

**STUDIES ON RHIZOME ROT COMPLEX OF
TURMERIC (*Curcuma longa* L.)**

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**STUDIES ON RHIZOME ROT COMPLEX OF
TURMERIC (*Curcuma longa* L.)**

**Thesis submitted to the
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in the partial fulfillment of the requirements for the
Degree of**

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in

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By

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CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON RHIZOME ROT COMPLEX OF TURMERIC (*Curcuma longa* L.)**” submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (HORTICULTURE) PLANT PATHOLOGY** to the University of Horticultural Sciences, Bagalkot, is a record of bonafide research work carried out by **Ms. Shruthi K.** under my guidance and supervision and that no part of the thesis has been submitted for the award of any other degree, diploma, associate ship, fellowship or other similar titles.

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*Affectionately Dedicated
to
My Chairman,
Parents,
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1. INTRODUCTION

Turmeric (*Curcuma longa* L.) is one of the important spice crops grown in India since the time immemorial. Turmeric is an herbaceous perennial plant is native to tropical south-east Asia belonging to the family *Zingiberaceae*. It is regarded as a symbol of well being and future and is widely used in ceremonies and religious functions. It is cultivated for its underground rhizomes which are used in many ways *viz.*, condiment in culinary preparation, coloring agent in textiles, food and confectioneries.

It is known as 'haridra' meaning yellow colored wood in Sanskrit, is a part of Indian delicacies, health care as well as rites and rituals since the time immemorial. The anti-oxidant attributes of this spice protect against the high energy free radical damage to organic cells (Maheshwari *et al.*, 2006). The antibacterial, antiviral, antifungal and anti inflammatory properties of this herb appear as an effective cure for several diseases (Koosirirat *et al.*, 2010). It acts as carminative, antiseptic and antiparasitic for many skin infections and cures the sore throat and common cold. It is used as an appetizer and helps in digestion and also used in the preparation of cosmetics, soaps, skin ointments and tooth pastes. It is also reported to detoxify the liver, balance cholesterol levels, fight allergies, boost immunity and enhance the complexion (Arafa, 2005).

It is cultivated mainly in India, Pakistan, Jamaica, Sri Lanka, Indonesia, Bangladesh, Taiwan and China. It is one of the important spice crops which play a key role in the national economy. India is the major producer and exporter of turmeric in the world (Satishkumar, 2005) and it accounts for 80 per cent of the world production. It is grown in an area of 2.33 lakh hectares with an average production of 11.90 lakh MT (Anon., 2014). It is cultivated in Southern and North eastern states of India in more than 200 districts spread over 25 states. The major production is confined to Andhra Pradesh, Assam, Kerala, Maharashtra, Orissa and Tamil Nadu which accounts for more than 75% of the turmeric produced in the country.

In Karnataka, it is grown in an area of 13.98 thousand hectares with an average production of 65.41 thousand MT, mainly grown in the districts of Bagalkot, Belagavi, Bidar, Chamarajnagar, Chikkamagaluru, Kodagu, Mandya and Mysore.

The major turmeric importing countries are Bangladesh, Germany, Iran, Japan, Malaysia, South Africa, Singapore, Sri Lanka, UAE and USA ([http](http://), 2016).

Turmeric crop is more vulnerable to a number of fungal diseases of both soil and air borne nature, compared to bacterial and viral diseases. The important diseases affecting the crop are rhizome rot, leaf spot, leaf blotch, leaf blast and leaf blight (Ravindran, 2007). Nematode infestations and storage rots are other problems.

The major constraint for cultivation of turmeric is the rhizome rot disease complex. Among the diseases, rhizome rot caused by *Pythium aphanidermatum* (Edson) Fitz (Rathaiah, 1982) is the most destructive one causing enormous economic damage. It was incited by *P. aphanidermatum*, was first reported in Sri Lanka by Park (1934). In India, it was reported by Ramakrishnan and Sowmini (1954) and yield losses to an extent of up to 60 per cent (Selvan *et al.*, 2002). Crop loss up to 50 per cent was reported in Telangana region of Andhra Pradesh where the crop is grown on a large scale (Rathaiah, 1982). The rhizome rot incidence of turmeric was noticed in all the locations surveyed with more than 50 per cent disease incidence and the major diseases diagnosed were soft rot caused by *P. aphanidermatum*, wet rot caused by *Fusarium solani*, bacterial wilt by *Ralstonia solanacearum*, *Sclerotium* rot caused by *Sclerotium rolfsii* and root knot caused by *Meloidogyne* sp. The individual pathogen can cause rhizome rot or combination of pathogens could cause rhizome rot complex (Shalini, 2006).

Turmeric is mainly exported in the form of dry and powder. Though turmeric is a high return crop however, the rhizome rot complex poses a persistent threat to the cultivation and storage of turmeric. About 50-80 per cent losses during storage have been reported due to this disease (Nirmal *et al.*, 1992). Traditionally, a large number of farmers cultivated turmeric in the region, but many gave up its cultivation owing to the frequent rhizome rot disease that destroyed the crop.

The correct diagnosis of the disease in a given location and involvement of one or more pathogens should be clearly understood to plan effective integrated management measures, which would be location specific. There is an urgent need to address this problem on war footing as this is a hitherto neglected but important disease of turmeric. Keeping in the view of above mentioned information, the present

investigation were carried out on studies on rhizome rot complex disease of turmeric to understand the etiology and integrated management practices with the following objectives:

1. To survey the incidence of rhizome rot disease of turmeric.
2. To study the etiology of turmeric rot disease complex.
3. To study the management of rhizome rot disease complex.

2. REVIEW OF LITERATURE

India, “the land of spices” is the largest producer, consumer and exporter in the world. Turmeric (*Curcuma longa* L.) stands next to black pepper and cardamom. Major constraint in turmeric cultivation is diseases. Among the various diseases, rhizome rot is major problem in all turmeric-growing areas of India, causing enormous economic damage (Rathaiah, 1982). Many fungal pathogens and other organisms were associated with the disease (Reddy *et al.*, 2003). Hence, identification of the pathogens associated with the disease in-order to develop crop protection measures accordingly to reduce the crop loss.

Early diagnosis of infections followed by integrated disease management which is effective and eco-friendly can enhance the rhizome quality, yield and shelf-life, leading to a rise in the export value. The review pertaining to the studies on rhizome rot complex disease of turmeric are presented here under.

2.1 Survey

2.1.1 Survey on rhizome rot disease incidence

Rhizome rot of turmeric incited by *P. aphanidermatum* (Edson) Fitz, was first reported in Sri Lanka by Park (1934). The pathogen infects roots, collar and succulent parts of the rhizome. In India, this disease was first reported from Krishna district of Andhra Pradesh, Thiruchina Pally and Coimbatore by Ramakrishna and Soumini (1954). It was also reported from Kasargod area of Kerala (Anon., 1975) and Assam region (Rathaiah, 1982). This was also known from Telangana area of Andhra Pradesh (Rao and Rao, 1988). Although the value of crop loss figure in turmeric is not available, more than 50 per cent loss have been reported in some parts of Telangana and farmers sort to distress harvest to salvage the remaining crop once the disease starts appearing (Anon., 1988).

Butler (1918) estimated the loss of more than ten thousand rupees in a single village *viz.*, Surat. Mc. Rac (1911) reported that, in Bangladesh, reduction in yield varied from 10-15 per cent in low lying fields and 6 per cent in uplands fields and causes moderate to severe incidence leading to crop loss of more than 50 and 80 per.

In Kerala, about 90 per cent yield loss was reported during heavy incidence (Rajan and Agnihotri, 1989). Crop loss depends on the stage of crop growth at which infection starts. If the infection occurs early, total loss of affected clump. Whereas the crop loss is partial if affected at a later stage (Sarma, 1994).

A survey was undertaken in ginger growing areas about 80-84 per cent of the plots suffered from the disease severely 2005 and 2006. From the survey, it was observed that June- July was the most vulnerable period for initiation and spread of the disease and the less incidence was noticed if the disease initiates after the second fortnight of July. Further, it was also observed that more than 3- 4 years crop rotation coupled with cultivation of buckwheat, coarse cereals and cruciferous crops as preceding crop was found better option for management of rhizome rot and wilt disease complex of ginger (Kumar and Suryanarayana, 2011). A survey was conducted in selected ginger growing areas of Malnad (Karnataka) revealed that seriousness of *Pythium* rot cum *Ralstonia* wilt complex was observed in different areas of Sirsi taluk of Uttara Kannada (25-50 %) followed by Soraba taluk (> 42 %) of Shivamoga district (Sharma *et al.* 2015).

Shalini *et al.* (2008) conducted a survey to know the prevalence of rhizome rot in Karnataka during kharif 2003-05 in major growing areas of Karnataka. Rhizome rot incidence was noticed in all the locations surveyed which ranged from 5.50 to 45.60 per cent. The maximum disease incidence of 23.70 per cent was observed in Shimoga district followed by Kodagu (22.90 %), Uttara Kannada (20.24 %), Chickmagalur (18.99 %) and Bidar (13.00 %). Therefore, these places were considered as 'hot spots' of rhizome rot disease of ginger.

A total of 37 different locations of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu were covered during the survey. The highest disease incidence was noted in Guntur district of Andhra Pradesh (32.22 %) followed by Salem district of Tamil Nadu (20.67 %). Among the four states surveyed, three locations in Kerala and Andhra Pradesh recorded no disease incidence. According to the information collected, the highest disease incidence and spread of the disease often coincided with the monsoon season of the respective locations (Anoop *et al.*, 2014).

Rekha *et al.* (2014) conducted survey on rhizome rot disease during kharif seasons of 2011 & 2012 in major ginger growing areas of Malnad district *viz.*, Shimoga, Coorg, Chikkamagalore, Hassan and Uttarkannada. Average disease incidence was more during kharif 2011 (24.68 %) than 2012 (20.80 %) and low rainfall during 2012 leads to the average of 22.74 per cent rhizome rot incidence in Malnad district.

2.1.2 Source of inoculum

Seed rhizome: *Pythium* species survive between crops on infected seed rhizome (Thomas, 1940; Park, 1941). It was thought to occur as oospores in scale leaves (Thomas, 1940). However, the nature of seed born inoculum was not well understood (Sarma, 1994)

Soil: *Pythium* species are capable of saprophytic survival on plant debris. They are normal inhabitants of many soils. They produce on non-host crops and weeds. Saprophytic survival of the fungus in soil is influenced by environmental factors, soil temperature, moisture and presence of other pathogenic micro-organisms. Severity of *Pythium* disease is more in areas where rainfall is high and heavy clay soil where drainage is impede (Rajan and Singh, 1973).

The bacterial disease is typically seed and soil borne, generally noticed during June – July and reaches maximum during August – September. Presence of high soil moisture and relative humidity and low temperature increases the infection by the bacterium *R. solanacerium* by increasing its multiplication rate in the soil. The disease spread is along the gradient and spreads through soil water (Sarma *et al.*, 1978).

2.1.3 Symptomatology

The important development in symptomatology and epidemiology of rhizome rot are the recent recognition of the role of root infection in rhizome rot. The following description of symptoms is based on that of Iyer (1987) and Sarma (1994). Turmeric is susceptible to infection throughout its life, but sprouts, roots, developing rhizome and collar regions of the pseudo stem are vulnerable to infection. The pre and post emergence rot are noticed, pre-emergence rots were noticed when infected seed rhizomes were sown or through bud infection. Whereas post-emergence rot can occur

at any time after sprouting. Pathogen may reach the sprout through roots or through the collar region and finally reaching the rhizome. Initial symptoms appear as water soaked patches and later enlarge and tissues of the collar region become soft, watery and rot and sprouts turn to pale colour and collapse. In mature plants, the leaves become pale and tips of leaf turn yellow. Yellowing along the margins of the leaves from tips to downwards. Tender tissues of the collar region turn soft, watery and rot and the plant topples. The rotten part emits foul smell owing to decay. Rotting is followed by invasion of opportunistic organisms like fungi, bacteria, insects and other saprophytes.

Sarathi *et al.* (2014) recorded symptoms of rhizome rot in *Curcuma longa*. The leaves of affected plants exhibit gradual drying along the margins. This ultimately results in complete drying of all the leaves. The collar region of the pseudo stem becomes soft and water soaked, resulting in collapse of the plant. The root system is very much reduced. In severe condition, the infection spreads to rhizomes which decomposes and turn into a decaying mass of tissues.

Atsushi *et al.* (2015) observed disease symptoms on turmeric, first appeared as sudden wilt, leaf edges curled under toward the centre of the midrib and leaves became yellow. Necrosis of the pseudo stem and rhizome rot with internal discoloration was observed in the diseased plants. The whole plant finally wilted and died. Similar symptoms were found on wild turmeric and zedoary plants. Visible bacterial ooze exuded from the cut surface of the affected rhizomes when dipped into water. The similar symptoms were also observed by Chauhan and Patel (1990) who reported that in turmeric, rapid drying of the shoots, followed by rhizome rotting were the major symptoms.

2.2 Etiology

Several *Pythium* spp. have been reported as causal agents of soft rot in different part of the world and six species were recorded in different part of India (excluding synonymous taxa). Among these, *P. myriotylum* is widely distributed, where as the other species are restricted to certain pockets. The distribution of *Pythium* spp. causing rhizome rot is given here under.

Rhizome rot of turmeric incited by *P. aphanidermatum* (Edson) Fitz, was first reported in Sri Lanka by Park (1934) ; Middleton (1943). Ramakrishnan and Soumini (1954) mentioned that turmeric was attacked by more than one species of *Pythium* including *P. aphanidermatum* and *P. graminicolum* has been reported as the causal agent in Madras state, South India. Association of *Pythium* spp. and *Fusarium* spp. especially *F. solani* and *F. equiset* (Carda) Sacc. (Hendrix and Campbell, 1973). *P. myriotylum* from Assam (Rathaiah, 1982) and *Pythium* sp. from Kerala (Anon, 1975) have been reported as pathogens of rhizome rot of turmeric. Ayyar (1926) first recorded *M. incognita* (Kofoid and White) Chit wood on turmeric from India. Sukumaran *et al.* (1993) reported *M. incognita* on turmeric and showed heavy root galling. Conflicting is the report on interaction of fungal pathogens and nematode in rhizome rot complex of ginger has been found to be infected by a number of genera of nematode including *Radopholus*, *Meloidogyne*, *Rotylenchulus* and *Tylenchorhyncus* (Sundaraju *et al.*, 1980).

In ginger, yield decline has been reported and proved that, bacterial wilt of ginger could aggravate in the presence of nematodes *M. incognita* and *Pratylenchus coffeae* Zimm. and concluded that bacterial wilt in ginger could aggravate in the presence of nematodes. (Samual and Mathew, 1983)

Combined inoculation of ginger with *M. incognita* and *P. myriotylum* resulted in significant reduction in weight of aerial shoot and rhizome in a plant culture test. (Lanjuewar and Shukla, 1985) *P. myriotylum* also caused significant growth reduction but *M. incognita* alone did not. An instance of synergistic effect of *P. aphanidermatum* and *M. javanica* (Treb) Chitwood was observed in Madhya Pradesh (Vadhera *et al.*, 1992).

Authentic information on epidemiology of rhizome rot disease is lacking. But some important observations were made. The high incidence of *Pythium* induced rhizome rot have been reported during wet years (Rajan and Agnihotri, 1989) implying the role of high soil water content on disease onset and spread.

Conversely, an instance of independent infection of ginger as well as interaction between *Pythium* species and *F. solani* leading to synergism has been reported from Gujarat. Both the organisms have been pathogenic in the independent

inoculations. Combined infection resulted in rapid drying of the shoot followed by rhizome rot (Chauhan and Patel, 1990)

In Karnataka, turmeric is planted as rain fed crop immediately after pre monsoon showers. It starts sprouting in June and tillering and adequate temperature (25-30 °C) prevailing during this period is conducive for disease onset (Sarma, 1994). Moreover, juvenile tissues of the host which *Pythium* prefers to infect is also readily available through soil water by means of zoospores, hyphal fragments etc. the disease is generally less in well drained fields (Sarma, 1994)

Kim *et al.* (1996) reported that average 18.10 per cent rhizome rot of ginger was recorded in Korea Republic and the disease starts early July, spreads rapidly in rainy season. Park *et al.* (1998) reported that *Z. officinale* plants were infected by rhizome rot in Seosan, Taean, Iksan and Korea Republic from September to October. The pathogens associated with rhizome rot were isolated and identified as *Pythium* & *Fusarium* spp. along with association of bacterium *R. solanacearum*.

Shalini *et al.* (2008) conducted a survey to know the prevalence of rhizome rot in Karnataka during kharif 2003-2005 in major ginger growing areas of Karnataka. *P. aphanidermatum* was isolated from all the locations and proved to be most predominant pathogen among the rhizome rot pathogens. Next predominant pathogen was *F. solani* and bacterium *R. solanacearum* was detected only from the southern parts of Karnataka.

Repeated survey during 1997-2000 in Guntur and Cuddaph districts indicated that the intensity of the rhizome rot of turmeric was high due to *F. solani* (Reddy *et al.*, 2011)

Anoop *et al.* (2014) undertaken survey in major turmeric growing tracts of South India to determine pathogen associated with turmeric rhizome rot and the fungi identified were *Pythium* (74.50 %), *Fusarium* (30.51 %), and *Rhizoctonia* (28.80 %) sp. and some samples yielded a combination of these three organisms.

Turmeric samples of disease infected rhizomes were collected from 5 different agricultural fields in Pudukkottai district (Andhra Pradesh). Samples were screened for isolation and identification of rhizome rot causing fungal pathogen. The isolate

was found that *P. aphanidermatum* was a well-known devastating pathogen. Pathogenicity testing was done according to Koch's postulates. Hence, this was the comprehensive report on identified major fungal pathogens associated with rhizome rot (Sarathi *et al.*, 2014).

Bacterial wilt of *Curcuma* species is caused by, *R. solanacearum* which has been reported previously in some other Asian countries (Kumar *et al.*, 2014). In Japan, bacterial wilt of *zingiberaceae* family crops caused by *R. solanacearum* has been reported on ginger, mioga and *curcuma* sp. (Morita *et al.*, 1996; Tsuchiya *et al.*, 1999; Yano *et al.*, 2005), and all strains belonged to race 4, biovar 4 and phylotype I (Waki *et al.*, 2013). A new bacterial disease was observed on three *Curcuma* species, *C. longa* (turmeric), *C. aromatica* (wild turmeric) and *C. zedoaria* (zedoary) caused by *R. solanacearum* in Okinawa Prefecture, Japan during January 2014 (Atsushi, 2015).

2.2.1 Morphological identification of pathogens.

The mycelium of the *Pythium* species is colourless, sometimes lustrous, occasionally slightly yellowish due to abundant oospores or hyphal swelling or greyish to lilac. Description of morphological character of different species of *Pythium* given in this review has been adopted from the monograph of the genus *Pythium* (Van der Plaats-Niterink, 1981).

The morphological characters of *Fusarium* sp. observed were all most similar to those described by Gerlach and Nirenberg (1982). The mycelia of pathogen were white cottony to pink, often with purple tinge or reddish coloration of the medium. Microconidia were borne on simple phialides arising laterally and were abundant, oval-ellipsoid, straight to curved, macroconidia, sparse to abundant were born on branched conidiophores or on the surface of sporodochia and were thin walled, three to five septate, fusoid-subulate and pointed at both ends, have pedicellate base. Three septate spores were predominant. Chlamydospores, both smooth and rough walled which are abundant and form terminally or on an intercalary basis. The pathogen *Sclerotium* is a fast growing fungus started producing branched snow white coloured *Sclerotia* at the periphery of the colony *Sclerotium* by Aycock (1996).

The identification of the bacterium *R. solanacearum* isolated from diseased rhizomes of turmeric was carried out by Kelman *et al.* (1954) and reported the typical mucoid, irregular, white colonies with pink centers resembling those of *R. solanacearum* on TZC medium as a selective medium. They also confirm the bacterial pathogen by conducting pathogenicity tests.

2.3 Pathogenicity

The plants inoculation with the *Pythium* sp. alone exhibited symptoms within 28 days of inoculation, lower most leaf exhibited yellowing symptoms. Later rhizomes were rotten, emitting foul smell. When plant inoculated with bacterium *Ralstonia* alone, exhibited the symptoms 15 days after inoculation showing yellowing of the older leaves from the tip towards midrib. Later rhizome become rotten and emits foul smell. When simultaneously inoculation of both the pathogens *Pythium* and *Ralstonia*, the plants exhibited the early symptoms within 24 days and recorded more rhizome rot incidence compared to individual pathogen inoculation. Re-isolation of pathogens from those samples yielded *Pythium* sp. and bacterium *R. solanacearum* (Sagar, 2006).

Horita and Tsuchiya (2012) assessed pathogenicity of the isolated bacteria. Seedlings or rhizomes of various kinds of turmeric plants in plastic pots were cultivated in a greenhouse for 6–12 weeks and used for the test. The strains were grown on nutrient agar for 48 h at 25 °C; 0.2–1.0 ml of bacteria suspended in sterile distilled water at ca. 1×10^8 CFU/ml served as inoculums. Two weeks after inoculation symptoms was noticed as such, necrosis of the pseudo stem and rhizome rot with internal discoloration were observed in the diseased plants. The whole plant finally wilted and died. Similarly, Ajitomi *et al.* (2015) also undertaken pathogenicity test, basal part of the stem or pseudo stem of three plants was punctured with a needle dipped in the inoculum of one strain. The inoculated plants were kept in a growth chamber at 30 °C, and plants were examined for disease symptoms 2 weeks later. These strains were highly virulent (wilted or killed) to original hosts (turmeric, wild turmeric and zedoary), and bacterial colonies similar to those of the inoculated strains were re-isolated from the inoculated plants. These strains also caused wilting on other plants belonging to the *zingiberaceae* family (ginger, mioga and siam tulip) and *solanaceous* family (tomato, potato, eggplant and green pepper).

In artificial inoculation tests have demonstrated that maximum rotting occurred only when *P. aphanidermatum* was inoculated first followed by *F. solani* (Joshi and Mathur, 1987). Dake and Edison (1989) reported that 19.80 per cent of rhizome rot of ginger was associated with *P. aphanidermatum*. A survey conducted in Kerala shows association of *Fusarium* spp. and *R. solanacearum* (Dake and Edison, 1989).

2.4 Management of turmeric rhizome rot

Rhizome rot is considered as a complex disease problem. Turmeric plant is a delicate, succulent herb. It easily succumbs to stress, both environment and biological. Therefore, it is essential that disease management practices are integrated with crop production at all possible stages of crop cycle for reducing the possibility of disease developed by adopting suitable cultural practices, application of fungicides, botanicals and biological control agents.

Use of chemical fungicides in management of rhizome rot consists of seed treatment with or without supplementary soil drenches with fungicides suspension before planting or to the standing crop. Seed born inoculums and soil drenches to check soil born inoculums. Emphasis has been on chemical control in India until recently and a number of fungicides formulations have been evaluated or recommended for the management of soft rot. Those includes Organomercurials, Copper fungicides, Dithiocarbamates and a number of systemic fungicides. Effectiveness of fungicides was assessed in terms of improved germination, reduction of incidence of rhizome rot and improvement in yield of rhizome. Results obtained in various test in India are tabulated as given here under.

Seed treatment and soil drenching with Bordeaux mixture 1 per cent (Bhagwat, 1961), and seed treatment with Cerasan (0.25 %) for 30 minutes (Thomas, 1940) effectively controlled rhizome rot. Seed dip in Emisan, Blitox and Mercuric chloride effectively controlled rhizome rot caused by *P. pleroticum* and their effectiveness was at par with Dithane M-45 (Sharma and Dahroo, 1982). Increased germination, reduced incidence of rhizome rot and better yield was obtained with Captafol when used for seed treatment (Koshy *et al.*, 1984; Mathur *et al.*, 1984). When four treatment *viz.*, seed treatment with Captan, Captafol, Dithane M-45 and hot water treatment superimposed by 200 ppm Streptocyclin were evaluated, it found that Capton was more effective against rhizome rot (Manmohandas *et al.*, 1990).

Table 1. Fungicides tested / recommended against rhizome rot disease

SI. No.	Pathogen	Fungicides	Method of applications	References
1.	<i>Pythium aphanidermatum</i>	Zineb + COC Capatafol Zineb	Seed and Soil	Sarma <i>et al.</i> , (1979)
2.	<i>P. aphanidermatum</i>	Aureofungin Mancozeb Capatafol Methixy Ethyl Mercuric Chloride (MEMC)	Seed and Soil	Sarma <i>et al.</i> , (1979)
3.	<i>P. aphanidermatum</i>	Metalaxyl Forsetyl Aluminium Oxadixyl Promocarb Etriazole	<i>In vitro</i> testes and seed and soil (pot culture study)	Ramachandra <i>et al.</i> (1989)
4.	<i>P. aphanidermatum</i>	Mancozeb Captafol Caotan Metalaxyl	Seed only	Thakore <i>et al.</i> (1988)
5.	<i>P. aphanidermatum</i>	Mancozeb Captafol Captan Metalaxyl	Seed only	Koshy <i>et al.</i> (1984)
6.	<i>P. aphanidermatum</i> / <i>F. solani</i>	Bayleton Finaminosulf Syllit Metalaxyl	Seed only	Joshi and Mathur (1987)
7.	<i>P. aphanidermatum</i> / <i>F. solani</i>	Fosetyl- Al Bordeaux Mixture Mancozeb	Seed and soil	Rathaiah (1982)
8.	<i>P. myriotylum</i>	Metalxyl Metalaxyl + Captafol Metalaxyl + Captan Metalaxyl + Mancozeb	Seed and soil	Rathaiah (1982)
9.	<i>P. plerotium</i>	Mancozeb Daconil Emisan Mercuric chloride Anthracol	Seed only	Sharma and Dohroo (1982)
10.	<i>Pythium</i> spp. <i>F. solani</i>	Metalaxyl Bordeaux mixture	<i>In -vitro</i> tests	Chauhan and Patel (1990)
11.	<i>P. aphanidermatum</i>	Captan Captafol Mancozeb Streptocycline	Seed only	Manamohandas <i>et al.</i> (1990)

Recently, systemic fungicides were also tested against rhizome rot and recommendation has been made. The use of systemic fungicides is justified in view of internally seed born nature of the pathogen.

In an *in-vitro* study with five systemic fungicides against *P. aphanidermatum* viz., Metalaxyl, Oxidixyl 35 WP, Fosetyl Aluminium, Promocrab and Ethazole (Etharidiazole) as Terrazole 35 WP, the last one gave effective control and had the lowest ED 50 and ED 90 values followed by Metalaxyl (Ramachandran *et al.*, 1989). These fungicides were also tested as seed and soil treatment in pre infected soil in pot culture (Ramachandran *et al.*, 1989) Metaxyl formulation (Ridomil 5G granules) and Ethazole (Terrazole, 35 WP) gave best control. Thakore *et al.* (1988) evaluated six non systemic and four systemic fungicides by treating *P. aphanidermatum* inoculated ginger rhizome respective fungicide before planting of these Dithane M-45, Captafol, Ziride, Captan and Metalaxyl controlled rhizome rot incidence and increase germination of rhizome and yield. Anandam *et al.* (1996) reported that seed rhizome treatment with Ridomil- MZ @ 0.4 per cent gave the lowest rhizome rot incidence (0.05 %) compared to control (5.13 %).

Sharma *et al.* (1978) assessed systemic and contact fungicides in the control of rhizome rot of ginger caused by *P. aphanidermatum*. They found that the yield of rhizome was increased when they used fungicides. They reported that the Dithane Z-78 (Zineb) was the best fungicides in controlling rhizome rot of ginger, followed by Captan and Difolatan (Captafol). Ichitani (1980) worked on the control of rhizome rot of ginger by cultivating successively and protectively for immature rhizome production in plastic house. He reported that *P. zingiberum* was not consistently isolated from rotted ginger tissues and rhizome rot disease did not develop when disease free rhizomes were sown in soil fumigated with Methyl Bromide. He found that rhizome rot incidence was reduced when seed treated with Echlomezol and Methyl bromide.

Dohroo and Sharma (1983) evaluated fungicides for the control of rhizome rot of ginger caused by *P. pleroticum* and *F. equiseti* in storage and obtained good control

with Antracol (Propineb 0.25%), Fycop and Blitox-50 (both copper oxychloride 0.3 %) as 30 min rhizome dip.

Rathaiah (1987) tested soft rot (*P. muriotylum*) of ginger by Ridomil and in combination with Captafol, Captan or Mancozeb. He stated that dipping or wetting of seed pieces one day before planting and soil drenching with a mixture of Ridomil + Captafol for 3 months after planting controlled the disease and significantly increased the yield of ginger.

Raj *et al.* (1989) observed the chemical control of rhizome rot of ginger by seed and soil treatments, they found that soil treatment with 4 per cent Formaldehyde combined with treatment of the rhizome planting material with Topsin M-70 (Thiophanate-Methyl) at 0.1 per cent gave the best control of this disease caused by *F. oxysporum*. They also noticed that rhizome treated with 0.1 per cent Bavistin (Carbendazim) or 0.3 per cent Dithane M-45 (Mancozeb) in combination with soil treated with the Formaldehyde gave satisfactory control of this disease.

Das *et al.* (1990) stated the efficacy of fungicides for seed treatment against pre-emergence rhizome rot of ginger. They found the lowest disease incidence and the highest germination percentage was yielded by seed treatment with Captan (0.2 %) for 30 min, while Captafol (0.2 %) and Dithane M-45 (0.3 %) were also found effective.

Singh *et al.* (2004) studied the efficacy of chemicals *viz.*, (0.2 % Dithane M-45, 0.3 % Ridomil- MZ, 0.1 % Bavistan, 0.2 % SAAF, 0.2 % Shield, 0.3 % Blitox-50 and 0.25 % Dithane M-45 + 0.05 % Bavistin) in controlling rhizome rot of ginger caused by *P. aphanidermatum* under storage and field conditions in Bihar (India). Application of 0.3 per cent Ridomil -MZ resulted in the lowest incidence of the disease. In field conditions, application of Ridomil- MZ resulted in the highest seed germination (96.50 %) and yield (250.25 q/ha) and lowest disease incidence (5.0 %). Kumar and Suryanarayana (2011) reported that before planting dipping of rhizome in Streptocycline (0.05 %) + Copper Oxy Chloride (0.2 %) solution for 20 minutes and

post sowing soil drench with Bleaching powder (0.2 %) and Metalaxyl- MZ (0.1 %) thrice at 20 days intervals from disease inception found very effective in reducing the disease to the maximum extent (PDI- 2.79) compared PDI (51.63 %) in control. The same treatment showed the highest rhizome yield (172.75 q/ha) compared to (58.75 q/ha) in control. Hasant *et al.* (2014) reported that the rhizome treatment with Bavistin 50 WP and Ridomil Gold MZ-72 were efficiently suppress the pathogen and increased the yield of ginger.

Ayub *et al.* (2009) conducted two field experiments at Nilphamari district to find out an effective control measure against rhizome rot (*P. aphanidermatum*) disease of ginger. Fungicides were used as seed treatment and soil drenching and organic materials and bio control agents were used as pre plant soil amendments. The most effective treatment was seed treatment (0.2 %) and soil drenching (0.2 %) with Ridomil Gold which significantly decreased the incidence and severity of the diseases (18.75 %) and increased germination, tiller number and rhizome yield (18.54 t/ha) which was highly significant over (12.74 t/ha) the control.

Biological control of *Pythium* species is very difficult because of rapid germination of sporangia in response to seed or root exudates followed by immediate infection and the ability to cause long term root rot (Whipps and Lumsden, 1991). In spite of these constraints many important diseases have been controlled with antagonistic fungi, bacteria and actinomycetes. In several cases, extents of disease control obtained were similar to those of standard fungicides.

Among fungal antagonists, the genus *Trichoderma* and mycoparasitic species are the most studied. Among bacteria and *Actinomycetes*, *Pseudomonas*, *Bacillus* and *Streptomyces* species received maximum attention. These antagonistic microorganisms were multiplied on large scale and applied to seeds or soil. Seed treatment reduced the quantity of inoculums required. Examples of biological control of *Pythium* are given here under.

Table 2. Examples of biological control of *Pythium* spp.

Antagonist	Target species	References
Bacteria		
<i>Bacillus</i> sp.	<i>P. ultimum</i> <i>P. aphanidermatum</i>	Broadbent <i>et al.</i> (1971)
<i>Pseudomonas migula</i>	<i>P. aphanidermatum</i>	Elad and Chet (1987)
Fungi		
<i>Trichoderma virens</i> Miller Gidden Foster	<i>P. ultimum</i>	Lumsden and Papavizas (1988)
<i>T. koningii</i> Oudem,	<i>Pythium</i> spp.	Bharadwaj <i>et al.</i> (1988)
<i>T. hamatum</i> (Bonord.) Bainier <i>T. harzianum</i> Rifal	<i>P. aphanidermatum</i> <i>P. aphanidermatum</i>	Sivan and Chet (1989) Bharadwaj and Gupta (1987) Bharadwaj <i>et al.</i> (1988)

Ushamailini *et al.* (2008) reported that the rhizome rot incidence was at a minimum (8.93 and 13.33 %) in soil applied with FYM based biomanure 7 and 8 months after planting, respectively, with a yield of 682.9 g/pot. It was followed by FYM + DCP-based biomanure which recorded 10.84 and 14.9 per cent of rhizome rot 7 and 8 months after planting, respectively, with a yield of 670.2 g/pot, while in the control it recorded an incidence of 46.40 and 60.80 per cent 7 and 8 months after planting with a yield of 426.6 g/pot. Bharathi and Sudhakar (2011) recorded better reduction in rhizome rot incidence was observed by soil application of FYM @ 2.5 t/ha + *T. viride* @ 5 kg/ha + neem cake @ 0.2 t/ha.

Bacillus megaterium (AUM72), a plant growth promoting rhizobacteria (PGPR) were evaluated for their ability to control rhizome rot in turmeric, which was

found to be effective in reducing rhizome rot disease incidence both under greenhouse (30.20 %) and field conditions (29.00 %) and increased the plant growth and rhizome yield (Boominathan and Sivakumaar, 2013).

Dohroo and Sharma (1984) stated biological control of rhizome rot of ginger in storage with *T. viride*. They reported that treatment with this antagonist resulted in 80 per cent control of the disease, caused by *P. pleroticum* (wet rot) and *F. equiseti* (dry rot).

Sharma and Dohroo (1991) described the post harvest management of rhizome rot (*F. oxysporum* f sp. *zingiberi trujillo*) of ginger through chemical and antagonist. They also described that *Trichoderma* and *Gliocladium virens* inhibited growth of fungus under *in vitro* by 73 and 68 per cent, respectively.

Dohroo *et al.* (1994) reported that the incidence of rhizome rot of *Z. officinale* was minimum in soil treated with pinus needle and neem cake powder. The *Meloidogyne* population was reduced to 74 per cent but no *Pratylenchus* population was recorded in soil following any of the treatments such as neem cake powder, saw dust, pinus needles or quercus leaves. *Trichoderma* and *Gliocladium* populations were maximum in neem cake and pinus needle treatments.

Shanmugam *et al.* (2015) reported that, rhizome treatment with *P. fluorescens* @ 10 gm / kg & *T. harzianum* @ 4 gm/kg for 30 minutes and soil application of 2.5 kg / ha each of *P. fluorescens* & *T. harzianum* in 50 kg FYM as basal and top dressing on 150 days after planting was found to be most effective in controlling the rhizome rot in BSR 2 and CO₂ varieties with the disease incidence of 15.80 and 16.40 per cent, respectively.

Ichitani (1980) worked on the control of rhizome rot of ginger by cultivating successively and protectively for immature rhizome production in plastic house. He reported that *P. zingiberum* was not consistently isolated from rotted ginger tissues and rhizome rot disease did not develop when disease free rhizomes were sown in soil fumigated with methyl bromide. He found that rhizome rot incidence was reduced when seed treated with Echlomezol and Methyl bromide.

In-vitro tests using *T. viride*, *T. harzianum* and *T. hamatum* against *P. aphanidermatum*, *P. equiseti* and *F. solani* showed that these antagonists were inhibitory to the pathogens (Bharadwaj and Gupta, 1987). Good control of storage rot caused by *P. aphanidermatum* and *F. equiseti* was obtained when *T. viride* and *T. hamatum* were applied to rhizome either by dipping them in spore suspension or smearing them with the antagonists (Bharadwaj *et al.*, 1988). 80 per cent of disease caused by *P. pleroticum* and *F. equiseti* was obtained when stored rhizomes were treated with *T. viride* (Dohroo and Sharma, 1983).

On farm trials were also conducted with BCAs in India and the results revealed that the incidence of rhizome rot was low when *T. viride* was applied to soil along with wood saw dust (Bharadwaj *et al.*, 1988).

Effective suppression of rhizome rot under field conditions have been obtained in Rajasthan state when *T. viride*, *T. harzianum* were applied to soil in combination with wood sawdust (Anon., 1994). Good control of rhizome rot caused by *P. aphanidermatum* was obtained in Kerala state when *T. hamatum* or *T. harzianum* was applied to soil along with neem oil cake. *T. viride*, *T. harzianum*, *Azadirachata indica* Juss and *Agave Americana* L. have been reported to be the most effective to reducing mycelia growth of *F. oxysporum* f. sp. *zingiberi* and *P. aphanidermatum* causing yellows and rhizome rot of ginger respectively (Sharma, 1998).

Ram *et al.* (2000) evaluated indigenous isolates of biocontrol agents *viz.*, *T. harzianum*, *T. viride* and *T. virens* for control of ginger rot. All the bioagents could establish and reduced disease incidence and increased yield (Reddy *et al.*, 2003).

Though the use of biocontrol agents offers an environmentally, economic and safe alternative for fungicides but they really give better control than a good fungicide (Chet, 1987). Also, biocontrol agents have not attained efficiencies matching those of currently available fungicides under all environmental conditions. Therefore, It is necessary to develop methods to enhance the efficiency of biocontrol agents and attain consistency in their performance over a wide range of agro climatic conditions.

Integration of fungicides with bocontrol agents is such a step for improving the efficiency of biocontrol agents. Integrated management of disease with fungicides and biocontrol agents is possible only if they are compatible. Investigations have been

carried out to identify organisms resistant or tolerant to fungicides and to evaluate such altered organisms in combination with fungicides for disease control under field conditions (Papavizas, 1985). Some instances of such investigations are briefly described. For *example.*, *T. harzianum* was tolerant to Metalaxyl as exemplified by uninhibited growth, sporulation and spore germination up to 1000 ppm level of the fungicides (Sawant and Mukhopadhyay, 1993).

Instances of successful management of disease in field by integration of biocontrol agents and fungicidal seed/ soil treatments are available. Up to hundred per cent control of *Pythium* damping off of sugar beet was obtained when soil application of *T. harzianum* at low concentration was integrated with seed treatment with Metalaxyl (Sawant and Mukhopadhyay, 1990). Meena and Mathur (2003) conducted an experiment with three biological control agents *i.e.*, *T. viride*, *G. virens* and *P. fluorescens* and an effective fungicidal mixture of Ridomil-MZ and Bavistin 50 WP were used for treating seed rhizome and soil, individually and in combinations, for the suppression of rhizome rot of ginger crop and disease parameters, such as crop stand, rhizome yield, rotting percentage and pathogen suppression in the rhizosphere, were determined. Pelleting of seed rhizome with biological control agents was not found effective. Pelleting either with the fungicidal mixture or BCAs combined with soil application of BCAs were effective in suppressing the disease and increasing the yield. In the rhizosphere pot study, integrated approach resulted in reduction of inoculum density of *F. solani* and increased in the BCAs population. Rhizome seed treatment with fungicidal mixture, followed by soil application of *G. virens* was the most effective treatment and superior to all other treatments.

Sagar (2006) studied the effect of different treatments, rhizomes treated with Metalaxyl- MZ @ 0.3 per cent + soil application of *T. harzianum* @ 10 kg along with 25 t FYM/ha + soil application of *Eupatorium* sp. @ 10 t/ha recorded the highest percent germination, lesser disease incidence, higher yield of 11720.20 kg/ha and more benefit cost ratio.

Debnath *et al.* (2010) reported that the rhizome rot and wilt disease being complex in nature, it is very difficult to manage the disease through chemical treatment alone. The present investigation finds that application bio agent consortium (*Trichoderma*, *Pseudomonas*, Neem cake and Azophos) both as seed treatment and

soil application reduced the disease incidence considerably and it also helped to increase the yield of ginger crop.

Basistha and Homan (2015) reported that, among several chemicals, botanicals and bio-pesticides tested against rhizome rot disease of ginger, seed treatment with hot water (50 °C for 10 min) and *Trichoderma* (10 gm/lt) and soil application of *Trichoderma* (1kg *Trichogramma* /20 kg FYM) as well have been found effective in disease management in a eco-friendly way. These two treatments could be combined to give more efficacious result on rhizome rot control in field condition. In case of use of safer chemicals, seed treatment with Ridomil MZ (0.2 %) + Bavistin (0.1 %) combination has been found the most effective for disease management with highest fresh rhizome production, lowest rhizome rot severity and least diseased rhizome production.

3. MATERIAL AND METHODS

Present investigations were carried out during 2015-2016. Laboratory experiments were carried out in the Department of Plant Pathology, Kittur Rani Channamma College of Horticulture, Arabhavi, Gokak taluk, Belgavi district, University of Horticultural Sciences, Bagalkot, Karnataka.

The materials used and the techniques adopted during the course of investigations are described in this chapter.

3.1 Survey for the disease

Roving survey was conducted in 34 villages of Belagavi and Bagalkote district during 2015-2016 in turmeric growing areas to record the rhizome rot disease incidence. The plants showing symptoms of rhizome rot like yellowing of the foliage, rotting of the pseudo stem, stunted growth, reduced tillering with galling and rhizome and root rotting, *etc.*, were identified and recorded.

In each plot 25 plants were selected randomly and out of 25 plants, the numbers of plants infected were recorded and then per cent disease incidence was calculated by using the formula as mentioned below. During survey, observations also recorded with respect to cultivar and age of the crop.

$$\text{Per cent disease incidence} = \frac{\text{No. of plants affected}}{\text{Total number of plants}} \times 100$$

3.1.1 Sample collection

Infected turmeric rhizomes were collected in sterilized polythene bags from different villages of Belagavi and Bagalkote district, The infected rhizomes were washed by tap water and surface sterilized by using 75 per cent ethanol solution for 1 minute. The rhizomes were stored at refrigerator for further studies.

3.2 Isolation and identification of fungal pathogen from infected turmeric

The infected samples collected during the survey were brought to the laboratory and the infected portions including pseudo stem, roots and rhizomes were used for isolation. The infected parts were washed thoroughly with tap water to remove the adhered soil. Small bits cut from the diseased portions along with some healthy portions were surface sterilized with Sodium hypochloride (10 %) or with ethanol (75 %) for 1-3 minutes and then washed in three changes of sterile distilled water and transferred on to Potato Dextrose Agar (PDA) in 90 mm petriplate and incubated at 27 ± 1 °C for eight days. The hyphal tips growing out from the tissue were excised and transferred on to PDA slants for further growth and identification. The fungal isolates were sub cultured from time to time and maintained on PDA slants and also stored in paraffin oil. Pure culture of the fungus was obtained by single spore isolation and hyphal tip isolation method.

3.2.1 Single spore isolation

A loopful of well sporulated culture was taken with the help of inoculation needle and suspended in to sterilized water blank, serial dilutions were made so as to obtain 50 spores /ml and spore suspension was mixed with 2 per cent molten agar in the ratio of 1:15 and poured into sterile petridishes and allowed to solidify. After solidification, petridishes were inverted on the stage of the microscope and examined under low power objective. Separated spores were located and marked them with glass marking pencil. Marked area was cut with the help of sterilized scalpel and transferred the blocks into centre of petriplates containing PDA medium and incubated at 27 ± 1 °C for eight days. If no saltation or sectoring was observed in the culture, it was concluded that it was a pure culture of the fungus. Such cultures were used for further studies after incubation period the plates were examined and the fungal colony was observed (Van Der Plaats-Niterink, 1981).

3.2.2 Hyphal tip technique

A loopful of well sporulated culture was taken with the help of inoculation needle and suspended in to sterilized water blank, serial dilutions were made up to 10^{-7}

⁶ dilutions, so as to obtain 50 spore/ml and suspension was mixed with 2 per cent molten agar (1:15) and later poured into sterile petridishes. After four to six hours, petriplates were examined under the low power objective of the microscope. Growing tip of the mycelium was located and marked them with glass marking pencil. Marked area was cut with the help of sterilized scalpel and transferred the blocks into centre of petriplates containing PDA medium and incubated at 27 ± 1 °C for eight days. If no saltation or sectoring was observed in the culture, it was concluded that it was a pure culture of the fungus. Such cultures were used for further studies (Van Der Plaats-Niterink, 1981).

3.2.3 Maintenance of the culture

The fungal pathogen was sub cultured on PDA slants and allowed to grow at 27 ± 1 ° C for ten days and such slants were preserved in refrigerator at 5 ° C and revived once in thirty days.

3.2.4 General procedure

3.2.4.1 Cleaning of glassware

Borosil and Corning glassware were used for all the laboratory experimental studies. They were boiled in hot water for 20-30 minutes, cooled and they were cleaned by washing with detergent solution followed by rinsing several times in tap water and finally in distilled water.

3.2.4.2 Sterilization

All the glassware used in the studies were sterilized in an autoclave at 1.1 kg cm^{-2} pressure for 20 minutes and kept in hot air oven at 60°C for one hour. Both solid and liquid media were sterilized at 1.1 kg cm^{-2} pressure for 15 minutes.

3.2.4.3 Media

Name of the media used, their composition and method of preparation are briefly described here under.

a) Potato dextrose agar (Tuite, 1969)

Peeled and sliced potatoes	200 g
Dextrose (C ₆ H ₁₂ O ₆)	20 g
Agar agar	20 g
Distilled water (to make up)	1000 ml

The peeled and sliced potatoes were boiled in 400 ml of distilled water for 20 minutes and the extract was collected by filtering through a muslin cloth. Agar-agar was melted separately in 400 ml of distilled water. The potato extract was mixed in the molten agar and 20 g of dextrose was added to the mixture. The volume was made up to 1000 ml with distilled water and sterilized at 1.1 kg cm⁻² pressure for 15 minutes.

b) Sucrose peptone agar

Sucrose (C ₁₂ H ₂₂ O ₁₁)	20 g
Potassium dihydrogen phosphate (KH ₂ PO ₄)	1 g
Magnesium chloride (MgCl ₂)	5 g
Peptone	5 g
Agar	15-18 g
Distilled water	1000 ml
pH	7.2

Just before pouring into the plates. 500 µl of stock solution of sterilized 2, 3, 5- Triphenyl Tetrazolium Chloride (stock 10 mg/ml) was added.

3.2.5 Isolation of *R. solanacearum* from infected turmeric rhizome

Turmeric plants showing typical symptom of wilting caused by *R. solanacearum* were collected. Tentative diagnosis of the disease was done by ooze test. The bacterium was isolated by extracting the ooze in sterile distilled water taken in test tube, followed by dilution plate technique on Triphenyl Tetrazolium Chloride medium (TZC). Small pieces of infected vascular tissue were taken aseptically cut with a sterile surgical blade after removing the bark. The infected pieces of tissues were surface sterilized in 70 percent alcohol for a minute and were washed in two to three series of sterile water to remove traces of alcohol. The pieces were then suspended in a sterile water taken in test tube and which became turbid due to oozing of bacterial cells from the infected tissue. The bacterial suspension was serially diluted up to 10^{-6} and 100 ml of the diluted bacterial suspension was poured on to the surface of solidified TZC medium with a sterilized spreader. The inoculated plates were incubated at 32 °C for 48 hours. The plates were observed for the development of well separated virulent colonies.

3.2.6 Purification and preservation of *R. solanacearum*

The virulent colonies of *R. solanacearum* were irregular, dull white, fluidal, slimy with slight pink centre. For the purpose of purification, well separated virulent colonies of *R. solanacearum* on TZC medium were picked up and streaked on the surface of TZC medium and plate were incubated at 32 °C for 48 hours. Three to four loopful of the bacterial culture was picked up from the well separated colonies and inoculated into 2 ml sterilized distilled water contained in small culture tubes. The inoculated tubes were kept at room temperature which served as stock culture for further use.

3.2.7 Morphological identification

The main and traditional methods for identifying fungal species are based on morphological studies. Identification of *P. aphanidermatum* was based on standard keys suggested by Plaats- Niterink and Vander (1981) and Waterhouse (1967).

Fungus isolated from rotted rhizomes was compared for variation in morphological and cultural characters on PDA medium. 20 ml of medium was poured into each sterilized petriplate and five millimeter mycelial disc from actively growing seven days old culture of each isolate of the associated pathogens were inoculated at the centre of PDA medium. Petri plates were incubated at 27 ± 1 °C for eight days. Observations on colony color and linear growth measurements were recorded up to seven days.

3.3 Pathogenicity test

3.3.1 Preparation of pots for sowing of turmeric plants

The sterilized potting mixture containing soil, sand and farm yard manure (1:1:1) was filled in clay pot. The soil mixture used in the research was steam sterilized for 2 h. The healthy rhizomes of turmeric were planted in all pots filled with sterilized potting mixture. The pots were separated into 4 sets, one set was control and other 3 set was treated.

3.3.2 Inoculum preparation

To prepare the inoculum of pathogen *P. aphanidermatum*, the potato dextrose broth was prepared and sterilized at 121°C for 15 minutes. After sterilization the broth was allowed to cool and then 6 mm diameter of *P. aphanidermatum* pure culture was inoculated in to conical flask containing Potato Dextrose Broth. After inoculation the flasks were stored in orbital shaker at 150 rpm for 7 days.

Inocula of *R. solanacium* was prepared by using Nutrient Broth with 48 h old culture grown on TZC medium at 32 °C. Colonies were suspended in sterilized water to get 1×10^8 CFU /ml using a spectrophotometer (transmission at $A_{600}=0.1$) and were used for inoculation immediately after preparation.

3.3.3 Inoculation of pathogens

Root zone was damaged using a sterilized scalpel and 5 ml (50 g L^{-1}) prepared culture *i.e.*, liquid culture of *P. aphanidermatum* (spore load of 1×10^6

CFU/ml) was inoculated in first set of pots containing 40 days older healthy turmeric plants, second set of pot was treated with 20 ml bacterium suspension, and third set was inoculated with both the cultures simultaneously. The plants without inoculum served as control. Three replicates were kept for each test. The pots were irrigated once in a week and were protected from insects and animals throughout the experimentation. The rhizome rot symptoms showed by these plants were observed carefully and were recorded at regular intervals.

3.3.4 Reisolation of the pathogens

The plants which showed symptoms of rhizome rot disease were collected and brought to the laboratory. The infected portions including roots and rhizomes were used for isolation. They were washed thoroughly with tap water to remove the adhered soil particles. Small bits excised from the diseased portions along with some healthy portions were surface sterilized with 75 % ethanol for a minute and then rinsed with sterile distilled water and placed on petriplates containing PDA medium and incubated at 27 ± 1 °C for eight days. After incubation the mycelial growth was observed on PDA plates, later the organisms were identified by using standard methods.

The bacterium was isolated by extracting the ooze in sterile distilled water taken in test tube, followed by dilution plate technique on TZC medium. The inoculated plates were incubated at 32 °C for 48 hours and observed for the development of well separated virulent colonies.

3.4 Management for rhizome rot disease

There were 12 treatments replicated six times with complete randomized design. A turmeric cv. Salem was planted in pots containing sterilized soil. Inoculation was done at 45 days after planting with the following treatments.

Table 3. Information of pesticides used for management of rhizome rot disease of turmeric

Sl. No.	Chemical name	Trade name	Concentration	Formulations
1.	N-Trichloromethyl Mercapta 4- Cyclolexene-1-2- Dicarboximide N-Trichloromethyl Thiotetrahydrophthalamide	Captan	0.3 %	50 % WP
2.	Copper Oxy Chloride	Blitox	0.3 %	50 % WP
3.	Methyl N - (2 Methoxyacetyl) -N- (2- 6,Xylyl) -DL Alaninate)	Ridomil- MZ	0.3 %	75 WP
4.	Copper Sulphate + Lime + water in the ratio 1:1:100	Bordeaux Mixture	1 %	-
5.	Streptomycin Sulphate I. P.	Streptomil	0.05 %	90 % W/V
6.	Chlorpyrifos	Calban	0.2 %	20 % EC

Table 4. Details of treatments used for the experiment

Treatment No.	Treatments
T ₁	Rhizome treatment with <i>T. harzianum</i> (5 g/kg) seed and soil application of <i>T. harzianum</i> (10 g/kg) + Neem cake (10 g/kg of soil)
T ₂	Treatment of rhizome with hot water at 51 °C for 10 minutes and soil application of <i>T. harzianum</i> (10 g /kg soil) + Neem cake (10 g/kg of soil)
T ₃	Rhizome treatment with <i>T. harzianum</i> (5 g/kg) + <i>P. fluorescens</i> (5 g/kg) and soil application of <i>T. harzianum</i> (10 g/kg) + <i>P. fluorescens</i> (10 g/kg)
T ₄	Rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of <i>T. harzianum</i> (10 g/kg)

T ₅	Soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %)
T ₆	Soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) + Chloropyrifos (0.2 %)
T ₇	Soil application of Captan (0.3 %) + Chloropyrifos 20 EC (0.2 %)
T ₈	Metalaxyl -MZ (0.3 %) + Chloropyrifos 20 EC (0.2 %)
T ₉	Soil application of Bordeaux mixture (1 %)
T ₁₀	Soil application of Metalaxyl- MZ (0.3 %) alone
T ₁₁	Control inoculated
T ₁₂	Control un-inoculated

Biocontrol agents

Isolate of biocontrol agents used *i.e.*, *Trichoderma harzianum* and *Pseudomonas fluorescens* (spore load of 1×10^8 CFU/g) as obtained from UAS, Dharwad.

The efficacy of the above mentioned treatments will be evaluated against turmeric rhizome rot causing major pathogens in pot culture experiments. Seed treatments will be carried out by dip the rhizome seeds in different chemicals and bio-agent for 30 minutes. And post sowing soil drench with different chemicals at 20 days intervals from disease inception. Soil application of biocontrol agents and neem cake may be done at the time of sowing and at regular intervals to manage the rhizome rot complex.

4. EXPERIMENTAL RESULTS

Rhizome rot of turmeric is a complex disease caused by many fungal pathogens *viz.*, *P. aphanidermatum*, *Fusarium* and *Sclerotium* sp. in association with bacteria *R. solanacearum* and root-knot nematode *Meloidogyne* sp. have been occurring in serious form and affecting the yield and quality. The present investigations about this disease have been studied as per the objectives. The results of the experiments conducted on various aspects with reference to survey on rhizome rot disease, etiology, and management of the disease.

4.1 Survey for the disease

Roving survey was conducted during 2015 - 2016 in major turmeric growing regions of North Karnataka *viz.*, Belagavi and Bagalkote districts to assess the rhizome rot disease. A total of 26 villages under Belagavi and 9 villages in Bagalkote district were covered.

In Belagavi district, per cent disease incidence (PDI) varied considerably among different locations, which ranged between 24.50 - 68.15 per cent. Among the 26 villages surveyed in Belagavi district, the highest disease incidence was recorded from Pamaladinni village (68.15 %) followed by Kallolli (52.05 %). While, the least per cent disease incidence was noticed in Shindikurbet village (24.50 %). In Bagalkote district, the disease incidence varied from 25.95 - 45.36 per cent. The highest disease incidence was noticed in Dhawaleswar (45.36 %) followed by Sanganatti (42.35 %) and the least per cent disease incidence was noticed in Madabhavi of 25.95 per cent (Table 5).

The survey result of 2015-16 showed that the highest mean per cent disease incidence was observed in Belagavi district (44.27 %) followed by Bagalkote (38.40 %).

In all locations, the time of appearance of the rhizome rot disease was found to be one month after planting *viz.*, June and July if cropping is done in the month of May and June. The severity of the disease was reported to be observed during September to November, when the secondary sprout and finger formation start (Fig. 1).

Table 5. Survey on turmeric rhizome rot disease incidence in Belagavi and Bagalkote districts of Karnataka

District	Time Of Collection	Crop Stage (Days)	Location	Variety	Per Cent Disease Incidence
Belagavi	August	120	Gurlapur	Salem Local	35.35
	August	130	Shindikurbet	Cuddapah	24.50
	September	120	Naganur	Cuddapah	38.54
	September	150	Duradundi	Cuddapah	39.45
	September	160	Jaganur	Salem Local	38.10
	September	155	Beerangaddi	Salem Local	44.05
	October	150	Harugeri	Salem Local	38.55
	October	155	Sanganakeri	Cuddapah	44.54
	October	160	Badigwad	Cuddapah	48.50
	October	165	Masaguppi	Salem Local	38.90
	October	165	Gujanatti	Salem Local	49.98
	October	180	Patagundi	Salem Local	46.79
	October	150	Hallur	Salem Local	44.67
	November	180	Mugalkod	Salem Local	48.90
	November	180	Rajapur	Salem Local	44.54
	November	185	Mallapura	Salem Local	49.15
	November	190	Mudalgi	Cuddapah	57.50
	November	195	Tukkanatti	Salem Local	53.54
	November	185	Shivapur	Salem Local	55.96
	November	180	Hunshyal(P. G.)	Salem Local	46.05
	November	180	Raibag	Cuddapah	48.60
	November	190	Arabhavi	Salem Local	50.23
	November	180	Kankanwadi	Salem Local	59.34
	November	180	Hidkal	Cuddapah	58.25
November	195	Kallolli	Salem Local	62.05	
November	190	Pamaladinni	Salem Local	68.15	
Mean					44.27
Bagalkote	September	120	Madabhavi	Salem Local	25.95
	September	150	Lokapura	Salem Local	35.37
	October	150	Belagali	Salem Local	38.86
	October	160	Sanganatti	Salem Local	42.35
	October	165	Mahalingapur	Salem Local	36.25
	November	180	Dhawleshwar	Salem Local	45.36
	November	180	Handigudda	Cuddapah	41.50
	November	190	Mudhol	Cuddapah	39.45
	November	185	Kanatti	Salem Local	40.55
Mean					38.40
Grand Mean					41.33

% disease incidence = No. of infected plants/Total No. of plant observed× 100

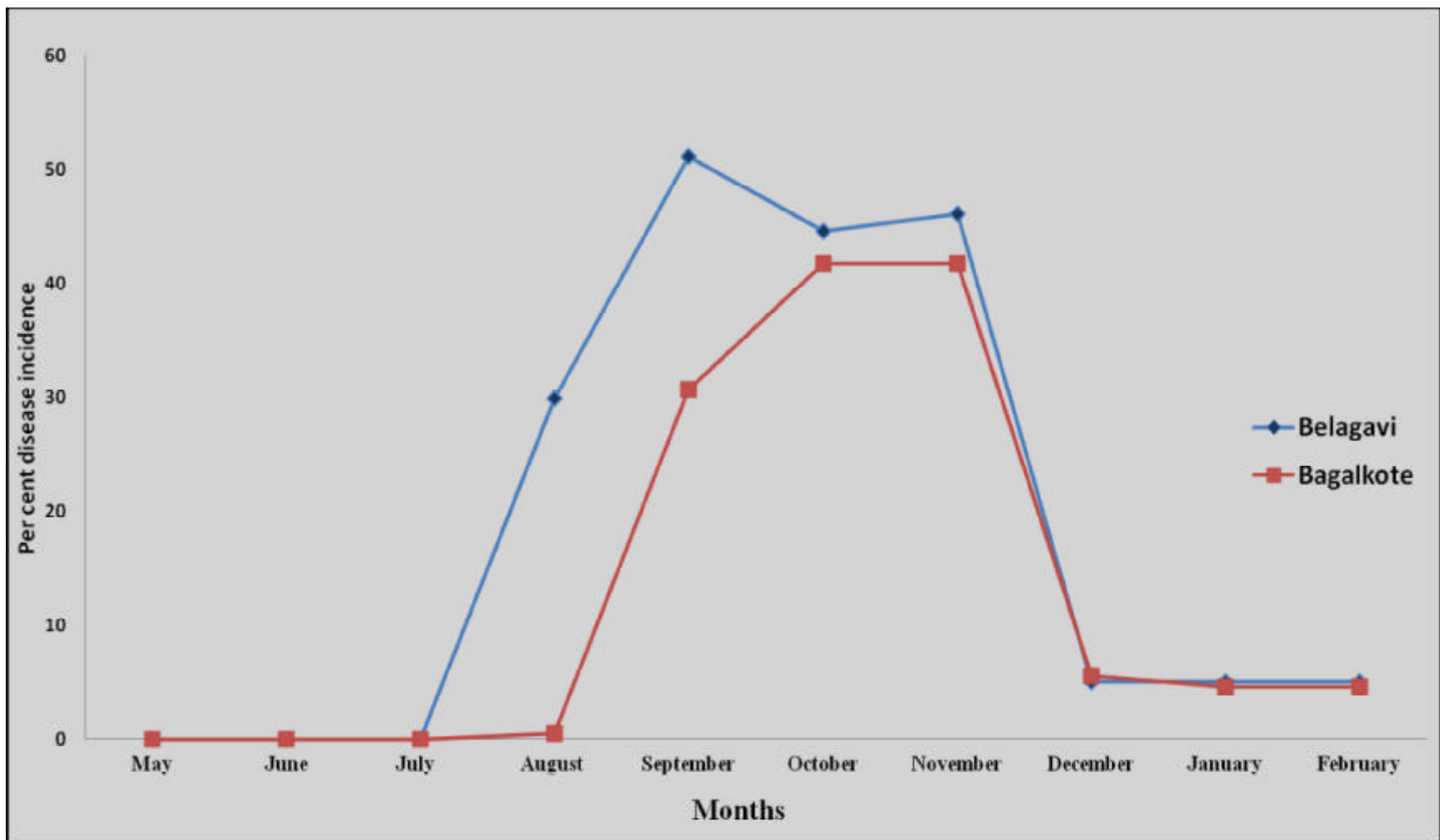


Fig. 1: Turmeric rhizome rot disease incidence during 2015-2016

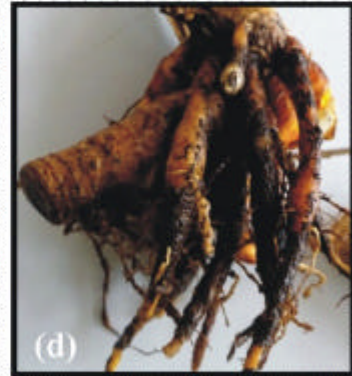
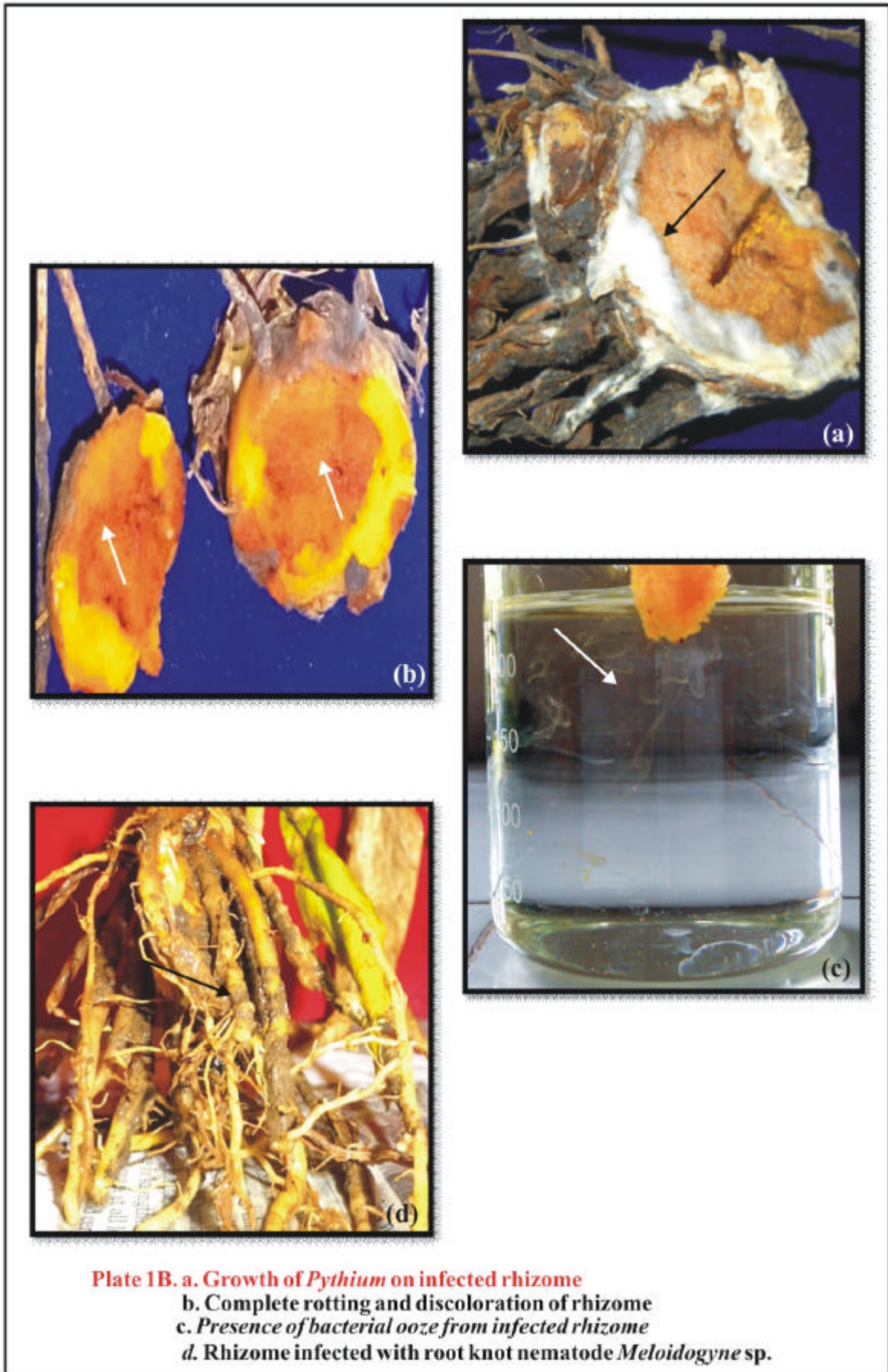


Plate 1A. Visual symptoms of turmeric rhizome rot

- a. Rhizome rot infected field b. Yellowing of foliage
c. Water soaked lesion on pseudo stem d. Rotting of rhizome in advance stage



The plant showing symptoms of rhizome rot as such yellowing of foliage, rotting of pseudo stem, root rot and rhizome rot *etc.*, were identified and recorded. In mature plants, the leaves become pale and tips of leaf turn yellow. Yellowing and drying along the margins of the leaves from tips downwards. Tender tissues of the collar region turn soft, watery and rot and the plant topples. The rotten part emits foul smell owing to decay (Plate 1. A & B). The representative samples of infected plant were collected for isolation and identification of pathogens for further studies.

4.2 Etiology

4.2.1 Organisms associated with rhizome rot of turmeric

A total of 34 samples collected from different locations were used for the isolation of organisms associated with rhizome rot disease of turmeric. Out of 34 samples, 30 samples yielded *P. aphanidermatum* (88.23%), 21 samples yielded *Fusarium* (61.76 %) and 12 samples yielded *Sclerotium* sp. (35.29 %). Among the fungal pathogens isolated, *P. aphanidermatum* was dominated in majority of the diseased samples followed by *Fusarium* and *Sclerotium* sp. (Fig. 2). Few samples were affected with root knot nematode *Meloidogyne* sp. 26.47 per cent (Table 6). However, there were some samples which yielded a combination of these three organisms (Table 7). Out of 34 samples, *Pythium* and *Fusarium* sp. were isolated from 17 samples (50.00 %), 3 samples yielded *Pythium* + *Fusarium* + *Sclerotium* sp. (8.82 %) and 2 samples (6.89 %) showed the presence of *Fusarium* and *Sclerotium* sp. and only a single sample yielded *Pythium* and *Sclerotium* sp. (2.94 %), few samples recorded presence of *Meloidogyne* sp. along with combination of *Pythium* + *Fusarium* (8.82 %) ; *Pythium* + *Sclerotium* sp. (5.88 %) ; *Pythium* + *Fusarium* + *Sclerotium* sp. (8.82 %). Another rot causing bacterium *R. solanacearum* was also one of the most important pathogen associated with all rotted samples, this can be confirmed by cross sectioning on affected rhizome produced white milky strand of bacterial cells in clear water. This ooze distinguishes the rot caused by the bacterium from that caused by fungal pathogens. Among the pathogens of rhizome rot of turmeric from the surveyed samples of Belagavi districts, 84 per cent of *P. aphanidermatum*, 56 per cent of *Fusarium* sp., 32 per cent of *Sclerotium* sp. and 24 per cent of *Meloidogyne* sp. were recorded. Whereas under Bagalkote district, we noticed 50 per cent of *P. aphanidermatum*, 39 per cent of *Fusarium* sp., 22 per cent of *Sclerotium* sp and 16

Table 6. Pathogens associated with rhizome rot of turmeric.

District	Location	Major Pathogens isolated					Other saphrophytic pathogens.	
		<i>Pythium aphanidermatum</i>	<i>Fusarium</i> sp.	<i>Sclerotium</i> Sp	<i>Ralstonia solanacearum</i>	<i>Meloidogyne</i> sp.	A	P
Belagavi	Kalloli	+	+	+	+	-	+	-
	Nagnoor	+	-	-	+	-	+	-
	Mudalagi	+	+	-	+	-	+	-
	Gurlapur	+	-	-	+	-	+	+
	Hallur	-	+	+	+	-	+	-
	Mugalkode	+	-	-	+	-	-	+
	Hidkal	-	+	+	+	-	+	+
	Harugere	+	-	-	+	-	+	-
	Raibhag	-	+	+	+	-	+	+
	Kankanwadi	+	-	+	+	-	-	-
	Jaganoor	+	-	-	+	-	-	-
	Pamaldinni	+	+	+	+	+	+	-
	Bheerangaddi	+	+	-	+	-	+	-
	Tukanatti	+	-	+	+	+	-	+
	Arabhavi	+	+	-	+	+	+	+
	Gujanatti	+	+	-	+	-	+	-
	Shivapur	+	-	+	+	+	-	-
	Sangakeri	+	-	-	+	-	+	-
	Musuguppi	+	-	-	+	-	-	+
	Patagundi	+	+	-	+	-	-	+
	Unshal	-	+	-	+	+	-	-
	Badigawada	+	+	-	+	-	+	-
	Sindhikurbhat	+	-	-	+	-	+	-
Mallapura	+	+	-	+	+	-	-	
Dhurdunddi	+	-	-	+	-	-	-	
Rajapura	+	+	-	+	-	+	+	
Bagalkote	Belagali	+	+	-	+	-	-	-
	Mahalingapur	+	+	-	+	+	+	+
	Lokapura	+	-	-	+	-	+	+
	Handigudda	+	+	+	+	+	-	+
	Mudhol	+	+	+	+	-	-	-
	Dhawleshwar	+	+	+	+	+	-	-
	Sanganatti	+	+	-	+	-	-	-
	Madabhavi	+	-	-	+	-	-	-
	Kanatti	+	+	+	+	-	+	-
		+ = present; - = absence					A- <i>Aspergillus</i> ;P- <i>Pencillium</i>	

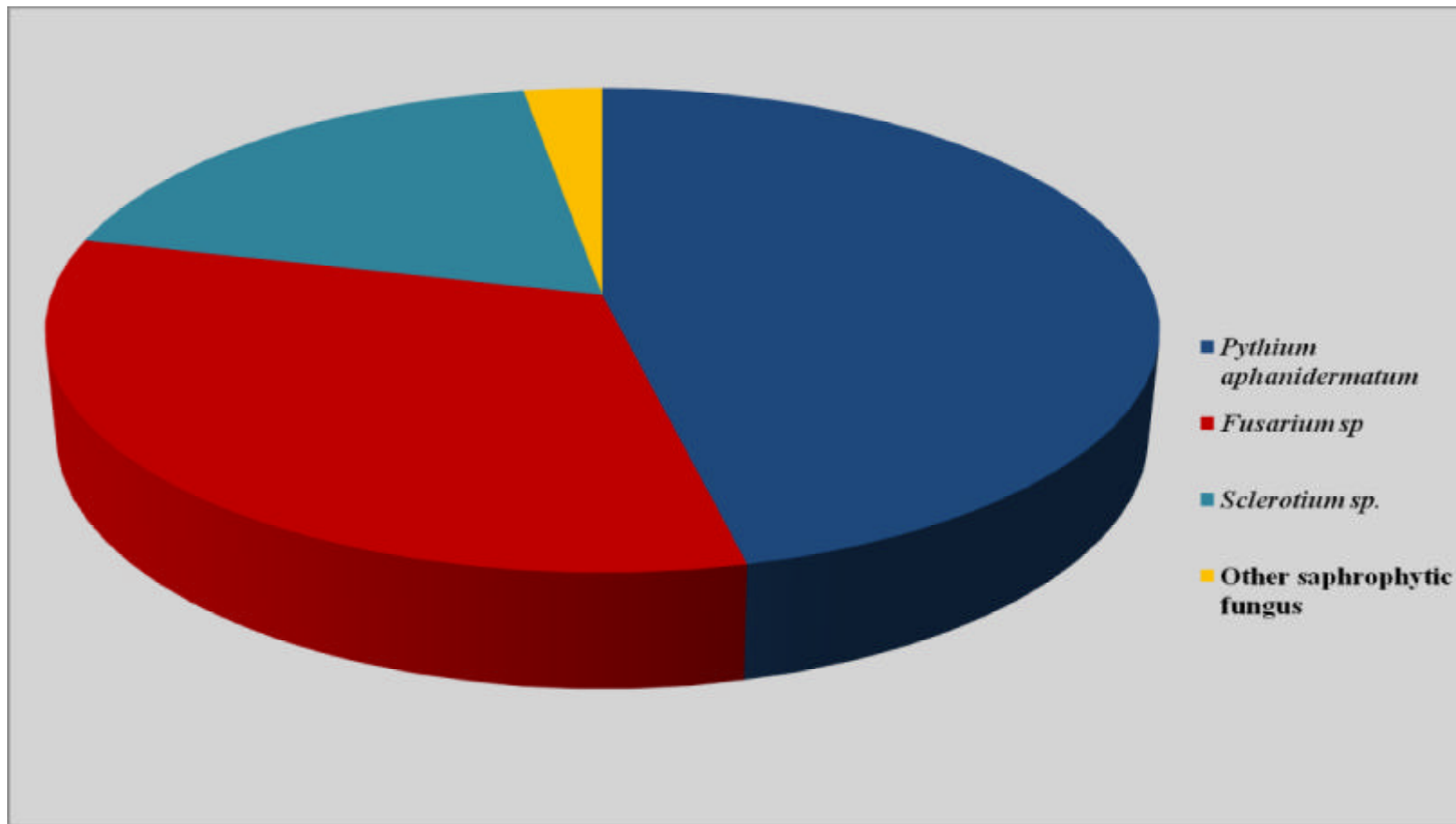


Fig. 2: Fungal pathogens associated with the rhizome rot disease of turmeric

Table 7. Association of pathogens combination with infected samples

Fungal Pathogens	<i>Ralstonia solanacearum</i>	No. of samples	Pathogens association (%)
P+F	+	17	50.00
F+S	+	2	6.89
P+S	+	1	2.94
P+F+M	+	3	8.82
P+S+M	+	2	5.88
P+F+S	+	3	8.82
P+F+S+M	+	3	8.82

P- *Pythium* sp.; F- *Fusarium* sp.; S- *Sclerotium* sp.; M- *Meloidogyne* sp.

per cent of *Meloidogyne* sp. were recorded and all the samples showed the presence of (100 %) *R. solanacearum* (Table 8) (Fig 3).

4.2.2 Identification of pathogens

The morphological characters of *P. aphanidermatum* observed were all most similar to those described by Plaats-Niterink and Vander (1981). The mycelium of fungus were white cottony on PDA, the hyphae is hyaline and no cross walls. Oospores spherical, smooth, sporangia was lobate consisting of terminal complexes of swollen hyphal branches of various length. The presence of apluerotic oogonium, oogonia oboes, terminal smooth and antheridia typically intercalary (Plate 3a, b & c).

The morphological characters of *Fusarium* sp observed were all most similar to those described by Gerlach and Nirenberg (1982). The mycelia of the pathogen was white cottony to pink often with purple tinge or reddish colouration of the medium. Micro conidia were borne on simple phialides arising laterally and were abundant, oval-ellipsoid, straight to curved, macro conidia, sparse to abundant were born on branched conidiophores or on the surface of sporodochia and were thin walled, three to five septate, fusoid-subulate and pointed at both ends and have pedicellate base. Three septate spores were predominant. Chlamydospores, both smooth and rough walled which are abundant and form terminally or on an intercalary basis (Plate 2b).

The pathogen *Sclerotium* is a fast growing fungus started producing branched snow white coloured *Sclerotia* at the periphery of the colony. The description of the fungus was similar to the description given for *Sclerotium* by Aycocock (1966) (Plate 2c).

Isolation of *R. solanacearum* was made from the turmeric plants showing typical symptoms of wilts from major turmeric growing areas Belagavi and Bagalakote district of Karnataka. The bacterium produced irregular, slimy, fluidal, white colonies with slight red centre on TZC agar medium (Plate 3d).

4.3 Pathogenicity test

For study of rhizome rot of turmeric, predominant pathogens *viz.*, *P. aphanidermatum* and *R. solanacearum* were inoculated to plants individually and also in combinations and results were recorded as fallow (Table 9) (Plate 4).

Table 8. Percentage of individual pathogen in association with infected sample

District	<i>Pythium aphanidermatum</i> (%)	<i>Fusarium sp.</i> (%)	<i>Sclerotium sp.</i> (%)	<i>Meloidogyne sp.</i> (%)	<i>Ralstonia solanacearum</i> (%)
Belagavi	84.00	56.00	32.00	24.00	100
Bagalkote	50.00	39.80	22.00	16.60	100
Mean	67.00	47.50	27.00	20.30	100.00

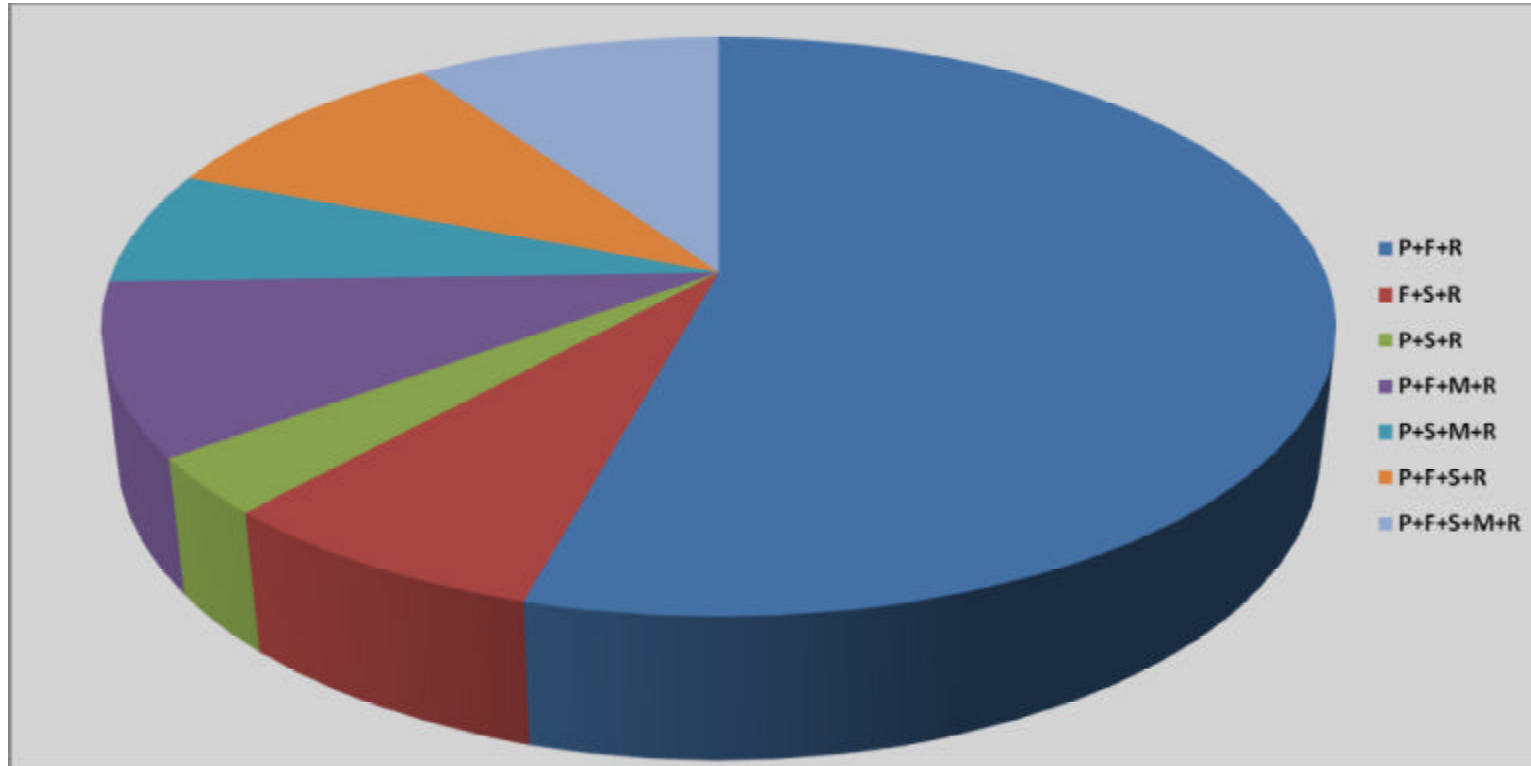
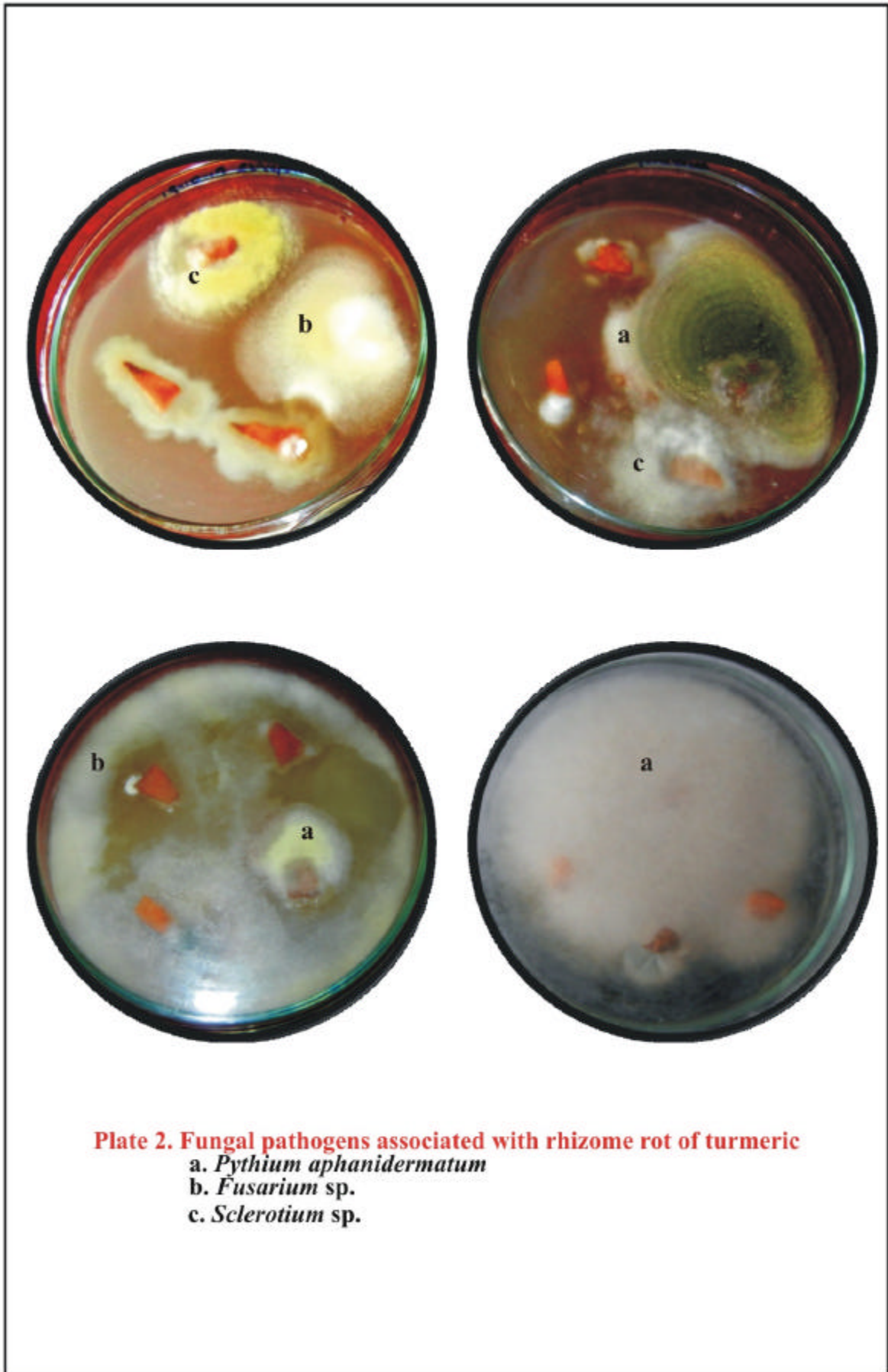
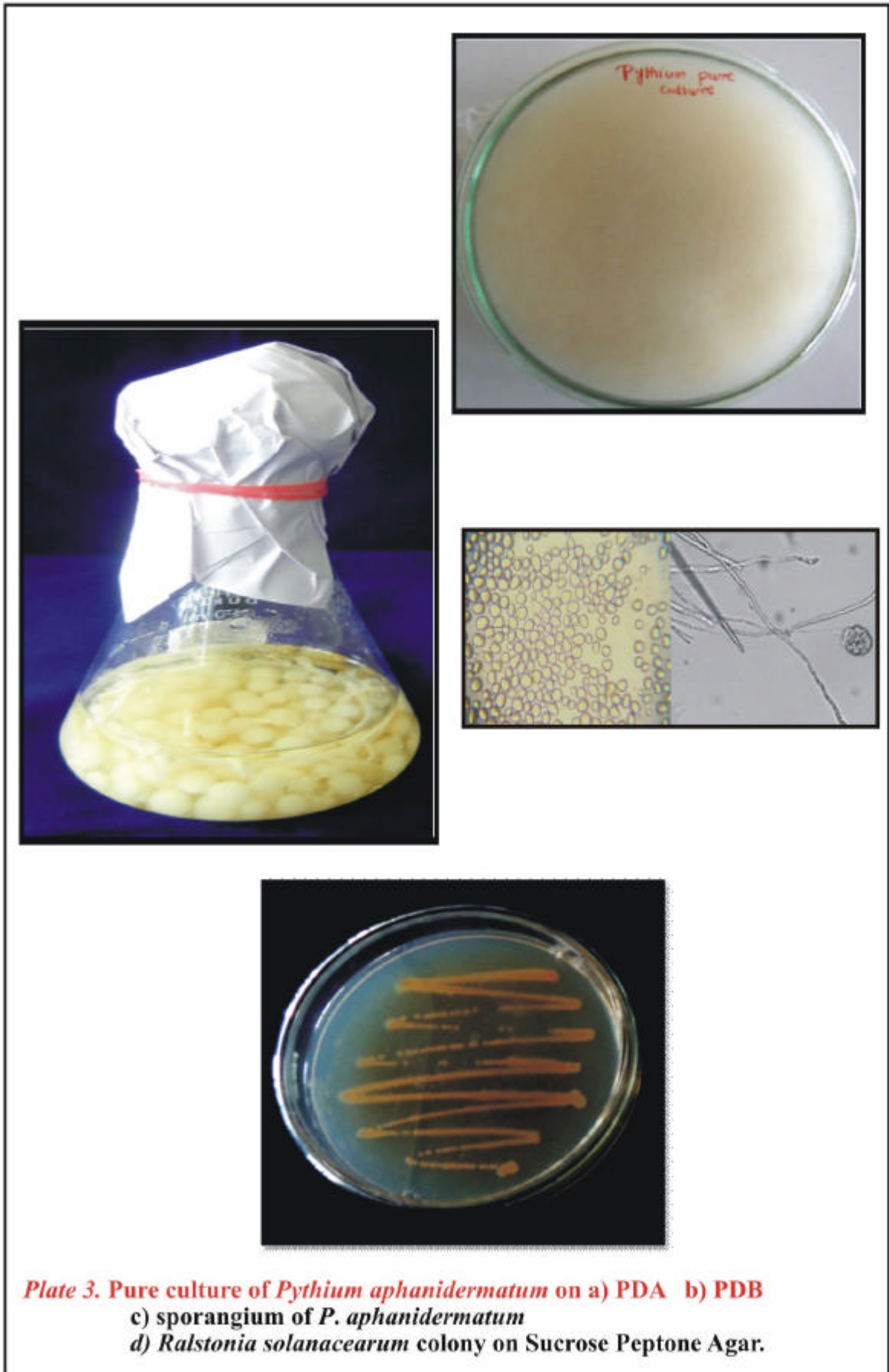


Fig. 3: Association of pathogens combination with rhizome rot infected samples

P-Pythium sp.; *F-Fusarium sp.*; *S-Sclerotium sp.*; *M-Meloidogyne sp.*; *R-Ralstonia solanacearum*





**Plate 3. Pure culture of *Pythium aphanidermatum* on a) PDA b) PDB
c) sporangium of *P. aphanidermatum*
d) *Ralstonia solanacearum* colony on Sucrose Peptone Agar.**

Table 9. Pathogenicity of major pathogens affecting rhizome rot of turmeric

Pathogens inoculated	Per cent Disease Incidence			
	30 DAP	90 DAP	150 DAP	Detection of pathogen
<i>P. aphanidermatum</i> alone	17.85	45.88	80.88	P
<i>R. solanacearum</i> alone	10.88	34.00	68.96	R
<i>P. aphanidermatum</i> + <i>R. solanacearum</i>	30.75	65.84	95.55	P, R
control(un-inoculated)	-	-	-	-

P- *Pythium aphanidermatum*., R- *Ralstonia solanacearum*.

DAP= Days after planting

4.3.1 Pathogen inoculation alone

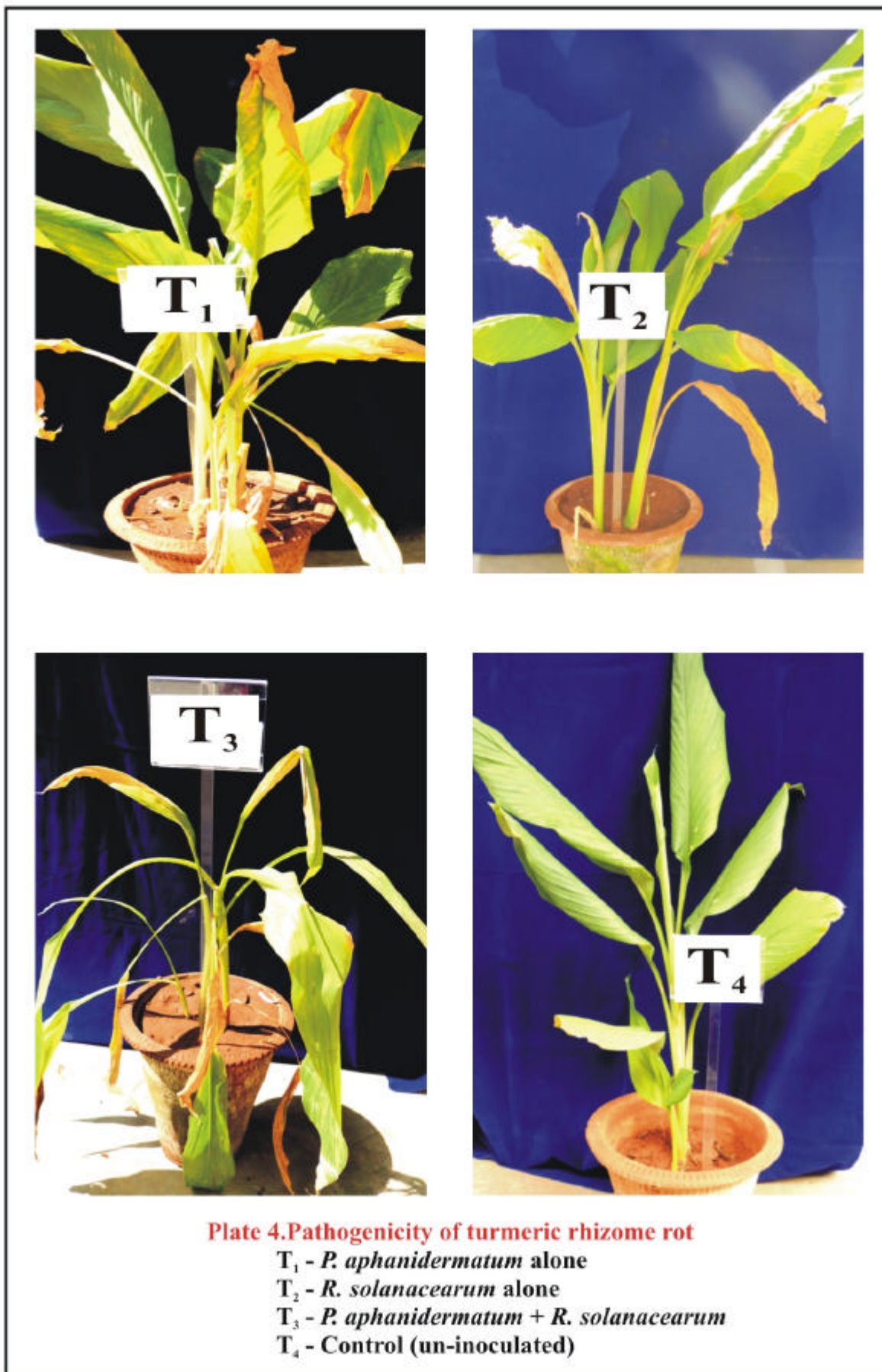
The plants inoculated with *P. aphanidermatum* alone exhibited symptoms within 28 days after inoculation with the symptoms like lower most leaf exhibited yellowing, ultimately results in complete drying of all the leaves. The collar region of the pseudo stem becomes soft and water soaked, resulting in collapse of the plant. The root system was much reduced and its tissues were also affected. In severe condition, the infection spreads to rhizomes which decompose and turn into a decaying mass of tissues. The development of rhizomes was poor. Later rhizome was rotten, emitting foul smell. Disease incidence of 17.85, 45.88 and 80.88 per cent was noticed at 30, 90 and 150 days after inoculation respectively.

The plants inoculated with *R. solanacearum* alone, exhibited the symptoms 24 days after inoculation, first appeared as sudden wilt, leaf edges curled towards the centre of the midrib, and leaves became yellow. Necrosis of the pseudo stem and rhizome rot with internal discoloration was observed in the diseased plants. The whole plant finally wilted and died. Later rhizome became rotten and emits foul smell. For further confirmation, cross sectioning of affected rhizome produced white bacterial ooze in clear water. Disease incidence was recorded at 30 days, 90 days and 150 days after inoculation which showed 10.88, 34.00 and 68.96 per cent disease was noticed in inoculated pots.

Re-isolations from diseased plant consistently yielded the original isolate of fungi and bacterium by producing white cottony mycelia growth without cross wall on PDA medium and irregular, slimy, fluidal, white colonies with slight red center on TZC agar medium, respectively.

4.3.2 Simultaneous inoculation of pathogens

Simultaneous inoculation of both the pathogens viz., *P. aphanidermatum* and *R. solanacearum*, plants exhibited the early symptoms within 21 days and recorded more rhizome rot incidence compared to individual inoculated one and it showed 30.75, 65.84 and 95.55 per cent at 30, 90 and 150 days after inoculation, respectively (Plate 4). Re-isolation of the causal organism was made from the artificially inoculated plants and was similar to the original culture with respect to their morphology and cultural characters.



Hence, in this experiment we concluded that combination of *P. aphanidermatum* and *R. solanacearum* affects the rhizome and induces more disease incidence when compared to the individual pathogen. Control treatment showed no visible symptoms. The results of this study revealed that, the inoculation of both the pathogens alone and in combination were pathogenic to turmeric.

4.4 Management of rhizome rot disease in turmeric

A pot experiment was carried out for the management of turmeric rhizome rot. Biocontrol agents like *T. harzianum* and *P. fluorescens*, organic amendments like FYM and Neem cake, fungicides like Metalaxyl- MZ, Copper Oxy Chloride, Captan, Bordeaux mixture and antibiotics like Streptocyclin were used. Due to rhizome fly infestation insecticide like Chloropyrifos was also used. These pesticides were used in various combinations as a different treatment in the experiment. The data on the effect of various treatments on disease management, plant growth parameter and yield parameter were presented.

4.4.1 Effect of different treatment on turmeric rhizome rot disease incidence

A significant performance of the treatments used in the experiment was observed in reducing the disease incidence in comparison to control (Fig. 4) (Plate 5). The highest potential performance was recorded in case of T₄- rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) with disease incidence of 3.41 per cent followed by T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) with disease incidence of 4.88 per cent which is on par with the treatment T₆- comprising of soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chlorpyrifos (0.2 %) having disease incidence of 4.94 per cent and the lowest performance was noticed in case of T₃- rhizome treatment with *T. harzianum* + *P. fluorescens* and soil application of *T. harzianum* + *P. fluorescens*. Rest of the treatments like T₉- soil application of Bordeaux mixture (1%), T₁- rhizome treatment with *T.harzianum* (5 g/kg) and soil application of *T. harziaum* (10 g/kg) + Neem cake (10 g/kg), T₁₀- soil application of Metalaxyl- MZ (0.3 %) and T₂- rhizome treatment with hot water at 51 °C for 10 minutes and soil application of *T. harzianum* (10 g/kg) + Neem cake (10 g/kg) also showed significant performance in reducing the disease

Table 10. Effect of different treatments against turmeric rhizome rot disease

Treatment No.	Treatment details	Per cent disease incidence			Disease reduction over control (%)
		90 DAP	150 DAP	240 DAP	
T ₁	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) seed and soil application of <i>T. harzianum</i> (10g/Kg) + Neem cake (10g/Kg of soil)	8.36 (16.68) ^{cd}	17.54 (24.70) ^c	20.35 (26.64) ^c	69.72
T ₂	Hot water treatment with rhizome at 51 ⁰ C for 10 minutes and soil application of <i>T. harzianum</i> (10g / Kg soil) + Neem cake (10g/Kg of soil)	11.99 (20.21) ^{bc}	24.51 (29.64) ^b	27.46 (31.56) ^b	58.13
T ₃	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) + <i>Pseudomonas fluorescens</i> (5g/Kg) and soil application of <i>T. harzianum</i> (10g/Kg) + <i>P. fluorescens</i> (10g/Kg)	13.44 (21.54) ^b	27.54 (31.58) ^b	30.86 (33.79) ^b	52.97
T ₄	Rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of <i>T. harzianum</i> (10g/Kg)	3.41 (10.16) ^f	5.72 (13.57) ^{fg}	6.71 (14.49) ^g	89.63
T ₅	Soil application of Streptocyclin (0.05 %) +Copper Oxy Chloride (0.3 %)	4.88 (12.10) ^{ef}	6.63 (14.66) ^{efg}	8.75 (16.94) ^{fg}	86.74
T ₆	Soil application of Streptocyclin (0.05 %) + COC (0.3%) + Chloropyriphos (0.2 %)	4.94 (12.309) ^{ef}	7.85 (16.60) ^{efgh}	9.5 (17.71) ^{efg}	85.40
T ₇	Soil application of Capton (0.3 %) + Chloropyriphos (0.2%)	7.15 (15.25) ^{de}	11.42 (19.66) ^d	13.42 (21.42) ^{de}	79.05
T ₈	Metalaxyl -MZ (0.3 %) + Chloropyriphos (0.2 %)	7.82 (15.75) ^{de}	9.21 (17.43) ^{def}	11.77 (19.98) ^{def}	81.14
T ₉	Soil application of Bordeaux mixture (1%)	5.83 (13.56) ^{def}	7.37 (15.59) ^{efg}	9.2 (17.55) ^{efg}	85.33
T ₁₀	Soil application of Metalaxyl - MZ (0.3 %)	8.45 (16.40) ^{cd}	11.72 (19.92) ^d	14.02 (21.88) ^d	77.6
T ₁₁	Control inoculated	25.55 (30.32) ^a	54.53 (47.70) ^a	72.68 (58.81) ^a	-
T ₁₂	Control uninoculated	1.40 (5.91) ^g	5.51 (13.45) ^g	9.00 (17.16) ^{efg}	-
	CD (0.05)	4.06	3.62	4.02	-
	S.Em ±	12.45	10.78	12.86	-

Figures in parentheses are arc sine transformed values; Figures followed by the same letter did not differ significantly. DAP= days after planting.

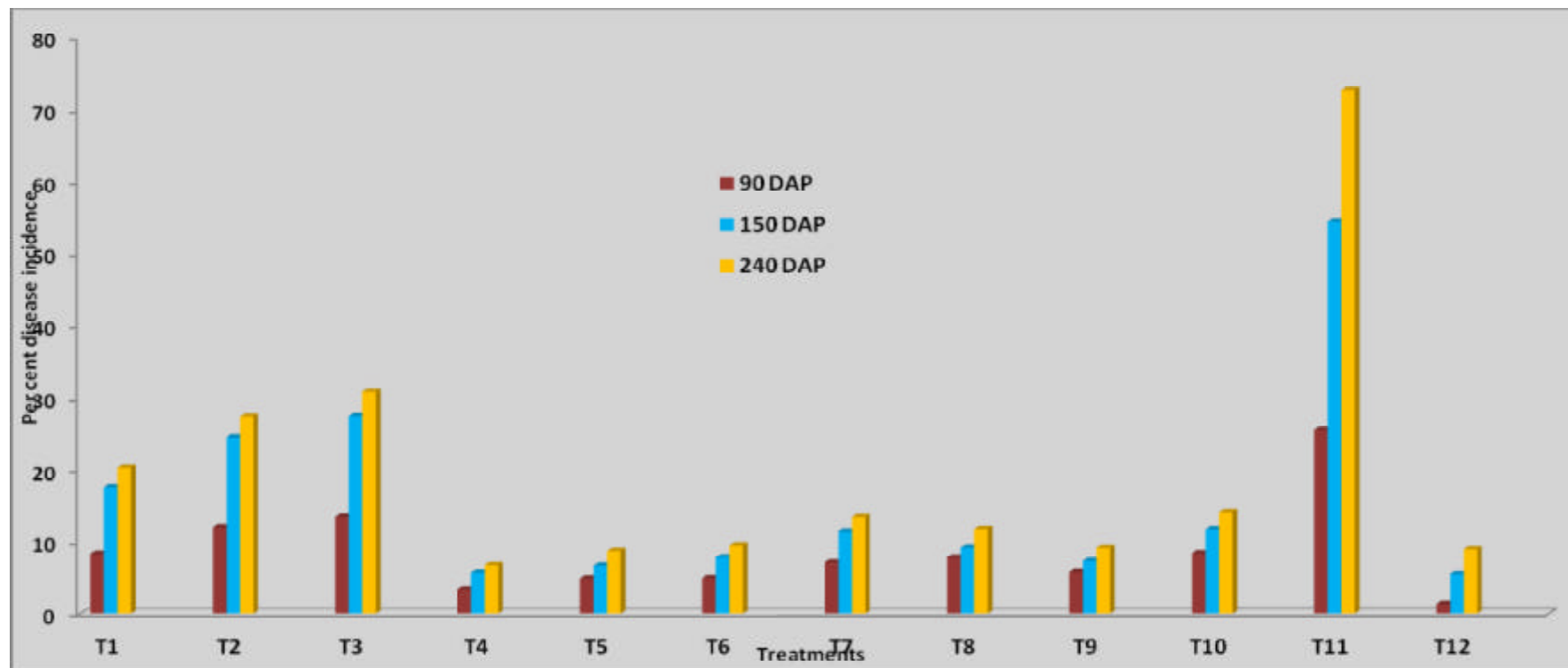
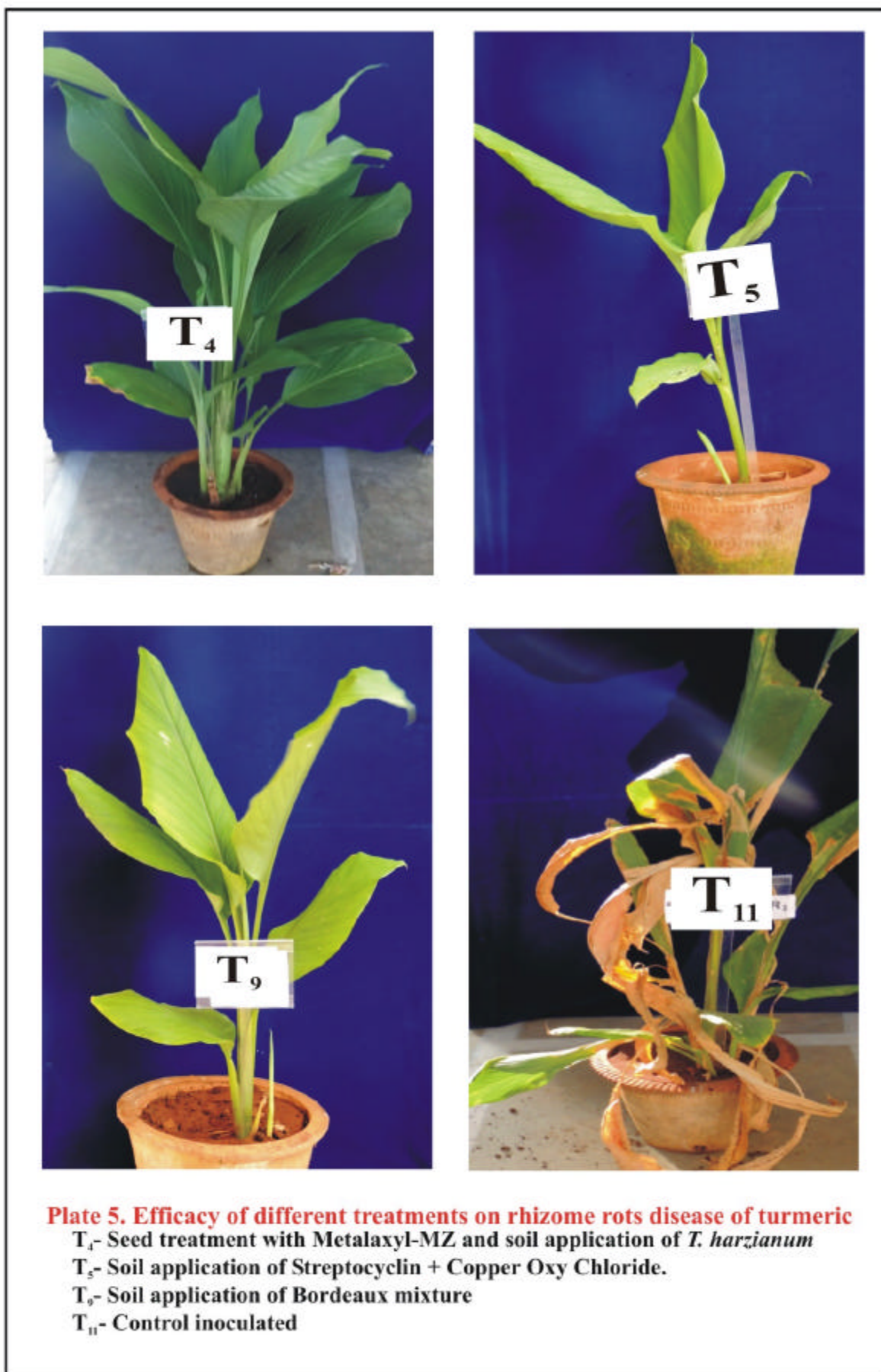


Fig. 4: Effect of different treatments against turmeric rhizome rot disease incidence

- T₁- Seed treatment with *Trichoderme harzianum* seed and soil application of *T. harzium* + Neem cake
- T₂- Treatment of rhizome with hot water at 51 °C for 10 minutes and soil application of *T. harzianum* + Neem cake
- T₃- Seed treatment with *T. harzianum* + *Pseudomonas fluorescens* (5 g/Kg) and soil application of *T. harzianum* + *P. fluorescens*
- T₄- Seed treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum*
- T₅- Soil application of Streptocyclin (0.05 %) +Copper Oxy Chloride (0.3%)
- T₆- Soil application of Streptocyclin (0.05 %)+COC (0.3 %) + Chloropyrifos (0.2%)
- T₇- Soil application of Capton (0.3 %)+ Chloropyrifos 20 EC (0.2%)
- T₈- Metalaxyl -MZ @ (0.3 %)+ Chloropyrifos 20 EC(0.2%)
- T₉- Soil application of Bordeaux mixture (1 %)
- T₁₀- Soil application of Metalaxyl - MZ (0.3 %) alone
- T₁₁- Control inoculated
- T₁₂- Controlun-inoculated



incidence with 5.83, 8.36, 8.45, 11.99 per cent disease incidence, respectively at 90 days after planting. Similarly, significant performance of all the treatment was noticed throughout the growing period of the crop in reducing the disease incidence and the data was recorded at 150 and 240 days after planting (DAP). T₄- rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) recorded the least disease incidence of 5.72 and 6.71 per cent, followed by T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) which showed lower incidence of 6.63 and 8.75 per cent at 150 and 240 DAP, respectively. While in the control it recorded an incidence of 25.55, 54.53 and 72.68 per cent at 90, 150 and 240 DAP, respectively.

The highest per cent disease reduction over the control was found in the treatment T₄ comprised of rhizome treatment with Metalaxyl -MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) with 89.63 per cent reduction followed by 86.74, 85.33 per cent reduction in the treatment T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %), and T₉- soil application of Bordeaux mixture (1%) which is almost on par with the T₆- soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chloropyrifos (0.2 %). Rest of the treatment also found effective in the reducing the disease over the control and ranged between 52.97 - 81.14 per cent (Table 10).

4.4.2 Effect of different treatments on the plant growth parameters of turmeric

Effect of different treatments on growth parameters *viz.*, plant height, number of leaves, leaf area and number of tillers were recorded and the data is presented in table 11 & Fig. 5.

a. Plant height

Among the different treatment, the rhizome treated with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the plant height having 75.02 cm (T₄) which was followed by soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) showing 73.05 cm (T₅), which is on par with soil application of Streptocyclin (0.05 %) + COC (0.3 %) +

Table 11. Effect of different treatments on growth parameters of turmeric

Treatment No.	Treatment details	Plant height (cm)	No. of leaves per plant	Leaf area (cm²)	No. of tillers per plant
T₁	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) seed and soil application of <i>T. harzianum</i> (10g/Kg) + Neem cake (10g/Kg of soil)	67.14 ^{bcde}	9.66 ^{de}	38.50 ^{bcde}	8.00 ^{ab}
T₂	Hot water treatment with rhizome at 51 ^o C for 10 minutes and soil application of <i>T. harzianum</i> (10g / Kg soil) + Neem cake (10g/Kg of soil)	65.22 ^{def}	10.33 ^{bcde}	36.36 ^{de}	7.16 ^b
T₃	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) + <i>Pseudomonas fluorescens</i> (5g/Kg) and soil application of <i>T. harzianum</i> (10g/Kg) + <i>P. fluorescens</i> (10g/Kg)	63.02 ^{ef}	10.36 ^{bcde}	34.47 ^{ef}	7.00 ^{bc}
T₄	Rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of <i>T. harzianum</i> (10g/Kg)	75.02 ^a	12.00 ^a	45.53 ^a	10.66 ^a
T₅	Soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %)	73.05 ^{ab}	11.66 ^{ab}	43.43 ^{ab}	9.83 ^{ab}
T₆	Soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chloropyriphos (0.2 %)	73.00 ^{ab}	11.66 ^{ab}	43.25 ^{ab}	9.00 ^{ab}
T₇	Soil application of Captan (0.3%) + Chloropyriphos (0.2 %)	65.16 ^{cdef}	10.66 ^{abcd}	38.41 ^{bcde}	7.16 ^b
T₈	Metalaxyl -MZ (0.3 %) + Chloropyriphos (0.2 %)	69.08 ^{abcd}	11.00 ^{abcd}	41.33 ^{abcd}	8.04 ^{ab}
T₉	Soil application of Bordeaux mixture (1 %)	72.12 ^{abc}	11.66 ^{ab}	42.45 ^{abc}	9.02 ^{ab}
T₁₀	Soil application of Metalaxyl - MZ (0.3 %)	67.83 ^{bcd}	11.16 ^{abc}	37.36 ^{cde}	8.83 ^{ab}
T₁₁	Control inoculated	60.32 ^f	9.16 ^e	30.43 ^f	4.08 ^c
T₁₂	Control un-inoculated	70.24 ^{abcd}	9.83 ^{cde}	40.60 ^{abcd}	9.33 ^{ab}
	CD(0.05)	6.99	1.38	5.51	2.90
	S.Em±	21.08	4.35	16.92	9.14

Figures followed by the same letter did not differ significantly

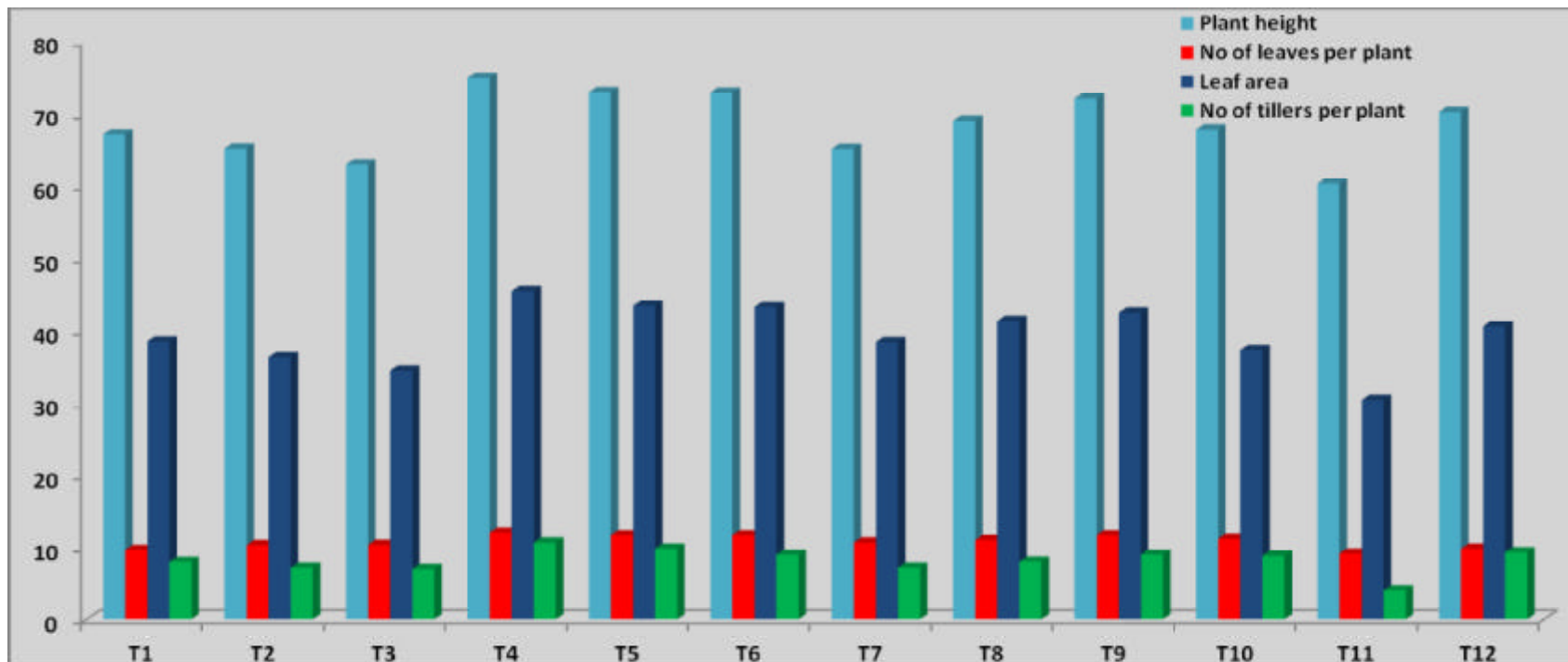


Fig. 5: Effect of different treatments on growth parameters of turmeric

- T₁- Seed treatment with *Trichoderme harzianum* seed and soil application of *T. harzium* + Neem cake
- T₂- Treatment of rhizome with hot water at 51 °C for 10 minutes and soil application of *T. harzianum* + Neem cake
- T₃- Seed treatment with *T. harzianum* + *Pseudomonas fluorescens* (5 g/Kg) and soil application of *T. harzianum* + *P. fluorescens*
- T₄- Seed treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum*
- T₅- Soil application of Streptocyclin (0.05 %) +Copper Oxy Chloride (0.3%)
- T₆- Soil application of Streptocyclin (0.05 %)+COC (0.3 %) + Chloropyrifos (0.2%)
- T₇- Soil application of Capton (0.3 %)+ Chloropyrifos 20 EC (0.2%)
- T₈- Metalaxyl -MZ @ (0.3 %)+ Chloropyrifos 20 EC(0.2%)
- T₉- Soil application of Bordeaux mixture (1 %)
- T₁₀- Soil application of Metalaxyl - MZ (0.3 %) alone
- T₁₁- Control inoculated
- T₁₂- Controlun-inoculated

Chlorpyrifos (0.2 %) and soil application of Bordeaux mixture (1%) showing 72.12 cm (T₆) & (T₉), respectively. Which were also found more significant when compared to the inoculated control 60.32 cm plant height (T₁₁). Rest of the treatment also found to be more significant in increasing the plant height when compared to the inoculated control and the height ranged from 69.08 to 63.02 cm.

b. No. of leaves

Among the different treatment, T₄-rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the number of leaves per plant (12.00) followed by T₅-soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) and T₆- soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chlorpyrifos (0.2 %) showed 11.66 number of leaves per plant, both the treatment found highly significant over the inoculated control (T₁₁) showing 9.16 leaf number. And it was noticed that there was not much variation in the number of leaves in rest of the treatments and it could be found between 9.66 to 11.66 number of leaves.

c. Leaf area

Among the different treatments, T₄- rhizome treatment with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the area of the leaf 45.53 cm followed by soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) 43.43 cm (T₅) and soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chlorpyrifos (0.2 %) 43.25 cm (T₆). Other treatment also found significant in leaf area and its ranges from 34.47 to 42.45 cm. All the treatment were found significant over the inoculated control 30.43 cm (T₁₁).

d. No. of tillers

The significant effect was seen among different treatments on the number of tillers per clump, and found that the T₄- rhizome treated with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the number of tillers/clump (10.66) followed by T₅-soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) showed 9.83 tillers/clump, other treatment were also found significant in the production of number of tillers/clump and it ranged from

7 to 9.02. All the treatments were found significant over the inoculated control (T₁₁) which recorded 4.08 tillers/clump (Table 11).

4.4.3 Effect of different treatments on the yield parameters of turmeric

Effect of different treatments on yield parameters *viz.*, number of primary and secondary rhizome and total fresh rhizome yield were recorded and the data are presented in table 12.

a. No. of primary rhizome

Among the different treatments, T₄- the rhizome treated with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the number of primary rhizomes (17.00/ plant) followed by T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) and T₉-soil application of Bordeaux mixture (1%). Both of this treatment showed 15.33 number of primary rhizomes per plant. Other treatments were also found significant in the number of primary rhizome per plant and it ranged from 10 to 13.00 in number. All the treatments were found significant over the control inoculated (T₁₁) which recorded 5.16 primary rhizomes per plant, where as the un-inoculated control plants (T₁₂) showed better number of primary rhizome of 14.16 per plant and it was almost on par with the treatment T₆- soil application of Streptocyclin (0.05 %) + COC (0.3 %) + Chlorpyrifos (0.2 %).

b. No. of secondary rhizome

Highly significant effect of different treatments on number of secondary rhizome was noticed and it was found that the T₄- rhizome treated with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) and T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) showed significant increased in the number of secondary rhizomes 13.00 and 12.50 per plant, respectively. Later followed by T₉- soil application of Bordeaux mixture (1%) recorded 12.00 rhizome per plant, other treatments were also found significant in the number of secondary rhizome per plant and it ranged between 10.33 to 8.33 as compared to inoculated control T₁₁ (7.00 rhizomes /plant).

c. Total fresh rhizome yield (g/plant)

Rhizome treatment with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg) showed significant increase in the fresh rhizome yield per plant (672.97 g) followed by soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3%) which yielded 644.51 g/plant. Other treatments were also found significant with respect to the rhizome yield and it ranged from 604.14 to 551.49 g/plant over the inoculated control (T₁₁) which yielded 441.89 g/plant (Fig. 6). These treatments also recorded 52.29 and 45.85 per cent yield increased and it is highly significant over control.

Table 12. Effect of different treatments on yield parameters

Treatment No.	Treatment details	No of primary rhizomes per plant	No of secondary rhizomes per plant	Total fresh rhizome yield per plant (g)	yield increase over control (%)
T ₁	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) seed and soil application of <i>T. harzianum</i> (10g/Kg) + Neem cake (10g/Kg of soil)	11.16 ^{de}	9.16 ^{bcd}	586.82 ^f	32.79
T ₂	Hot water treatment with rhizome at 51 ^o C for 10 minutes and soil application of <i>T. harzianum</i> (10g / Kg soil) + Neem cake (10g/Kg of soil)	10.00 ^e	8.33 ^{cd}	559.47 ^g	26.60
T ₃	Rhizome treatment with <i>T. harzianum</i> (5g/Kg) + <i>Pseudomonas fluorescens</i> (5g/Kg) and soil application of <i>T. harzianum</i> (10g/Kg) + <i>P. fluorescens</i> (10g/Kg)	10.00 ^e	8.33 ^{cd}	551.49 ^h	24.80
T ₄	Rhizome treatment with Metalaxyl-MZ (0.3 %) and soil application of <i>T. harzianum</i> (10g/Kg)	17.00 ^a	13.00 ^a	672.97 ^a	52.29
T ₅	Soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %)	15.33 ^{ab}	12.50 ^a	644.51 ^b	45.85
T ₆	Soil application of Streptocyclin (0.05 %) + COC (0.3%) + Chloropyriphos (0.2 %)	14.00 ^{bc}	11.00 ^{abc}	604.14 ^d	36.71
T ₇	Soil application of Captan (0.3 %) + Chloropyriphos (0.2 %)	12.16 ^{cde}	10.33 ^{abc}	592.543 ^e	34.09
T ₈	Metalaxyl -MZ (0.3 %) + Chloropyriphos (0.2 %)	14.16 ^{bc}	11.00 ^{abc}	607.05 ^d	37.37
T ₉	Soil application of Bordeaux mixture (1%)	15.33 ^{ab}	12.00 ^{ab}	635.22 ^c	43.75
T ₁₀	Soil application of Metalaxyl - MZ (0.3 %)	13.00 ^{bcd}	10.50 ^{abc}	604.88 ^d	36.88
T ₁₁	Control inoculated	5.16 ^f	7.00 ^d	441.89 ^j	-
T ₁₂	Control un-inoculated	14.16 ^{bc}	11.00 ^{abc}	516.38 ⁱ	-
	CD(0.05)	2.48	3.01	3.41	-
	S.Em±	9.60	11.4	11.92	-

Figures followed by the same letter did not differ significantly

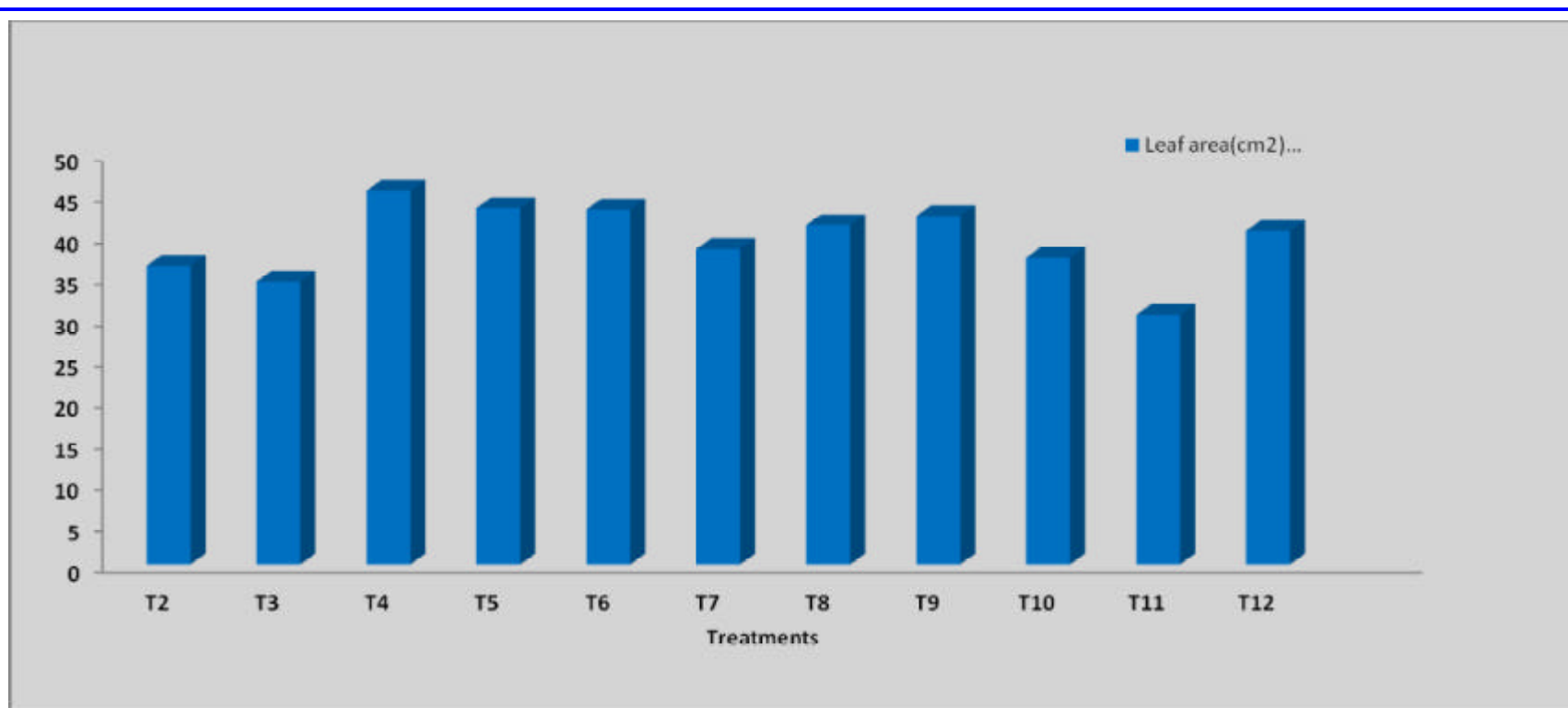


Fig. 6: Effect of different treatments on fresh rhizome yield of turmeric

- T₁- Seed treatment with *Trichoderme harzianum* seed and soil application of *T. harzium* + Neem cake
- T₂- Treatment of rhizome with hot water at 51 °C for 10 minutes and soil application of *T. harzianum* + Neem cake
- T₃- Seed treatment with *T. harzianum* + *Pseudomonas fluorescens* (5 g/Kg) and soil application of *T. harzianum* + *P. fluorescens*
- T₄- Seed treatment with Metalaxyl-MZ (0.3 %) and soil application of *T. harzianum*
- T₅- Soil application of Streptocyclin (0.05 %) +Copper Oxy Chloride (0.3%)
- T₆- Soil application of Streptocyclin (0.05 %)+COC (0.3 %) + Chloropyrifos (0.2%)
- T₇- Soil application of Capton (0.3 %)+ Chloropyrifos 20 EC (0.2%)
- T₈- Metalaxyl -MZ @ (0.3 %)+ Chloropyrifos 20 EC(0.2%)
- T₉- Soil application of Bordeaux mixture (1 %)
- T₁₀- Soil application of Metalaxyl - MZ (0.3 %) alone
- T₁₁- Control inoculated
- T₁₂- Controlun-inoculated

5. DISCUSSION

India is considered as 'land of spices'. India enjoys from time immemorial a unique position in the production and export of turmeric. Turmeric is cultivated for its underground rhizome used in many ways. One of the major constraints for growing this crop is the rhizome rot disease. Although important foliar diseases do exist in this crop, but rhizome rot is very important in view of severe crop losses and also losses affecting quality of rhizomes. It occurs in several parts of India wherever this crop is grown. It is caused by multitude of pathogens either alone or in combination and distributed worldwide, wherever turmeric cultivation is taken up intensively.

Rhizome rot as the name indicates results ultimately in rotting of rhizomes, which are economically important part of turmeric crop. The term rhizome rot is loosely used for all the diseases affecting the rhizome irrespective of the pathogens involved. Since the ultimate result is the partial or total loss of rhizomes, the pathogens involved decide the nature of the damage and symptoms expression. The major pathogens involved in rhizome rot are *viz.*, *Pythium* sp. causing soft rot, *Fusarium* sp. causing yellows or wilt and bacteria causing wilt and basal rot caused by *Sclerotium rolfsii* which appears later in the season. All these pathogens are known to increase the severity of the disease. Nematode *Meloidogyne* sp. is the major one. They predispose the crop to secondary pathogens. It is also coincidence that the pathogens involved in turmeric are almost similar to ginger crop.

Survey and surveillance helps to study the major disease prone in Belagavi and Bagalkote districts of Karnataka. The lack of information on etiology and management subjects of the disease made an important task to undertaken the present investigation carried out on serious aspects of etiology and management of rhizome rot turmeric.

In Karnataka, every year there is increase in acreage of turmeric cultivation but rhizome rot disease has become a major constraint and farmers gave up its cultivation. Hence there is an urgent need to educate the farmers for managing this disease.

5.1 Survey

To know the prevalence of rhizome rot disease incidence, a survey was conducted during 2015-2016 in major turmeric growing areas of North Karnataka (*viz.*, Belagavi and Bagalkote Dist.). In general, it was observed that, the disease progress under natural condition was in the month of June – August and reaches its severity during September to November which were coincide with heavy rains and cool weather. Survey data revealed that, rhizome rot incidence was noticed in all the locations surveyed with a range of 24.50 - 68.15 per cent. The maximum disease incidence was recorded in Belagavi district (24.50 - 68.15 %) followed by Bagalkote district (25.95 - 45.36 %) and highest mean per cent incidence was observed in Belagavi district (44.27 %) followed by Bagalkote (38.40 %). Similarly, Shalini *et al.* (2008) reported that, the rhizome rot incidence of 5.50 to 45.60 per cent had recorded in Southern Karnataka and noticed the initiation of the rhizome rot disease one month after planting and severity of the disease was reported during September to November.

The diseases incidence varied from one location to another location, because of cropping pattern, environmental condition and buildup of inoculums. The higher disease incidence may be attributed to heavy rains leading to improper drainage which favored the rhizome rot disease. Mono-cropping, improper drainage, non-adoption of disease management practices, unfavorable weather condition, unpredictable start of rainy season and also cultivation of diseased rhizome could be reasons for higher incidence in different locations of North Karnataka. Similar findings were also recorded by Anoop *et al.* (2014) in Tamil Nadu, reported that, the factors like land of poor physical characteristics could reduce productivity, imposes stress on the host plant and favors the activities of the pathogens. It was also observed that, rhizome rot incidence was more in poor drainage system. During the survey, it was observed that, wherever farmers had grown the turmeric without raised beds, the disease incidence was more because of improper drainage. Hence, adoption of adequate drainage system may help in managing rhizome rot disease. Similar observation was done by Mc Rac (1911) in Bangladesh, Butler (1918) Sharma and Dohroo (1982).

Crop loss depends on the stage of the crop growth at which infection starts. If it occurs early, results in off affected clumps, where, the crop loss is partial, if

affected at a later stage. This is agreement with Sarma (1994). In Kerala, losses due to this disease could be as high as 90 per cent during the years of heavy rains (Rajan and Agnihotri, 1989).

The plant showing symptoms of rhizome rot like yellowing and drying along the margins of the leaves, rotting of pseudo stem, root rot and rhizome rot, rotten part emits foul smell owing to decay. The similar descriptions of symptoms were given by Sarathi *et al.* (2014) ; Iyer (1987) and Sarma (1994). Visible bacterial ooze exuded from the cut surface of the affected rhizomes when dipped into water. The similar symptoms were also observed by Atsushi *et al.* (2015), Chauhan and Patel (1990) and Kelman (1954).

5.2 Etiology

A total of 34 samples collected from different locations were used for the isolation of organisms associated with rhizome rot disease of turmeric. *Pythium*, *Fusarium*, and *Sclerotium* spp. were the major fungal pathogens isolated from the infected samples. Among them, *Pythium* sp. dominated in majority of the diseased samples followed by *Fusarium* and *Sclerotium* sp. However, there were some samples which yielded a combination of these three organisms. Majority of the samples yielded combination of *Pythium* and *Fusarium* sp. followed by *Fusarium* and *Sclerotium* sp., *Pythium*, *Fusarium* and *Sclerotium* sp. and then followed by *Pythium* and *Sclerotium* sp., few samples recorded presence of *Meloidogyne* sp. with *Pythium* and *Fusarium* sp., *Pythium* and *Sclerotium* sp. and *Pythium* + *Fusarium* + *Sclerotium* sp. Another rot causing bacterium *Ralstonia solanacearum* was also one of the most important pathogen associated with all rotted samples, this can be confirmed by cross sectioning on affected rhizome produced white milky strand of bacterial cells in clear water. This ooze distinguishes the rot caused by the bacterium from that caused by fungal pathogens.

All most similar isolation frequency of three fungal pathogens *viz.*, *Pythium*, *Fusarium* and *Sclerotium* sp. was reported by Shalini (2006). The predominant occurrence of *Pythium* on turmeric rhizome rot affected sample was also noticed by Sarathi *et al.* (2014) and Anoop *et al.* (2014). There are several reports of simultaneous occurrence of fungal pathogens together and causing rhizome rot

disease complex (Bharadwaj *et al.*, 1988; Dake and Edison. 1989). Sundaraju *et al.* (1980) reported the synergetic interaction between *Pythium*, *Fusarium* and *Meloidogyne* sp. in causing rhizome rot disease. Similar findings were observed by Sarma *et al.* (1974) reported that nematode-fungal complex could induce the rhizome rot disease in turmeric. Root knot infestation in turmeric was noticed in Telangana area where rhizome rot incidence was severe (Sarma, 1994). The bacterium *R. solanacearum* was also one of the most important pathogen associated with turmeric rhizome rot. It was also recorded by Atsushi *et al.* (2015) ; Kumar *et al.* (2014) ; Yano *et al.* (2005) ; Kelman (1954) ; Morita *et al.* (1996) ; Tsuchiya *et al.* (1999).

Morphological character of predominant pathogen *P. aphanidermatum* was similar to the description made by Sarathi *et al.* (2014) on studying the rhizome rot of turmeric caused by *P. aphanidermatum*. The morphological characters of *Fusarium* sp. was observed and were all most similar to those described by Gerlach and Nirenberg (1982). The pathogen *Scrotium rolfsii* was a fast growing fungus which produces branched snow white coloured *Sclerotia* at the periphery of the colony. The description of the fungus was similar to the description given by Aycock (1966).

Isolation of the bacterium was made from the turmeric plants showing typical symptoms of disease on TZC medium. The morphological characters were similar to the findings of Atsushi *et al.* (2015) and Kelman (1954) who isolated typical mucoid, irregular, white colonies with pink centres resembling those of *R. solanacearum* from diseased plants.

5.3 Pathogenicity

Pathogenicity tests for predominant pathogens *viz.*, *P. aphanidermatum* and *R. solanacearum* were carried out on turmeric. The symptoms were similar to that described in symptomatology.

When plant inoculated with *P. aphanidermatum* alone, exhibited symptoms within 28 days of inoculation and showed symptoms like lower most leaf exhibited yellowing, ultimately results in complete drying of all the leaves and finally rotting of the rhizome with the emission of foul smell. Similar findings were supported by Sarathi *et al.* (2014) and Anoop *et al.* (2014) in rhizome rot causing pathogen *P. aphanidermatum*

The bacterium *R. solanacearum* alone exhibited the symptoms 24 days after inoculation, showing yellowing of the older leaves from the tip towards midrib. Later rhizome become rotten and emits foul smell. The present investigation results were supported by the review of Shalini *et al.* (2006) and Lum (1973) who conducted a pathogenicity study on ginger inoculated with *R. solanacearum* and proved that, it caused early symptom and maximum disease incidence. Rajan *et al.* (2002) reported that inoculation of individual pathogens *viz.*, *P. aphanidermatum*, *F. solani* and *R. solanacearum* caused the maximum disease incidence in ginger. Atsushi (2015) conducted pathogenicity test and confirmed that the appearance of rhizome rot disease symptoms 15 days after inoculation with *R. solanacearum* on turmeric plants.

When simultaneous inoculation of *P. aphanidermatum* and *R. solanacearum* exhibited early rhizome rot symptoms recorded within 21 days with maximum disease incidence compared to individual pathogens inoculated. Similar findings were supported by the review of Shalini *et al.* (2006). Similarly, Chauhan and Patel (1990) reported that independent spp. are pathogenic in independent inoculations. But combine infection resulted in rapid drying of the shoot followed by rhizome rot.

5.4 Management

All the treatments against rhizome rot showed significant decrease in disease incidence and increase in yield when compared to inoculated control. Among the different treatments tested, highest per cent disease reduction over the control was found in T4- rhizome treatment with Metalaxyl- MZ (0.3 %) and soil application of *T. harzianum* (10 g/kg soil) followed by T₅- soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride (0.3 %) and T₉- soil application of Bordeaux mixture (1 %). Rest of the treatment also found effective in the reduction of the disease over the control. In addition to the suppression of diseases, these treatments greatly induced plant growth parameters as well as yield parameters. The use of fungicides in combination with biocontrol agents has become an inevitable method in the management of plant disease particularly in turmeric in the absence of availability of resistant varieties for rhizome rot. Rhizome treatment along with soil application of fungicides and biocontrol agents, gives maximum protection against rhizome borne disease, which was spread through rhizome and also through soil.

Integration of fungicides with biocontrol agents is a step for improving the efficacy of biocontrol agents. The compatibility of antagonist *T. harzianum* with Metalaxyl- MZ and copper oxy chloride was tested by Sagar (2006) and found they both have synergistic effect and fully compatible with *T. harzianum* with a minimum effect on mycelia growth at both concentration of 0.025 and 0.05 per cent followed by Mancozeb.

Integration of the best components of the disease management have given an encouraging results. The disease could be managed effectively by incorporating fungicides, biocontrol agents and organic amendments. Keeping this in mind, we used *T. harzianum* and *P. fluorescens* with the fungicide like Copper Oxy Chloride, Metalaxyl- MZ and Captan. These antagonistic micro-organisms were multiplied in large scale and applied to rhizome or soil. Seed treatment reduced the quantity of inoculums required for causing disease.

Similarly Reddy *et al.* (2003) reported that, the combination of *Trichoderma* + Metalaxyl- MZ was more effective in suppressing the rhizome rot as compared to individual inoculation of *Trichoderma* or Ridomil alone. Jayasheker *et al.* (2000) reported that, seed treatment and soil application of Metalaxyl-MZ (0.1 %) at 45 and 90 DAP recorded the lowest disease incidence 4.23 per cent followed by Bordeaux mixture (1 %). Sagar (2006) reported that, among the different treatments for managing rhizome rot of turmeric results that, combined application of Metalaxyl-MZ (Rhizome treatment @ 0.3 %), *T. harzianum* (rhizome treatment @ 10g /kg rhizome) and soil application of neem cake (2 %) reduced the disease incidence, increased rhizome germination and yield. Integration of soil application of biocontrol agents with fungicidal rhizome treatment (Bavistin + Ridomil- MZ) increased the efficiency of disease control as compared to their individual treatments. Soil application of *T. harzianum* and rhizome treatment with *P. fluorescens* and fungicides were the most effective among all the tested treatments (Ram *et al.*, 1999). Das *et al.* (1990) reported that, Ridomil-MZ 72 (0.2 %) effectively reduced the disease with only 18.63 per cent disease incidence and also showed maximum germination of rhizome as well as the highest yield and followed by Copper Oxy Chloride (0.3 %), Bordeaux mixture (1 %) Mancozeb (0.25 %) Captan (0.25 %). Up to hundred per cent control of *Pythium* damping off of sugar beet was obtained when soil application of *T.*

harzianum at low concentration was integrated with seed treatment with Metalaxyl-MZ (Sawant and Mukhopadhyay, 1993). Kumar and Suryanarayana (2011) reported that before planting dipping of rhizome in Streptocycline (0.05 %) + Copper Oxy Chloride (0.2 %) solution for 20 minutes and post sowing soil drench with Bleaching powder (0.2 %) and Metalaxyl- MZ (0.1 %) thrice at 20 days intervals from disease inception found very effective in reducing the disease to the maximum extent (2.79 %) compared PDI in control (51.63 %). The same treatment showed the highest rhizome yield (172.75 q/ha) compared to control (58.75 q/ha).

6. SUMMARY AND CONCLUSIONS

Turmeric (*Curcuma longa* L.) is an important rhizomatous spice crop being cultivated in India since ancient times for its rhizomes, and has a potential to earn foreign exchange because of its wide utilization in Ayurvedic industry. Rhizome rot disease complex has been identified to be a major constraint for turmeric production. It occurs in several parts of India wherever this crop is grown. It is caused by multitude of pathogens either alone or in combination and distributed worldwide, wherever turmeric cultivation is taken up intensively. Although important foliar diseases do exist in these crop, but rhizome rot is very important in view of severe crop losses and also losses affecting quality of rhizomes.

Roving survey from different locations in major turmeric growing regions of North Karnataka (*viz.*, Belagavi and Bagalkote districts) revealed rhizome rot disease of turmeric was noticed in all the villages with the range from 24.50 to 68.15 per cent. The maximum disease incidence of 68.15 per cent was noticed in Belagavi district and 45.36 per cent in Bagalkote district.

Turmeric rhizome rot disease is characterized by yellowing and marginal drying of the leaves, rotting of pseudo stem, root and rhizome rot are the important symptoms.

Isolation of pathogens from affected samples revealed that, presence of *Pythium*, *Fusarium*, and *Sclerotium* sp. were the major fungal pathogens associated with infected samples. Among them *Pythium* sp. dominated in majority of the diseased samples followed by *Fusarium* and *Sclerotium* sp. And all the samples showed the presence of bacterium *R. solanacearum*. Along with these pathogens infection, some samples also recorded the aggregation of *Meloidogyne* sp.

Pathogenicity test confirmed that, artificial inoculation of major pathogens causing rhizome rot diseases *viz.*, *P. aphanidermatum* and *R. solanacearum* cause rhizome infection when inoculation was done with individual pathogens alone and simultaneous inoculation of both pathogens induces early and higher disease incidence when compared to the individual pathogen.

Among different treatments, significant reduction in the disease incidence was recorded in the seed treatment with Metalaxyl-MZ @ 0.3 per cent and soil application of *T. harzianum* (10 g/kg of soil) recorded least disease incidence (6.71 %) followed by soil application of Streptocyclin (0.05 %) + Copper Oxy Chloride @ 0.3 per cent (8.75 %) when compared to control (72.68 %) at 240 DAP.

Future line of work

There is no full stop to gain insight into scientific knowledge. Any amount of work does not satisfy the hunger of scientists. As problems creep in, new ideas will continue to flow and this is not an exception. The present investigation has produced new information pertaining to the survey, etiology and management of rhizome rot disease of turmeric. The investigation has given way to new ideas on turmeric rhizome rot. Hence the following future line of work has been suggested.

1. Development of specific probes (molecular and immunological) for detection of pathogens causing rhizome rot disease of turmeric.
2. Screening of resistant varieties against rhizome rot disease.
3. Development of suitable epidemiological models and their utilization in rhizome rot disease and their management.
4. Sequential inoculation studies of pathogens associated with the rhizome rot disease.
5. Production of disease free seed material, through tissue culture technique would be ideal.
6. The pot culture experiment should be investigated at field level.
7. Evaluation of defense mechanism against rhizome rot causing pathogens.

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STUDIES ON RHIZOME ROT COMPLEX OF TURMERIC (*Curcuma longa* L.)

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ABSTRACT

Turmeric (*Curcuma longa* L.) is one of the important spice crops grown in India since times immemorial. The major constraint for cultivation of turmeric is the rhizome rot disease complex. Roving survey was conducted during 2015 - 2016 in Belagavi and Bagalkote districts to assess the rhizome rot disease incidence in the farmer's field. Among the 26 villages surveyed in Belagavi district, the highest disease incidence was recorded in Pamaladinni village (68.15 %) followed by Kallolli (52.05 %). While, the least per cent disease incidence was noticed in Shindikurbet village (24.50 %). In Bagalkote district, the highest disease incidence was noticed in Dhawaleswar (45.36 %) followed by Sanganatti (42.35 %) and the least per cent disease incidence was noticed in Madabhavi (25.95%). The survey results of 2015-16 showed that the highest mean per cent disease incidence was observed in Belagavi district (44.27 %) followed by Bagalkote (38.40 %).

The analysis of rhizome rot samples collected during the survey revealed that *Pythium* (88.23 %), *Fusarium* (61.76 %) and *Sclerotium* sp. (35.29 %) were found to be involved in causing the rhizome rot of turmeric. Some samples yielded combination of these three pathogens. Few samples associated with root knot nematode *Meloidogyne* sp. (26.47 %) and all the samples were infected with bacterium *Ralstonia solanacearum*.

A pot experiment was carried out for managing rhizome rot disease. Among twelve different treatments, significant reduction in the disease incidence was recorded in the seed treatment with Metalaxyl-MZ (0.3 %) and soil application of *Trichoderma harzianum* (10 g/Kg of soil) recorded least disease incidence (6.71 %) followed by soil application of Streptocycline (0.05 %) + Copper Oxy Chloride (0.3 %) recorded 8.75 per cent when compared to control (72.68 %) at 240 DAP.

