. The findings of the investigations are summarized in this chapter.

Survey carried out during 2012-13 and 2013-14 revealed that among the three states the highest fruit rot incidence (19.97%) with 13.77 PDI was observed in Maharashtra followed by Andhra Pradesh (19.82%, 13.07 PDI) where as the highest die-back incidence (11.23%) with 42.79 PDI was observed in Andhra Pradesh followed by Karnataka (9.06%, 38.14 PDI). Among eight districts of Karnataka the highest fruit rot incidence (22.18%) with 14.75 PDI was observed in Bellary, where as the highest die-back incidence (11.18%) with 43.92 PDI was observed in Gadag. In Guntur district of Andhra Pradesh the highest fruit rot incidence (21.84%) with 12.98 PDI was recorded.

With respect to rainfed and irrigated conditions during survey, it revealed that, both rainfed and irrigated conditions disease was equally distributed in severe form. In both soil types (black and red) there was no distinct differentiation for fruit rot disease. In both sole crop and inter crop disease was uniformly distributed in severe

form. With reference to genotypes observed during survey, fruit rot and die-back disease was equally severe in all genotypes.

During investigation, different symptoms of the disease were noticed *viz.,* seed and seedling rot, acervulii of *Colletotrichum* were observed on plumule and radical, softening, rotting and decaying of tissues at collar region of seedlings were observed. Necrosis of tender twigs from the tip to backwards, brown to grayish white straw colored lesions developed. Circular to elliptical sunken spots with salmon color and acervuli with conidia observed on *Colletotrichum* infected both red and green colored fruits. Black color spore masses with sunken lesions on *Alternaria* infected fruit was observed. Rotting of fruit from tip and pink color spore mass was observed on *Fusarium* infected fruits. Brown color discoloration and acervuli with conidia were observed on pedicel.

Predominance of various pathogens was observed during survey. Frequency of occurrence of single pathogen was always less compared to combination of pathogens. In combination of *C. capsici* and *Fusarium* spp. were found in 28.37 per cent where as *C. capsici* with *A. alternata* was 11.35 per cent. Among the mean frequency of fruit rot pathogens observed the *C. capsici* recorded highest frequency of 38.56 per cent followed by *A. alternata* (18.98 %), where as *C. acutatum* occurred in lowest frequency of 5.04 per cent.

The colony of *C. capsici* varied from white to grey color, flat to raised fluffy and smooth regular to coarse irregular margin. Acervuli size varied between 130.0 to 162.6 µm with setae length 145.4 to 179.1 µm. Medium to good sporulation with falcate shaped spores were observed.

The colony of *C. gloeosporioides* varied from white to grey color to whitish saffron color with flat to raised fluffy and smooth regular to coarse irregular margin was observed. Medium to excellent sporulation of cylindrical shaped spores with oil globules were observed under microscope.

The colony of *C. acutatum* varied from whitish pink to brownish pink color, flat to fluffy and smooth regular to coarse irregular margin. Medium to good sporulation of fusiform shaped spores were observed under microscope.

The colony of *A. alternata,* varied from ash to dark ash color, medium fluffy to raised fluffy and smooth regular to coarse irregular margin. Medium to excellent sporulation of muriform spores were observed.

The colony of *F. oxysporum* varied from white to whitish purple color, flat, smooth and regular margin. Medium to excellent sporulation of falcate macro conidia were observed under microscope.

The colony of *F. sporotrichioides* varied from light brown to white rose color, fluffy, smooth to coarse and regular to irregular margin. Good to excellent sporulation of falcate macro conidia with 3 – 5 horizontal septa were observed under microscope.

The isolates were identified as *Colletotrichum* spp., *Alternaria* sp. and *Fusarium* spp. by morphological characters. Later, the identity of the pathogen was confirmed by sequencing the amplified ITS rDNA region, and analysing in NCBI BLAST program and identified as *C. capsici, C. gloeosporioides, C. acutatum*, *A. alternata, F. sporotrichioides* and *F. oxysporum.*

Specific DNA amplification was observed with fairly consistent band for *C. capsici* at 450 bp by C. cap primer, for *C. gloeosporioides* fairly consistent band was observed with CgInt region at 450 bp and *C. acutatum* was amplified with CaInt region at 490 bp with concentration of 437 µg/µl. Whereas, *A. alternata* amplification was observed at 390 bp by AAR and AAF primer, for *Fusarium* spp. approximately at 550-570 bp by Tef- Fu primer.

The products of the PCR ITS rDNA digestion with *Hind III* revealed that no restriction sites were present. The digestion with *HaeIII,* resulted in a characteristic pattern of three fragments in all the isolates. *C. capsici* isolates were grouped into four clusters, *C. gloeosporioides* isolates were grouped into five clusters, *C. acutatum* isolates were grouped into three clusters. The digestion with *Taq I,* resulted in a characteristic pattern of three fragments in *Alternaria* and *Fusarium* isolates. *A. alternata* isolates were grouped into two clusters, *Fusarium* isolates grouped into five clusters.

PCR-based detection method using specific primers is best early detection and diagnosis system of fruit rot disease of chilli.

The survival ability of *Colletotrichum* spp., *A. alternata* and *F. oxysporum* was more in lab condition (150-165 days) and reduced to 90-125 days on soil surface and still reduction in survival was recorded in 10cm depth of soil condition (45-60 days).

C. capsici showed symptoms on both tested solanaceous vegetables (tomato and brinjal) and also all seven tested legume crops (cowpea, green gram, black gram, mothbean soybean chickpea and pea).

C. capsici can cause seed rot, die-back of twigs, pedicel discoloration and fruit rot from all tested above ground parts of chilli plant by cross inoculation.

Combinations of more than one pathogen cause high fruit rot severity and fast disease development was confirmed by pathogen interaction study.

The weather factors had direct and significant influence on the spore load of *Colletotrichum* spp. in which cumulative rainfall recorded highly significant positive correlation.

The weather factors and *Colletotrichum* spp. spore load had significant influence on the fruit rot incidence spore load recorded highly significant positive correlation
(r = 0.94) followed by cumulative rainfall (r = 0.80), and maximum temperature (r = 0.41).

The highest fruit rot incidence and severity was observed in July 15th planting and in Byadgi Dabbi variety, where as die-back disease incidence and severity were distributed uniformly irrespective of genotypes in all dates of planting.

Among 343 genotypes screened under natural endemic field condition during *kharif* season of 2012 and 2013 none were immune, eight genotypes found resistant where as 21 genotypes found moderate resistant.

38 genotypes were screened under laboratory condition by pin prick method results indicated that none of them showed immune and resistant reaction. However, moderately resistant reaction was observed in 17 genotypes.

The frequency of seed mycoflora observed under stereo-binocular microscope, revealed the presence of *C. capsici* (72.85%), *C. gloeosporioides* (9.26%) and *C. acutatum* (4.76%), *A. alternata* (5.20%) and *F. sporotrichioides* (3.45%) and *F. oxysporum* (4.30%).

Seed treatment of carboxin 37.5% + thiram 37.5% (vitavax power 75WS) at 2g/kg seed and combinations of *T. harzianum* 5.0g + *P. fluorescens* 5.0g were most effective in management of fruit rot causing seed borne fungal pathogens.

Among four systemic fungicides difenconazole 25EC and pyraclostrobin 20WG at 0.1% concentration and among five combiproduct fungicides, tricyclazole 18% + mancozeb 62% WP and pyraclostrobin 5% + metiram 55% found effective against fruit rot and dieback disease. Highest yield was observed in difenconazole 25EC (8.86 q/ha) with cost benefit ratio 2.59 which was on par with pyraclostrobin 5% + metiram 55% (8.33 q/ha, C:B 2.40) and tricyclazole 18% + mancozeb 62% WP (8.21 q/ha C:B 2.29).

Integrated management of chilli fruit rot disease during *kharif* 2012 and 2013 indicated that adoptive module showed least seedling infection (7.06 %), die-back incidence (1.21 %) and severity (9.30 PDI), fruit rot incidence (4.47 %), severity (2.68 PDI) and recorded high yield 8.92 q/ha with 2.44 cost benefit ratio which was also on par with chemical intensive module with 8.71 q/ha 2.32 CB ratio.

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Appendix I: Physical and chemical properties of the experimental site at MARS Dharwad

A. physical properties	**Values**
Particle size	(%)
a. Coarse sand	6.01
b. Fine sand	13.21
c. Silt	27.83
Textural class	Clayey
Soil moisture constants	
Field capacity	
0-15 cm	32.03
15-30 cm	34.18
30-45 m	38.23
Permanent wilting point (%)	
0-15 cm	13.63
15-30 cm	15.78
30-45 m	16.81
Bulk density (g/cc)	
0-15 cm	1.23
15-30 cm	1.26
30-45 cm	1.30
B. Chemical properties	
1. Organic carbon (%)	0.73
2. pH	7.50
3. Available nitrogen (kg ha^{-1})	223.8
4. Available P_2O_5 (kg ha^{-1})	31.60
5. Available K_2O, (kg ha^{-1})	332.3

Appendix II: Price of fungicides biofungicides which used in during investigation 2012-13 and 2013-14

Products	Trade Name	a.i. (%)	Formulation	Price (Rs.)	Quantity
Carbendazim	Bavistin	50	WP	220	500 g
Difenconazole	Score	25	EC	2720	1000 ml
Hexaconazloe	Contaf	5	EC	567	1000 ml
Propiconazole	Tilt	25	EC	1328	1000 ml
Pyraclostrobin	Headline	20	WG	1675	500 g
Tebuconazole	Folicur	25.9	EC	1700	1000 ml
Mancozeb	IndofilM45	75	WP	44	100 g
Carboxin 37.5 + Thiram 37.5	Vitavaxpower	75	WS	356	250 g
Carbendazim 12%+ Mancozeb 63%	Saaf	75	WP	780	1000 g
Hexaconazole 4% + Zineb 68%	Avatar	72	WP	390	500 g
Tricyclazole 18% + Mancozeb62%	Merger	80	WP	480	500 g
Pyraclostrobin 5% + Metiram 55%	Cabriotop	60	WG	441	500 g
Imidachloprid	Confidar	17.80	SL,	1279	500 ml
Fenazaquin	Magister	10	EC	1007	500 ml
Spiromesifen	Oberon	22.9	W/W SC	2042	500 ml
Indoxacarb	Avuant	14.5	SC	1540	500 ml
Neem oil				277	1000 ml
Trichoderma harzianum				60	500 g
Pseudomonas fluorescens				60	500 g
Bacillus subtilis				60	500 g
Verticillium lecanii				60	500 g
Nomuraea rileyi				60	500 g
Fixed cost (Land cost, agronomical operations and labour)				30,000/ha.	

FRUIT ROT OF CHILLI: ITS DIVERSITY, CHARACTERIZATION, EPIDEMIOLOGY AND INTEGRATED MANAGEMENT

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ABSTRACT

Fruit rot of chilli caused by *Colletotrichum* spp. (*C. capsici*, *C. gloeosporioides* and *C. acutatum*), *Alternaria alternata* and *Fusarium* spp. is major yield limiting factor in all chilli growing areas. Highest fruit rot incidence (19.97%) with 13.77 PDI was observed in Maharashtra. The maximum die-back incidence (11.23%) with 42.79 PDI was observed in Andhra Pradesh followed by Karnataka (9.06%, 38.14 PDI). Predominance of *C. capsici* and *Fusarium* spp. in combination was to the extent of 28.37 per cent. *C. capsici* recorded highest frequency of 38.56 per cent followed by *A. alternata* (18.98%). Molecular identification of fungal pathogens by amplification of ITS rDNA region was done, sequenced and confirmed. By using specific primers amplification of *C. capsici* at 450 bp, *C. gloeosporioides* at 450 bp and *C. acutatum* at 490 bp, *A. alternata* at 390 bp and *Fusarium* spp. at 550-570 bp was obtained. PCR-RFLP with *HaeIII* resulted in four clusters each in *C. capsici* and *C. gloeosporioides,* five clusters in *C. acutatum* isolates. Digestion with *TaqI* in *A. alternata* isolates resulted in two clusters, *Fusarium* isolates into five clusters. PCR-based method was the best for early detection and quick diagnosis.

Seed treatment with carboxin + thiram at 2g/kg and combinations of *Trichoderma harzianum* 5g + *Pseudomonas fluorescens* 5g was most effective. Spraying of difenconazole and pyraclostrobin, tricyclazole + mancozeb and pyraclostrobin + metiram were found effective against fruit rot and dieback disease under field conditions. Integrated management study revealed that adoptive module including seed treatment with carboxin + thiram at 2g/kg, seedling dip in *P. fluorescens* (10g/l), spray with neem oil (10ml/l), hexaconazole, propicoanzole (0.1%) and carbendazim + mancozeb (0.2%) showed least seedling infection, die-back, fruit rot incidence and severity with high dry chilli yield (8.92 q/ha) and C:B ratio (2.44).