SURVEY, ETIOLOGY AND MANAGEMENT OF GINGER (*Zingiber officinale* Rosc.) RHIZOME ROT COMPLEX

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PAL 0069

DEPARTMENT OF PLANT PATHOLOGY

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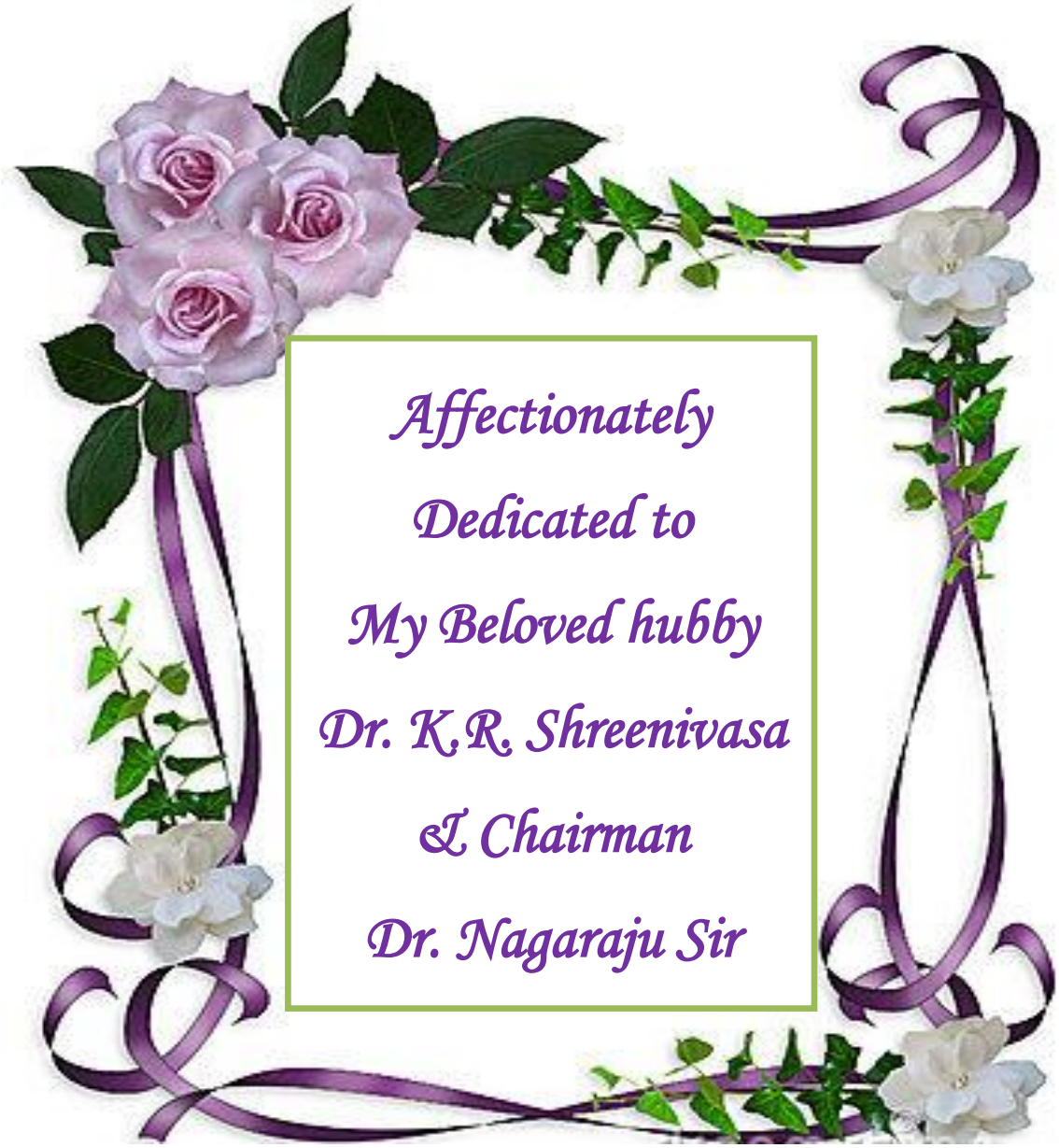
for the award of the Degree of

DOCTOR OF PHILOSOPHY

IN

PLANT PATHOLOGY

BANGALORE **JULY, 2013**


Affectionately
Dedicated to
My Beloved hubby
Dr. K.R. Shreenivasa
& Chairman
Dr. Nagaraju Sir

DEPARTMENT OF PLANT PATHOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE

CERTIFICATE

This is to certify that, the thesis entitled **"SURVEY, ETIOLOGY AND MANAGEMENT OF GINGER (*Zingiber officinale* Rosc.) RHIZOME ROT COMPLEX"** submitted by **Mrs. REKHA, D., ID No. PAL 0069** in the partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **PLANT PATHOLOGY** to the University of Agricultural Sciences, Bangalore is a record of research work carried out by her during the period of her study in this University, under my guidance and supervision, and the thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles.

BANGALORE
5th JULY, 2013

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SURVEY, ETIOLOGY AND MANAGEMENT OF GINGER (*Zingiber officinale* Rosc.) RHIZOME ROT COMPLEX

REKHA, D.

Ph. D THESIS ABSTRACT

Rhizome rot complex was the major constraint of ginger production. In malnad districts incidence was ranged from 3.5 per cent at N.R. pura to 56.00 per cent at Anavatti. The maximum incidence of 28.16 per cent was recorded in Uttara Kannada and least in Hassan (15.20%). Banavasi and Korlakotta of Uttara Kannada, Sevalal nagar, Hirekasvi, Rippanpet of Shimoga and Makod village of Chikkmagalore district were found to be endemic. Soil physicochemical parameters like pH, OC and N-content had significant negative correlation with rhizome rot incidence. *Ralstonia solanacearum* was the most predominant pathogen in malnad districts followed by *F. oxysporum, P. aphanidermatum* and *S. rolfsii.* Both individually and/or in combination of pathogens could cause rhizome rot complex. Foliar yellowing, stunted growth, wilting and drying of whole plant were the common symptoms observed irrespective of the pathogens involved. *R. solanacearum* was capable of inducing the symptoms at the earliest at all the stages of crop growth but *F. oxysporum* took longer time. *P. aphanidermatum* was potential pathogen at early stages of crop growth. *F. oxysporum* alone could induce disease in 25 days and *S. rolfsii* in 20 days after of inoculation in all the stages of ginger growth. Combined inoculation of pathogens caused more severe disease symptoms. Planting in March significantly showed less disease incidence (11.66 %) with higher yield (37.50 kg/plot). Humnabad local variety was moderately resistant to disease. Rhizomes treatment with 0.2% Curzate M8 + Streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens* and *Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha+One drench with 0.2% Curzate M8 immediately at the onset of the disease was found effective in reducing disease incidence (4.56 %) with increasing germination, tillers, plant height, yield and B: C ratio (15.61).

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(Major Advisor)

ಶುಂಠಿ ಗೆಡ್ಡೆಕೊಳೆ ರೋಗ ಸಂಕೀರ್ಣದ ಸಮೀಕ್ಷೆ, ರೋಗ ಮೂಲಶಾಸ್ತ್ರ ಮತ್ತು ನಿರ್ವಹಣೆ

ರೇಖಾ ಡಿ.

ಡಾಕ್ಟೊರೇಟ್ ಪ್ರಬಂಧ ಸಾರಾಂಶ

ಮಲೆನಾಡು ಜಿಲ್ಲೆಗಳಲ್ಲಿ ಶುಂಠಿ ಉತ್ಪಾದನೆಗೆ ಶುಂಠಿ ಕೊಳೆರೋಗ ಸಂಕೀರ್ಣ ಪ್ರಮುಖ ಸಮಸ್ಯೆಯಾಗಿದೆ. ಸಮೀಕ್ಷೆ ಕೈಗೊಂಡ ಪ್ರದೇಶಗಳಲ್ಲಿ ಕೊಳೆರೋಗದ ತೀವ್ರತೆಯು ಎನ್.ಆರ್.ಪುರದಲ್ಲಿ ಶೇ. 3.5 ರಿಂದ ಶೇ. 50 ರಷ್ಟು ಆನವಟ್ಟಿಯಲ್ಲಿ ದಾಖಲಾಗಿರುತ್ತದೆ. ರೋಗದ ತೀವ್ರತೆಯು ಅತ್ಯಧಿಕವಾಗಿ ಉತ್ತರ ಕನ್ನಡ ಜಿಲ್ಲೆಯಲ್ಲಿ (28.16%) ಮತ್ತು ಅತಿಕಡಿಮೆ ಹಾಸನದಲ್ಲಿ ಅಂದರೆ ಶೇ. 15.02% ರಷ್ಟು ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಉತ್ತರ ಕನ್ನಡ ಜಿಲ್ಲೆಯ ಬನವಾಸಿ, ಕೊರಲಕೊಟ್ಟ; ಶಿವಮೊಗ್ಗ ಜಿಲ್ಲೆಯ ಸೇವಾಲಾಲ್ ನಗರ, ಹಿರೇಕಸವಿ ಮತ್ತು ರಿಪ್ಪನ್‌ಪೇಟೆ ಹಾಗೂ ಚಿಕ್ಕಮಗಳೂರು ಜಿಲ್ಲೆಯ ಮಾಕೋಡು ಗ್ರಾಮಗಳು ಹೆಚ್ಚು ರೋಗಕ್ಕೆ ಒಳಗಾದ ಪ್ರದೇಶಗಳಾಗಿವೆ. ಕೊಳೆರೋಗದ ತೀವ್ರತೆಗೆ ಮಣ್ಣಿನ ಭೌತಿಕ ಹಾಗೂ ರಾಸಾಯನಿಕ ಅಂಶಗಳಾದ ರಸಸಾರ, ಸಾವಯವ ಇಂಗಾಲ ಮತ್ತು ಸಾರಜನಕದ ಪ್ರಮಾಣ ಋಣಾತ್ಮಕ ಸಂಬಂಧ ಹೊಂದಿರುತ್ತವೆ. ಮಲೆನಾಡು ಜಿಲ್ಲೆಗಳಲ್ಲಿ *ರಾಲ್‌ಸ್ಟೋನಿಯಾ ಸೋಲನೇಸಿಯಾರಂ* ಪ್ರಮುಖ ರೋಗಕಾರಕವಾಗಿದ್ದು, ನಂತರ ಪಿಥಿಯಂ ಅಫ್ಯೇನಿಡರ್‌ಮ್ಯಾಟಮ್, ಸ್ಕ್ಲೀರೋಷಿಯಂ ರಾಲ್ಫಸೈ ಗಳಾಗಿವೆ. ಶುಂಠಿ ಗಿಡಗಳಲ್ಲಿ ಯಾವುದೇ ರೋಗಕಾರಕಗಳು ಬಾಧಿಸಿದರೂ ಎಲೆಗಳ ಹಳದಿಯಾಗುವಿಕೆ, ಗಿಡಗಳ ಕುಂಠಿತ ಬೆಳವಣಿಗೆ, ಸೊರಗುವಿಕೆ ಮತ್ತು ಗಿಡಗಳ ಒಣಗುವಿಕೆಯು ಸಾಮಾನ್ಯ ಲಕ್ಷಣಗಳಾಗಿವೆ. ಶುಂಠಿ ಗೆಡ್ಡೆಕೊಳೆ ಉಂಟುಮಾಡುವ ರೋಗಕಾರಕಗಳನ್ನು ವೈಯಕ್ತಿಕವಾಗಿ ಹಾಗೂ ಸಂಕೀರ್ಣವಾಗಿ ವಿವಿಧ ಹಂತಗಳಲ್ಲಿ ಅಧ್ಯಯನ ಮಾಡಿದಾಗ *ರಾಲ್‌ಸ್ಟೋನಿಯಾ ಸೋಲನೇಸಿಯಾರಂ* ರೋಗಾಣುವು ಬೆಳೆಯಲ್ಲಿ ಶೀಘ್ರವಾಗಿ ರೋಗ ಲಕ್ಷಣಗಳನ್ನು ತೋರಿಸಿದರೆ ಫ್ಯೂಸೇರಿಯಂ ಆಕ್ಸಿಸ್ಪೋರಂ ರೋಗ ಲಕ್ಷಣ ತೋರಿಸಲು ಹೆಚ್ಚು ಸಮಯ ತೆಗೆದುಕೊಂಡಿತು. ಪಿಥಿಯಂ ಅಫ್ಯೇನಿಡರ್‌ಮ್ಯಾಟಮ್ ರೋಗಾಣು ಬೆಳೆಯ ಪ್ರಾರಂಭಿಕ ಹಂತದಲ್ಲಿ ಹೆಚ್ಚು ಸಂಭಾವ್ಯ ರೋಗಾಣುವಾಗಿತ್ತು ಮತ್ತು ಬಿತ್ತಿದ 105 ಮತ್ತು 135 ದಿನಗಳ ನಂತರ ಇದರ ತೀವ್ರತೆ ಕಡಿಮೆಯಾಗಿರುತ್ತದೆ. ಆದರೆ ಫ್ಯೂಸೇರಿಯಂ ಆಕ್ಸಿಸ್ಪೋರಂ ಬಳಸಿದ ಸಸ್ಯಗಳು ಸುಮಾರು 25 ದಿನಗಳ ನಂತರ ರೋಗದ ಲಕ್ಷಣಗಳನ್ನು ಪ್ರದರ್ಶಿಸಿದವು ಮತ್ತು ಸ್ಕ್ಲೀರೋಷಿಯಂ ರಾಲ್ಫಸೈ ರೋಗಾಣುವನ್ನು ಪ್ರತ್ಯೇಕವಾಗಿ ಬಳಸಿದ ಗಿಡಗಳಲ್ಲಿ ಬಿತ್ತಿದ 20 ದಿನಗಳ ನಂತರ ಎಲ್ಲಾ ಹಂತಗಳಲ್ಲಿ ರೋಗ ಲಕ್ಷಣ ಪ್ರದರ್ಶಿಸಿದವು. ಮಾರ್ಚ್ ತಿಂಗಳಲ್ಲಿ ಬಿತ್ತನೆಯಾದಲ್ಲಿ ರೋಗದ ತೀವ್ರತೆ ಅತೀ ಕಡಿಮೆ (11.66%) ಮತ್ತು ಹೆಚ್ಚು ಇಳುವರಿ (37.50 ಕೆ.ಜಿ/ತಾಕು) ಕಂಡು ಬಂದಿರುತ್ತದೆ. ಶುಂಠಿಯ ಹುಮ್ನಾಬಾದ್ ಲೊಕಲ್ ಸ್ಥಳೀಯ ಸಾಧಾರಣ ರೋಗ ನಿರೋಧಕತೆ ಹೊಂದಿರುತ್ತದೆ. ಶುಂಠಿ ಗೆಡ್ಡೆಗಳನ್ನು ಶೇ. 0.2 ರ ಕರ್ಜೆಟ್ ಮತ್ತು ಶೇ. 0.05 ರ ಸ್ಟ್ರೆಪ್ಟೋಸೈಕ್ಲಿನ್ ದ್ರಾವಣದಲ್ಲಿ 30 ನಿಮಿಷ + ಹೆಕ್ಟೇರಿಗೆ 5 ಕ್ವಿ. ಬೇವಿನ ಹಿಂಡಿ + ಹೆಕ್ಟೇರಿಗೆ 10 ಕೆ.ಜಿ. ಸುಡೋಮೊನಾಸ್ ಪ್ಲೋರೊಸೆನ್ಸ್ ಮತ್ತು 10 ಕೆ.ಜಿ. ಟ್ರೈಕೋಡರ್ಮಾವಿರೀಡೆಯನ್ನು 25 ಟನ್ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರದಲ್ಲಿ ಮಿಶ್ರಣ ಮಾಡಿ ಮಣ್ಣಿಗೆ ಹಾಕುವುದರಿಂದ + ರೋಗದ ಮೊದಲ ಲಕ್ಷಣ ಕಂಡಾಗ ಶೇ. 0.2 ರ ಕರ್ಜೆಟ್ ದ್ರಾವಣವನ್ನು ರೋಗ ಬಾಧಿತ ಗಿಡಗಳಿಗೆ ಹಾಕುವುದರಿಂದ ಶುಂಠಿ ಕೊಳೆರೋಗಕ್ಕೆ ಕಾರಣವಾದ ರೋಗಕಾರಕಗಳನ್ನು ನಿರ್ವಹಿಸುವುದರ ಜೊತೆ ಹೆಚ್ಚು ಶುಂಠಿಯ ಮೊಳೆಯುವಿಕೆ, ಸಸಿಗಳ ಕವಲೊಡೆಯುವಿಕೆ, ಗಿಡದ ಎತ್ತರ, ಇಳುವರಿ ಮತ್ತು ಆದಾಯ:ಖರ್ಚು(15.61) ಅನುಪಾತ ಹೆಚ್ಚಿಸಬಹುದಾಗಿದೆ.

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ಡಾ. ನಾಗರಾಜು
(ಮುಖ್ಯ ಸಲಹೆಗಾರರು)

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Introduction

I. INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) is an important crop grown for its aromatic rhizomes, used both as spice and medicine. It is an herbaceous tropical perennial belonging to the family Zingiberaceae. The rhizomes are white to yellowish brown in colour. It is usually grown as an annual. The whole plant is refreshingly aromatic, but it is the underground rhizome (raw or processed) which is valued as spice. Its medicinal value is increasingly being recognized nowadays.

Ginger originated in South- East Asia, probably in India (Burkill, 1966, Purseglove *et al.*, 1981). The refreshing pleasant aroma, biting taste and carminative property of ginger make it an indispensable ingredient of food processing throughout the world. Fresh ginger, ginger powder from dry ginger, oleoresin and oil are used for food processing. Fresh ginger is unique for its flowery flavour and spicy taste. It is also used in jams and marmalades. The syrup in which ginger is preserved is valued for pickle and sauce making (Pruthi, 1993).

The total production of ginger in the world amounts to 1683.00 thousand tons with the total acreage of 310.43 thousand ha (Anon., 2012). China, India, Nepal, Thailand, Nigeria, Indonesia, Bangladesh and Philippines are the major producers of ginger in the world, India and Indonesia have the largest area under cultivation. Among them, India and China are the dominant suppliers to the world market.

In India, ginger is cultivated in an area of 1,49,100 ha with the production of 702 MT and productivity of 4.7MT/ha during 2010-11. At present, India is the second largest producer of ginger in the world accounting for about one-fourth of the total world output (Anon., 2012). In India, a large portion of the ginger produced is consumed domestically as green ginger or dried ginger. It is cultivated in many states, but major

producers are *viz.,* Meghalaya, Kerala, Arunachal Pradesh, Karnataka, Orissa, West Bengal and Mizoram. In Karnataka, the area under ginger is 49,614 ha, with a production of 4, 96,556 MT and productivity of 10.07 t/ha during 2010-11 (Anon., 2003). Hassan, Shimoga, Bidar, Uttara Kannada, Chikmagalur, Kodagu and Mysore are major ginger growing districts in Karnataka.

Improper seed selection, rhizome rot complex, leaf spot (*Phyllosticta zingiberi*), shoot borer *(Conogethes punctiferalis*), rhizome fly (*Colobata indica*), nematodes and poor storage techniques are the major production barriers observed in ginger cultivation. Among the major constraints of ginger production rhizome rot is very important in view of severe crop losses. It occurs in several parts of India wherever the crop is grown. The term rhizome rot is loosely used for all the diseases affecting the rhizome irrespective of pathogens involved, since the ultimate result is partial or total loss of rhizome. The pathogens involved decide the nature of damage and also symptoms expression. The major symptoms identified are the soft rot caused by *Pythium spp.,* yellows resulting in wet rot caused by *Fusarium spp*. and bacterial wilt caused by *Ralstonia solanacearum* (Smith) Yabuuchi.

Soft rot and yellows disease are generally found together in the same field affecting the same plant parts and their symptoms often get mixed up. Soft rot is caused mostly by *Pythium aphanidermatum* but other species, *P. deliense, P. myriotylum, P.pleroticum, P. vexans* and *P. ultimum* were also reported by many worker from different states (Sarma, 1994). Yellows disease is mostly caused by *Fusarium oxysporum* f. sp. *zingiberi.* Other reported species causing ginger yellows are *F. solani* and *F. equiseti* and *Sclerotium* sp. (Mathur Kusum 2000). Bacterial wilt is endemic in majority of the ginger growing areas *viz.*, Kerala, Sikkim and many other north-eastern regions of the country. Race I of biovar III of *Ralstonia solanacearum* will infect the ginger.

In India, rhizome rot of ginger has been reported from almost all the states. The disease reduced potential yields to a greater extent in field, storage and market and many losses of even more than fifty per cent (Joshi and Sharma, 1980). Ginger is one of the important commercial crops grown for cash by many farmers in malnad districts of Karnataka. For the past five years, the area of ginger is increasing and replacing major food crop i.e. rice because of its market value.

In Karnataka, ginger is planted in April-May immediately after the premonsoon showers. It starts sprouting in June and tillering continues until late in the season. High soil moisture and adequate temperature (25-30^{0}C) prevailing during this period is conducive for disease onset. 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).

Rhizome rot is a major constraint in malnad districts of Karnataka because of favourable weather conditions. The correct diagnosis of the disease in view of involvement of one or more pathogens is important to plan effective integrated management measures, which would be location specific. There is an urgent need of developing IDM strategy for the disease. Keeping these points in view, in the present investigation attempts were made to diagnose the cause and measures to manage the disease by integrated approach with the following objectives.

Objectives of Investigation:

1. Survey for the incidence of rhizome rot of ginger in malnad districts of Karnataka
2. Isolation and identification of pathogens and proving pathogenicity
3. Interaction studies of pathogens associated with rhizome rot complex
4. Management of rhizome rot complex of ginger under field conditions

Review of Literature

II. REVIEW OF LITERATURE

Rhizome rot complex is a major constraint in the production of ginger caused by a multitude of pathogens either alone or in combination and distributed worldwide. Rhizome rot as the name indicates results ultimately in rotting of rhizome, an economically important part of ginger. The following review summarizes present knowledge on the diseases such as pathogens and their interaction in disease development and various aspects of management.

2.1 Survey, isolation and identification of causal agent/ agents of rhizome rot

Rhizome rot is the most destructive disease of ginger in India. Butler (1918) reported that the disease incidence ranges from 20 per cent to a total loss. Mc Rae (1911) reported that, in Bangladesh reduction in yield varied from 10 to 15 per cent in low-lying fields and six per cent in upland fields. Moderate to severe incidence leading to crop loss of more than 50 to 80 per cent have been reported on account of this disease

The incidence of rhizome rot disease has reached 54.3 per cent in the fields in Bongdong, Korea Republic in 1987 (Yang *et al.*, 1988). Out of the 87 isolates from diseased seed ginger plants, 62.80 per cent was due to *Fusarium* sp. and 11.8 per cent due to *Pythium* sp. and of the 190 isolates from diseased plants, 65.8 per cent was with the *Pythium* sp. and 31.2 per cent *Fusarium* spp. The *Fusarium* isolates reported to be *F. oxysporum* and *F. solani* while the *Pythium* sp. was *P. zingiberis*. Symptoms of rhizome rot were recorded by inoculating growing plants with *F. oxysporum f. sp. zingiberi* and *P. zingiberis*. The *Fusarium* isolates caused yellowing, wilting and brightening of stems 20 days after inoculation, while *P. zingiberis* had caused collapse of the plant 6 days after inoculation.

In Kerala losses was as high as 90 per cent during years of heavy incidence (Rajan and Agnihotri, 1989). Dake and Edison (1989) reported that 19.8 per cent of rhizome rot of ginger was associated with *P. aphanidermatum.* Crop loss depends on the stage of crop growth at which infection starts. If it occurs early, total loss of affected clump results whereas, the crop loss was partial if affected at a later stages (Sarma, 1994).

A roving survey was conducted by Shalini (2006) during kharif 2003-05 to estimate rhizome rot incidence. Per cent disease incidence during kharif 2003-04 was 5.5 to 45.60. The maximum disease incidence of 23.70 per cent was recorded in Shimoga district followed by Kodagu (22.90%), Uttara Kannada (20.24 %), Chickmagalur (18.99%) and Bidar (13.81%) and she observed the disease throughout state.

Gogoi *et al*. (2008) surveyed three major ginger growing areas at Sadiya (Tinsukia district), Borpathar (Golaghat district) and Jorhat (Jorhat district) of Assam and Roying (Lower Dibang Valley district) of Arunachal Pradesh for rhizome rot disease of ginger. They confirmed the association of *Ralstonia solanacearum* and *Fusarium oxysporum f.sp. zingiberi* in Sadiya, *R. solanacearum* and *Pythium myriotylum* in Borpathar and Jorhat. Only *F. oxysporum* was found to be associated with ginger in Roying. In all the regions, prominent disease symptoms observed as yellow to golden yellow colour on the older leaves starting from the leaf margins, wilting and toppling of the plants apart from rotting of the rhizomes. Plant parasitic nematodes *viz*, *Helicotylenchus dihystera, Hoplolaimus indicus* and *Tylenchus sp*. were isolated from the rhizosphere soil of the infected plants.

Surveys undertaken during Kharif, 2003-04 and 2004-05 in ginger growing areas of Ranchi district by Savita *et al.,* (2009) recorded rhizome rot disease. Out of 135 isolations made from infected rhizomes, 67

samples yielded *Pythium* spp. 33 yielded *Fusarium* spp. and the remaining 35 yielded *Ralstonia solanacearum*. In case of pseudostem, 55 samples yielded *Pythium* spp. 22 *Fusarium spp.* and remaining 24 yielded *Ralstonia*. While from sick soils, 47 samples yielded *Pythium spp.*, 13 *Fusarium spp*. and 11 samples yielded *Ralstonia solanacearum.* The result indicated association of *Pythium, Fusarium and Ralstonia* with local variation in regard to dominance of *P. aphanidermatum* as compared to *F. oxysporum f. sp. zingiberi* and *R. solanacearum* in the region.

Effect of soil physico-chemical parameters on rhizome rot incidence

Kim *et al*. (1997) reported that pH range of 6.0-7.0 was found to be optimum for the growth of the *Pythium myriotylum*, the causal agent of rhizome rot of ginger. The lower rhizome rot incidence was found in Wanjoo area of Korea Republic where soil were more sandy, lower in pH and had less organic matter, P_2O_5 and exchangeable cation. Consistent relationships between disease severity and soil physio-chemical properties were not found (Kim *et al.*, 1996).

Soil from Eunhari in Korea suppressive to rhizome rot caused by *P. zingiberum* and *Fusarium oxysporum f. sp. zingiberi* had a higher clay content and lower pH than the conducive Eouri and Eunhari soil. The percentage of germination of *F. oxysporum f. sp. zingiberi* conidia was lowest on Eunhari soil and germ tube growth was inhibited to a greater extent than on the other two soils (Lee *et al.*, 1990).

In Fiji, the disease generally develops during hot, wet conditions in March and April, and often causes losses of more than 50% in seed crops. In Australia, the disease was observed for the first time during the wet summer of 2007-08, almost totally destroying the immature ginger crop in field and causing 8-30% losses in other fields. Measurements

taken when soils were saturated due to almost constant rainfall indicated that many plants died within 3 weeks of showing the first signs of yellowing, with the disease spreading down slopes at rates of up to 4.5 m/day. Pathogenicity tests indicated that the disease was caused by *P. myriotylum* and that the pathogen was capable of destroying ginger rhizomes in 1-2 weeks in saturated soils at temperatures of 26-30^{0}C (Stirling *et al.,* 2009*).*

A study conducted by Sharma *et al.*, (2010) to find out the relationship of physico-chemical properties (*viz.* organic carbon (OC), pH, electrical conductivity (EC), nitrogen(N), phosphorus(P) and potassium (K) content) of ginger growing soil with incidence of rhizome rot and wilt disease complex of ginger. Organic carbon content and pH of the ginger soil contributed significantly (93%) in the prediction of ginger rhizome rot and wilt disease complex incidence with negative correlation. Soil having weak acidic reaction with OC per cent greater than 2.25 was observed to have the lower average incidence of the disease.

Suppression of *P. aphanidermatum* when soil samples treated with organic matter like compost (Hadar and Mandelbaum, 1986), *P. ultimum in* cucumber plants by hard woodbark (Chen *et al.,* 1988), *P. ultimum in* cucumber plants by peat (Hardy and Sivasithamparan, 1991), *P. ultimum* root rot of cucumber and *Poinsetia* by Peats mixtures (Boehm and Hoitink, 1992), *P. graminicola* damping off and root rot of *creeping bentgras* by Composts from a variety of feed stocks of different ages (Craft and Nelson, 1996) were reported.

Suppression of *Fusarium oxysporum* f. sp. *conglutinans* by organic matter Hardwood bark (Trilla Gay *et al.*1986), *Fusarium oxysporum* f.sp. *lini* by Organic fraction of the municipal solid wastes (Serra-Wittling *et al.* 1996), *Fusarium oxysporum* f. sp *lycopersici* by Grape marc compost (GMC), Cork compost CC) (Borrero *et al.* 2004; Saadi *et al.*, 2010),

Fusarium oxysporum f.sp. *dianthus* by Grape marc compost, cork compost, olive oil husk + cotton gin trash + rice husk, Spent mushroom and peat (Borrero *et al.* 2009) were reported.

2.2 Pathogens causing rhizome rot of ginger

Ginger rhizome rot was a complex disease caused by many organisms *viz.*, *Pythium* (soft rot), *Fusarium* (Yellows/Wet rot) and wilt (*Ralstonia solanacearum).* Literatures relating to each are furnished below.

2.2.1 Soft rot

As many as nine species of *Pythium* were reported to be associated with the soft rot of ginger all over the world wherever ginger was cultivated intensively.

Several spp. of *Pythium* have been reported as causal agents of soft rot in different parts of the world. Six species were recorded in different parts of India. Among these, *P. aphanidermatum* and *P. myriotylum* were widely distributed, whereas, the other species restricted to certain pockets.

Middleton (1943) mentioned that turmeric was attacked by more than one species of *Pythium* including, *P. aphanidermatum* and *P. graminicolum*. *P. graminicolum* has been reported as the causal agent in erstwhile Madras state, South India (Ramakrishnan and Soumini, 1954). *P. myriotylum* from Assam (Rathaiah, 1982) and *Pythium* sp. from Kerala (Anon., 1975) have been reported as pathogens of rhizome rot of turmeric. Higher 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.

Table 1: Distribution of *Pythium* species causing soft rot of ginger

Sl. No.	Organism	Place	References
1	*Pythium aphanidermatum* (Edson)Fitzp.	Pusa (Bihar) Hyderabad (AP) Nagpur Madhya Pradesh Kerala Karnataka	Mitra and Subramanian (1928) Vaheduddin (1955) Sahare and Asthana (1962) Haware and Joshi (1974) Sarma *et al.*, (1979) Shalini (2006)
2	*Pythium butleri* Subram.	Ceylon South Kanara	Park (1934) Thomas (1938)
3	*Pythium deliense*	Madhya Pradesh	Haware and Joshi (1974)
4	*Pythium myriotylum* Drech.	Poona Bombay Kerala Taiwan Ceylon Assam, Karnataka, Kerala, Sikkim and Uttar Pradesh	Uppal (1940) Patel *et al.*, (1949) Dake and Edison (1989) Lin *et al.*, (1971) Park (1937) Kumar *et al.,* (2008)
5	*Pythium pleroticum*	Solan (Himachal Pradesh)	Dohroo and Sharma (1985)
6	*Pythium vexans* de Bary	Malabar-Wayanad (Kerala)	Ramakrishnan (1949)
7	*Pythium ultimum* Trow.	Himachal Pradesh	Dohroo (1987)
8	*Pythium zingiberum* Takahashi.	Osaka (Japan) Korea	Takahashi(1954)
9	*Pythium graminicolum* Subram.	Ceylon	Park (1935)

High soil moisture and adequate temperature (25-30^{0}C) prevailing during the period was conducive for disease onset (Sarma, 1994). Moreover, juvenile tissues of the host which *Pythium* prefers to infect was also readily available through soil water by means of zoospores, hyphal fragments etc. The disease was generally less in well-drained fields (Sarma, 1994). *Pythium aphanidermatum* was reported as the principal cause of rhizome rot of ginger in the field. *Aspergillus* sp., *Penicillium* sp. and *Rhizopus* sp. were involved in pre-germinated rot of seed rhizome.

Fungal species isolated from rhizome rot affected ginger were identified based on the cultural and morphological characteristics as *Pythium* species. Among this, 50 isolates were characterized and the species were identified as *P. myriotylum*, *P. graminicola*, *P. aphanidermatum*, *P. ultimum*, *P. vexans* and *P. pleroticum*. Pathogenicity studies showed that *P. myriotylum*, P. *vexans* and *P. aphanidermatum* were pathogenic to ginger. *P. monospernum, P. torulosum* did not show any symptoms in ginger plants. On artificial inoculation the plants showed symptoms of yellowing and rhizome rot 7-10 days after inoculation (Silymol Philip, 2005).

Cultural characters of *Pythium aphanidermatum*

The mycelium of *Pythium* species was colourless, sometimes lustrous and occasionally slightly yellowish due to abundant oospores or hyphal swelling or grayish–lilac (Van der Plaats- Niterink, 1981). Production of aerial mycelium was dependent on the medium used.

Morphological Characters

Description of morphological characters of different spp. of *Pythium* given in this review have been adopted from the monograph of the genus *Pythium* (Van der Plaats- Niterink, 1981). Colonies *of P. aphanidermatum* on corn meal agar with cottony aerial mycelium, on potato-carrot agar

with some loose aerial mycelium without a special pattern. Main hyphae upto 10µm wide. Sporangia consisting of terminal complexes of swollen hyphal branches of varying length and up to 20µm wide. Oogonia terminal, globose, smooth, 20-25µm diameter. Antheridia mostly intercalary, sometimes, broadly sac shaped, 10-14µm wide, 2 per oogonium, monoclinous or diclinous, wall 1-2 µm thick. Main hyphae upto 11µm wide, sporangia mostly not formed and zoospores very rarely produced. Hyphal swellings were globose, intercalary sometimes terminal 20-25µm diameter. Oogonia terminal, sometimes intercalary, globose, smooth walled, 20-24µm diameter, antheridia either 1 per oogonium, sac like, mostly monoclinous originating from immediately below the oogonium. Oospores single, globose 12-21 µm diameter. Wall often 2µm or more thick.

Survival of inoculum

Seed rhizome: *Pythium* species survive between crops on infected seed rhizome (Thomas, 1940). It was thought to occur as oospore in scale leaves. But nature of seed borne inoculum is not well understood (Sarma, 1994).

Soil: *Pythium* species were capable of surviving saprophyticaly on plant debris (Rajan and Singh, 1973). They were normal inhabitants of many soils. They produce oospores, the perennating structures of the fungi may reproduce on non-host crops and weeds. Saprophytic survival of the fungus in soil was influenced by environmental factors *viz*, soil temperatures, moisture and presence of other microbes. Severity of *Pythium* disease was more in areas where rainfall was high.

2.2.2 Yellows/Wet rot

Ginger yellows; a serious stem and rhizome rot was first described by Simmonds (1955) from Queensland. Later this disease was reported from Hawaii (Trujillo, 1963) and India (Haware and Joshi, 1973).

In Kerala, survey for disease incidence showed that out of 195 gardens visited, 8.84 per cent gave positive to *Fusarium* sp. (Dake and Edison, 1988, 1989). During 1984-87, about 40 per cent losses have been reported from Shillai, Rajgarh, Ronhat and Sirmur areas of Himachal Pradesh (Dohroo *et al.*, 1988). Ginger production of 1,27,000 tonnes as dry ginger from 52,460 ha in Himachal Pradesh dwindled to 850 tonnes from 2,360 ha during 1984-87 due to severe disease incidence (Venkataramani, 1989).

2.2.2.1 Symptomatology

The infected plants exihibit foliar yellowing which starts from the lower leaves and progress upwards (Trujillo, 1963). The affected plants wilt and dry up but do not fall on the ground in contrast to soft rot and bacterial wilt affected ginger where affected rhizomes become soft and watery. The pseudostem comes off from mother rhizome with a gentle pull. Affected rhizomes show a creamy discolouration of the vascular system and cortical rot. The infected plants appear stunted with root rot and affects rhizome formation.

Causal agent of yellows

Fusarium oxysporum f.sp. *zingiberi* Trujillo is the causal agent identified (Haware and Joshi, 1973). Independent infection by *Fusarium solani* (Martius) Saccardo in Karnataka (Kumar, 1977) and also combined infections of *F. solani* and *Pythium* spp. have been reported (Chauhan and Patel, 1990).

In Guntur and Cuddapah districts, repeated surveys during 1997-2000 indicated that the intensity of the rhizome rot of turmeric was high due to *F. solani* (Reddy *et al.*, 2001). The disease occurs in patches with plants exhibiting yellow symptoms surrounded by green plants. The disease was reported to soil and seed borne and secondary spread was through water. The infected but apparently normal rhizomes serve as the primary source of inoculum and chlamydospores serve as the perennating propagules (Sharma and Jain, 1978). Disease development was found favourable at a temperature range of 15-38^{0}C. The infection increased at optimum temperatures of 23-29^{0}C with a high relative humidity of 87-95 per cent and presence of thin film of water (Sharma and Jain, 1978). The infected soil also plays an important role in the spread of inoculum (Rana and Sharma, 2001).

Samples of ginger with rhizome rot symptoms yielded only fungal pathogens (*Pythium pleroticum, P. aphanidermatum, Fusarium equiseti and F. solani*), while plants with the wilt and rhizome rot complex were also infested by the rhizome fly (*Mimegralla coeruleifrons*) or infected by nematodes (*Meloidogyne incognita and Pratylenchus coffeae*) (Dohroo *et al.,* 1987). Disease incidence was much greater where the complex was present.

Isolation, microscopic and pathogenic examinations of the pathogen from rhizome wilt and rot infected ginger from the growing areas of Bundelkhand region *viz.*, Lalitpur, Baruasagar, Tikamgarh, Datia, Panna, Chattarpur and Pichore in Madhya Pradesh (Siddiqui and Kaushal, 2000). Based on the micropscopic observations of the micro and macroconidia of the inoculum, the species causing rhizome rot and wilt in ginger was identified as *Fusarium oxysporum f.sp. zingiberi*. In pathogenic tests, plants inoculated with the inoculum gradually showed wilt and rot symptoms. Out of the 7 isolates of *F. oxysporum f.sp.*

zingiberi, isolate No. 1 from Lalitpur and adjoining areas was the most infective, recording 36.50 per cent disease incidence.

2.2.3 Bacterial wilt

The disease was endemic in majority of the ginger growing areas *viz.*, Kerala, Sikkim and many other north-eastern regions of the country causing yield loss up to 100 per cent under disease conducive conditions (Mathew *et al.*, 1979; Dohroo, 1991). The disease was first reported from madras state (Thomas, 1941). Later, it was reported from Kerala (Sarma *et al.*, 1978), Bihar (Ojha *et al.*, 1986) and Himachal Pradesh (Dohroo, 1991). Sharma *et al.* (1978) identified that causal agent of bacterial wilt of ginger is *Ralstonia solanacearum.* (Smith) Yabuuchi, biotype III.

Pathogenic bacteria from rotten ginger rhizomes collected from Korean farms and markets included 15 *Pseudomonas* isolates, 11 identified as *P. solanacearum* and four as *P. marginalis*, and 25 isolates of *Erwinia carotovora subsp. carotovora*. The *Erwinia* disease was termed 'bacterial soft rot of ginger' and that caused by the *Pseudomonas* spp. 'bacterial rhizome rot of ginger' (Choi and Han, 1990).

Once disease incited, the spread would be fast and incidence was as high as 50- 60 per cent resulting in severe loss of affected clumps (Sarma, 1994).

Ginger crop suffers from several diseases among which bacterial wilt (*Ralstonia solanacearum*) was a serious problem in Kerala and North-Eastern region of the country especially in Sikkim and West Bengal (Sarma and Anandaraj, 2000). Two isolates of *Ralstonia solanacearum* from Kerala isolated from ginger were not able to utilize dulcitol and lactose. Hence, they were categorized into a new taxo group within the system and designated as biovar-3B for the first time in India (Chandrashekara *et al.,* 2012*)*.

Samuel and Mathew (1983) reported that the bacterial wilt incidence increases when the nematodes were present in the ginger soil. Mulya *et al.* (1990) found that in Indonesia, the race I of biovar III of *Pseudomonas solanacearum* is considered as the cause of ginger rhizome wilt.

Prasanna Kumar (2004) reported that the *Ralstonia solanacearum* isolates which were collected from different parts of Karnataka and India utilized all the sugars and alcohols except three isolates from Kerala *viz.*, KERT-I, KERG-I and KERG-2 isolated from tomato and two from ginger behaved differently and were unable to utilize dulcitol and lactose. Hence, a new taxonomic group at the sub species level within the biotype was created and these three isolates have been designated as biovar-IIIB.

2.2.3.1 Symptomatology

Sarma, (1994) reported that, Water-soaked patches or linear streaks on the collar region of the pseudostems. Later, leaves become flaccid with intense yellowish bronze color and droop. The leaves roll up and the whole plant dries. Pseudostems come off easily with a gentle pull. Milky bacterial exudate oozes out on pressing the rhizome gently.

Causal agent

Pseudomonas solanacearum (Smith) Smith, biotype III has been identified as the causal agent of the disease (Sarma *et al.,* 1978). The disease is typically seed and soil borne. Generally noticed during June - July and maximum during August- September. Ensuring high soil moisture and relative humidity and low temperature. The disease spread along the gradient and spreads through soil water.

Enterobacter cloacae was a Gram-negative, facultative anaerobic, rod-shaped bacterium was consistently isolated from decayed as well as

symptomless ginger rhizomes. *E. Cloacae* can exist as an endophyte of ginger rhizomes and could cause rhizome rot under conditions that were favourable for bacterial growth, or host susceptibility. Rhizome quality may be impacted by the presence of *E. cloacae* under conditions such as high temperature, high relative humidity, and low oxygen atmosphere that affect the development of decay (Nishijima *et al.*, 2004).

The biology and ecology of *Mimegralla coeruleifrons* associated with rhizome rot affecting ginger rhizomes was investigated by Koya (1989). The egg, larval and pupal periods were 3-4, 9-13 and 8-11 days respectively. The larvae were present only in rhizomes affected by rhizome rot disease. They were also recorded from other species of *Zingiberaceae* and *Colocasia* sp.

2.3 Interaction studies of pathogens associated with rhizome rot complex

Biological Interactions

Dhosi and Mathur (1987) studied symptomatology and interaction of rhizome rot of ginger. Three different types of symptom, either by single infection with *F. solani* or *P. aphanidermatum*, or combined infection with both pathogens. Maximum rotting occurred when *P. aphanidermatum* was inoculated first, followed by *F. solani*. However no interaction occurred between the root knot nematode, *Meloidogyne incognita* and *P. aphanidermatum*.

In artificial inoculation tests it has been demonstrated that maximum rotting occurred only when *P. aphanidermatum* was inoculated first followed by *F.solani* (Joshi and Mathur, 1987).

Another experiment in Himachal Pradesh has shown that *P. aphanidermatum* infected both injured and uninjured rhizomes whereas

fungi like *F. equiseti*, *F.solani*, *Cladosporium cladosporoides* (Fresen) de Vries and *Mucor heimalis* caused dry rot symptoms on injured rhizomes (Bharadwaj *et al.*, 1988) providing circumstantial evidence that the latter group of fungi were secondary pathogens.

Conversely, an instance of independent infection of ginger as well as interaction between *Pythium* spp. and *F. solani* leading to synergism has been reported from Gujarat (Chauhan and Patel, 1990). Both the organisms were pathogenic in independent inoculations. Combined infection resulted in rapid drying of the shoot followed by rhizome rot. Conflicting was the reports on interaction of fungal pathogens and nematodes in rhizome rot complex of ginger. Ginger has been found to be infected by a number of genera of nematodes including *Radopholus*, *Meloidogyne*, *Rotylenchulus* and *Tylenchorhyncus* (Sundararaju *et al.*, 1980). However root knot nematodes produce extensive galling of roots and stunting of plants.

Of the five pathogens associated with rhizome rots of ginger, *Pythium aphanidermatum* cause wet rot and was able to attack both uninjured and injured rhizomes (Bhardwaj *et al.,* 1988). The other fungi, *Fusarium equiseti, F. solani, Cladosporium cladosporioides* and *Mucor hiemalis*, only cause dry rot symptoms on injured rhizomes.

Combined inoculations of ginger with *M. incognita* and *P. myriotylum* resulted in significant reduction in weight of aerial shoot, root and rhizome in a pot culture test (Lanjewar and Shukla, 1985). *P. myriotylum* alone caused significant growth reduction but *M. incognita* alone did not.

An instance of synergistic effect of *P. aphanidermatum* and *Meloidogyne javanica* (Treub.) Chitwood was observed in Madhya Pradesh (Vadhera *et al.*, 1992). In presence of *M. incognita* and *Pratylenchus*

coffeae Zimm. In ginger yield decline has been reported by Kaur *et al.*, (1989). Samuel and Mathew (1983) proved that, bacterial wilt in ginger could aggravate in the presence of nematodes.

Dake and Edison (1989) collected 195 diseased samples from Kerala, individual samples were plated on P10 VP media and peptone PCNB medium besides the nutrient agar and potato dextrose agar for isolation and identification. Of them, 19.79 per cent samples yielded *P. aphanidermatum* and *P. myriotylum*, 6.6 per cent were *F. oxysporum* f. sp. *zingiberi* and *F. solani* and 26.71 per cent had *P. solanacearum,* indicating the dominance of *Pythium* and none of the samples yielded more than one pathogen on isolation. Symptoms became apparent after 6 days in case of *P. solanacearum*, 10 days in *Pythium* and 16 days in *Fusarium* sp.

Rajan *et al.* (2002) conducted pathogenicity experiments; results showed that involvement of *Pythium* sp. (soft rot), *Fusarium oxysporium* (dry rot) and *R. solanacearum* (wilt) and also noticed that, *Pratylenchus coffeae* increased the severity of infection along with *F. oxysporum*. It was observed that the individual fungal and bacterial pathogens caused maximum disease and combination of pathogens didn't cause increase in the disease incidence.

Rhizome rot was caused predominantly by *P. aphanidermatum* (Edson.) Fitzp and occasionally by *P. myriotylum* Drech. in major ginger growing areas of Kerala. Bacterial wilt caused by *P. solanacearum* is equally important in Wynad district but sporadic in Ernakulam and Calicut districts. *P. solanacearum* consists of both biotype 3 and 4. Root knot nematode (*M. incognita*) also infects ginger. Interaction of *P. aphanidermatum* and *M. incognita* results in increased severity of the disease. Onset of rhizome rot occurs during July – August and becomes more severe in September-October. Survival structures of the pathogen

were oospores in scales of infected juvenile fingers. In soil it might survive in host plant debris (Balakrishnan Panayanthatta, 2005).

Savitha *et al*. (2009) isolated pathogens associated with rhizome rot complex in Ranchi and found that, *Pythium spp.*, *Fusarium spp.* and *Ralstonia* were associated with ginger rhizome rot. *P. aphanidermatum* was dominating compare to *F. oxysporum* f. sp. *zingiberi* and *Ralstonia*.

2.4 Management of rhizome rot diseases of ginger.

Investigation have been carried out to identify organisms resistant or tolerant to fungicides, to manipulate biocontrol agents genetically to develop tolerance to fungicides and to evaluate such altered organism in combination with fungicides for disease control under field conditions by Papavizas, (1985). Some instances of such investigations were briefly described. For example *Trichoderma harzianum* was tolerant to Metalaxyl as exemplified by uninhibited growth, sporulation and spore germination up to 1000ppm level of the fungicides (Sawant and Mukhopadhyay, 1991).

Instances of successful management of disease in field by integration of biocontrol agents and fungicidal seed/ soil treatments were 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, 1991).

2.4.1 Biological control

Though the use of biocontrol agents offers an environmentally, economic and safer alternative for fungicides but they really give better control than a good fungicide (Chet, 1987).

Gallardo *el al.* (1989) reported that inhibition of *R. solanancearum* under in *vitro* by using the antagonists Bc-8 strain of *P. fluorescens*. The growth of *R. solanancearum* was inhibited by *P. fluorescens* (str. Bc-8) or its culture extracts. It was found that extract contains rod shaped particles with the helical structure with 150 mm long and 25 mm diameter. These were interpreted as bacteriocin floucin Bc-8. Bacteriocin activity was found to be associated with plasmids, since plasmids DNA could not be detected electrophoritically.

Aoki *et al.* (1991) isolated and identified an antibacterial substances produced by *P. cepacia* (B5) against *R. solanancearum.* The antibacterial substance was identified as 2 keto-D gluconic acid (2KGA).

Hayward (1991) reported that the studies conducted in different countries have shown the potential of antagonistic rhizobacteria, soil solarization and vesicular arbuscular mycorrhizae (VAM) were potential to inhibit or displace soil borne pathogens at root soil interface and thereby protect the crop plants.

Several antagonists were tested for the biological control of rhizome rot of ginger caused by *Fusarium oxysporum* (Pandey *et al.*, 1992). An extract of *Agave americana* was found to be very effective in controlling the disease under laboratory and field conditions, followed closely by culture filtrates/extracts of *Bacillus subtilis*, *Cannabis sativa, Lyonia ovalifolia* and *Aspergillus niger*. The respective percent reductions of infection over controls were 75.9, 69.4, 58.5, 54.7 and 52.0.

Ciampi *et al.* (1996) isolated siderophore like substances from *P. fluorescens* responsible for inhibiting the growth of *R. solanancearum* and reported that these substances were responsible for inhibiting the growth of the pathogen and this siderophore activity was more when iron

in the medium was limited which chelate the iron compound required for the growth of *R. solanancearum.*

Joseph (1997) evolved an effective management strategy for rhizome rot of ginger by combining appropriate native AMF Mi-l and Mi-4 (identified as *Glomus* species) and antagonistic fungi Ai-12 (identified as *Aspergillus fumigatus),* for inoculation of seed rhizomes at planting time were the most efficient in rhizome rot suppression, yield increase and growth enhancement in ginger.

Ram *et al.* (1999) conducted an experiment to evaluate fungal and bacterial biocontrol agents (BCA) individually and in combination and finally both BCA's in integration with fungicidal rhizome treatment. Rhizome treatment with individual BCA resulted in better germination and stand of ginger. Significant suppression of the disease and increase in yield as compared to the control and these treatments were at par with the fungicides rhizome treatment. 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 *Pseudomonas sp.* and fungicides was the most effective among all the tested treatments.

Shanmugam *et al.* (1999) conducted experiment on different biocontrol agents and chemicals as both seed treatment and soil application. The results revealed that *T. harzianum* applied as seed treatment and soil application was equally effective to copper oxy chloride in inducing germination and reducing per cent rhizome rot incidence.

Rajan *et al.* (2002) evaluated efficacy of *Trichoderma harzianum* on control of ginger pathogens causing rhizome rot. In general *Trichoderma*

harzianum controlled rhizome rot, root rot and mortality caused by both fungal and bacterial pathogens. However, when the pathogens were combined the efficacy of *Trichoderma harzianum* in their control varied.

Biocontrol agents viz., *T. harzianum, A. niger, A. terreus, Penicillium sp*. and rhizosphere bacteria suppresses *P. aphanidermatum* and protects ginger from rhizome rot. Among the biocontrol agents, *T. harzianum* is also tolerant to fungicides viz., metalaxyl, mancozeb and captafol which makes it an ideal candidate for integrated management (Balakrishnan Panayanthatta, 2005).

Sood (2005) conducted an experiment to determine the potential of antagonistic rhizobacteria against *R. solanancearum* 386 rhizobacterial isolates were screened for their activity by dual culture technique using cross streak, tooth pick and paper disc methods. Six isolates of *Pseudomonas fluorescens* and one isolate of *Bacillus cereus* showed maximum antagonistic activity against *R. solanancearum.*

Bhai *et al*. (2005) collected native rhizobaterial isolates and identified as *P. fluorescence* and *Bacillus sp.*, they screened the isolates against *P. myriotylum* and found that all isolates were capable of reducing the pathogen except isolate IISR-914 (*Bacillus sp.)*. Further screened best performed six isolates along with VAM (vesicular arbuscular mycorrhizae) *in vivo*. Results revealed that all are very efficient in controlling the disease incidence with maximum root growth and biomass indicating the increased efficiency when applied along with VAM.

Ten *Pseudomonas fluorescens* strains were used against the disease caused by *Pythium*, *Fusarium* and *Ralstonia*, which cause rot and bacterial wilt in ginger. Among the ten isolates tested, the results showed

that most of them were effective in inhibiting the growth of the target pathogens under *in vitro* conditions (Smitha, 2005).

Trichoderma could utilize *Ralstonia* as its substrate for growth as indicated by their profuse growth when live or dead cells of *R. solanacearum* served as carbon source. The heat labile nature of metabolites from *T. viride* was established as temperature above 70^0C affected the biological activity of the metabolite (Asmaja, 2005).

The trials conducted at Kumarganj for the management of rhizome rot of ginger, minimum incidence and maximum yield was observed in the seed treatment with hot water at 51^0C for 10 minutes and *Trichoderma harzianum* for 30 minutes with neem cake (Anon., 2006).

The trials conducted at Pundibari for the management of rhizome rot of turmeric, showed that seed treatment + soil application of *Trichoderma viride* and *Pseudomonas fluorescens* + application of recommended NPK and FYM were found effective (Anon., 2006).

Combined applications of antagonists were more effective reducing the rotting when compared to individual application (Meenu Gupta *et al.*, 2010).The treatment THR+GM+G4 gave minimum per cent rotting in ginger (6.67%) followed by THR+GM+G3 (20.42%) which were statistically on par with each other. The combinations of *Trichoderma harzianum* + *Glomus mosseae* + G4 (fluorescent pseudomonad) performance was superior to individual strains in reducing the rhizome rot and growth performance under green house condition.

Pseudomonas solanacearum, the pathogen causing bacterial wilt in ginger root, was eliminated when exposed to heat for 30 min at 50°C and 45 min at 49°C, respectively. Exposing ginger seed pieces to hot air at 75 per cent RH until their mid temperatures attained 49°C for 30 and 60

min and 50°C for 30 min, resulted in minimal injury to the hosts. More than 87 per cent of the seed pieces germinated without adverse effect on growth. Rhizomes harvested from plants grown from seed pieces inoculated with. *P solanacearum,* and subsequently heat treated with hot air at the above time and temperatures, tested negative for *P. solanacearum*. Heat treatment with 75 per cent RH heated air may prove to be a convenient method to disinfect ginger seed pieces of the bacterial wilt pathogen.

2.4.2 Organic Amendments

Many evaluation trials with organic amendments have been conducted in India and some of them were recommended to growers. In an evaluation of soil amendments viz., castor, groundnut, sesamum, margosa and coconut oilcakes and sawdust with and without incorporation of urea conducted in *Pythium* sick plots, coconut oilcake gave the best yield (Rajan and Singh, 1973). Neem oilcake @ 2 t/ha gave reduction of rhizome rot and increased yield by 1.78 t/ha (Sadanadan and Iyer, 1986).

Ginger rhizome rot, caused by *Pythium aphanidermatum* and *Fusarium solani*, was reduced by amendments of cakes made from *Azadirachta indica, Calophyllum inophyllum* or *Pongamia glabra [P. pinnata]* (Thakore *et al.*, 1987). The maximum yield increase was given by cakes made from *P. glabra* followed by *Hibiscus sabdariffa* and *Brassica campestris.*

Neem oilcake as well as other oilcakes have also shown to reduce ginger rhizome rot caused by *P. aphanidermatum* and *F. solani* (Thakore *et al.*1988). Soil amendment with wood sawdust also reduced disease incidence.

Liming along with fertilizer or without it resulted in more disease than untreated plot (Sharma, 1998). Surface burning reduced rhizome rot incidence and increased yield. It increased availability of soil nutrients (Sadanandan *et al.*, 1988). *Azadirachta indica* and *Agave* a*mericanai* were most effective in reducing mycelial growth of *Fusarium oxysporum* f. sp. *zingiberi* and *P. aphanidermatum*.

The effects of 2 ton neem cake/ha and/or 10 t farmyard manure (FYM)/ha and soil drenching with 3 per cent copper oxy chloride on ginger in terms of the occurrence of rhizome rot caused by *Pythium aphanidermatum* and crop yield were determined in a field experiment conducted in Karnataka, India (Jeewa Ram and Thakore, 2010). All the treatments resulted in higher germination compared to the control. Neem cake amendment resulted in the lowest disease incidence (22.92%) and highest yield (32.91 q/ha) followed by application of FYM.

In-vitro efficacy of water soluble extracts of oil cakes of groundnut, margosa (*Azadirachta indica*), mahua (*Madhuca indica* [*M. longifolia*]) and castor (*Ricinus communis),* at 1.25, 2.50, 5.00 and 10.00 per cent (w/v), against the rhizome rot of ginger, caused by *F. oxysporum f. sp. zingiberi*, was tested by Kaushal and Siddiqui (2003). The extract of oil cake of castor was the most effective in all concentrations, followed by groundnut oil cake extract at 10.00%. The extract of mahua oil cake was the least effective.

Use of neem cake at 1 kg+100 gm of *Trichoderma harzianum* in 3 kg FYM mixed for 7 days applied to soil before planting and watering regularly gave maximum yield (13.45 t/ha) and minimum disease incidence (5.5%), next best treatment was seed treatment with hot water 51^0C+100 gm *T. harzianum* +1 Kg neem cake at sowing time (Thakore *et al.*, 1987). The results showed that these safer management tools against disease in ginger crop gave better protection and pesticide residue free

rhizome because of its use as direct consumption without any processing.

2.4.5 Cultural Practices

In Calicut, Kerala, planting during May or early June resulted in less disease incidence (Anon., 1984). Since the crop season varies at different places the ideal time of planting also vary accordingly (Sarma, 1994). The culturable bacterial count was reduced to a great extent (84.2% reduction) on the surface and also in vascular tissue of ginger (92% reduction) due to rhizome solarisation (Praseena 2005).

An attempt have been made to manage the rhizome rot problem by adjusting plant spacing, seed rhizome size by Sharma *et al.*, (2011). Plant spacing of 25 × 30 cm and seed rhizome size of 50 to 75 g was found optimum for better crop return and lower disease incidence. Mother rhizome extraction/removal that was, the common practice followed by ginger growers in the region had an additive effect on incidence of rhizome rot and wilt disease complex of ginger.

When sown early the crop becomes hardy and less vulnerable to infection during critical period of infection (July- August). In Calicut, Kerala, planting during May or early June resulted in less disease incidence (Anon., 1984).

In Karnataka, ginger is planted in April-May as rainfed crop immediately after the pre-monsoon showers. It starts sprouting in June and tillering continues until late in the season (Sarma, 1994). High soil moisture 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 was also readily available through soil water by means of zoospores, hyphal fragments etc. The disease is generally less in well-drained fields.

2.4.6 Chemical control

Hidaka and Murano (1956) studied *in vitro* effect of streptomycin on the behavior of *R. solanancearum,* and they found that streptomycin at 0.3 µg/ml water inhibited and killed the *R. solanancearum*. Duta and Verma (1969) studied the efficiency of streptocycline in controlling bacterial wilt of egg plant and found that seedling treatment of variety Pusa Purple Long with the antibiotic (1 g/lit) for 30 minutes before planting gave the best results.

Seed treatment and soil drenching with Bordeaux Mixture (2:2:50) (Bhagwat, 1961) and seed treatment with Ceresan (0.25%) for 30 minutes (Thomas, 1940) effectively controlled rhizome rot. Pre sowing soil treatment and subsequent treatments every week with Bordeaux mixture (4:4:50) or Perenox (0.35%) were recommended for successful control of rhizome rot caused by *P. myriotylum* and *P. aphanidermatum* (Sahare and Asthana, 1962).

Indresenan *et al.* (1981) reported that treatment of zinger rhizome with plantomycin at 1000 ppm was ineffective against the seed borne bacteria *R. solanancearum.*

Ojha *et al.* (1986) observed that treatment of seed rhizomes with Emisan 6 + Plantomycin for 30 minutes followed by three sprayings, first at 30th day after planting and others at an interval of 15 days also gives good control of the disease.

Rhizome germination was significantly increased by drenching with Aliette [fosetyl aluminium]. Pre and post drenching rotting was minimum in treatments with Aliette, Bordeaux mixture, Dithane M-45 [mancozeb] and Difolatan [Captafol]. These fungicides also increased yield of the rhizomes significantly (Doshi and Matur, 1987).

Soil treatment with 4 per cent formaldehyde combined with treatment of rhizome planting material with Topsin M-70 (Thiophanate-methyl) at 0.1% gave the best control of disease, caused by *Fusarium oxysporum* (Raj Kumar and Pandey, 1989). Rhizome treatment with 0.1% Bavistin (Carbendazim) or 0.3% Dithane M-45 [Mancozeb], with the formaldehyde soil treatment was also satisfactory, though less effective.

In-vitro study with five systemic fungicides against *P. aphanidermatum* viz., Metalaxyl, Oxadixyl 35 WP, Fosetyl aluminium, Promocarb and Ethazole (Etridiazole) as Terrazole 35 WP. Terrazole 35 WP gave effective control and had the lowest ED 50 and ED 90 values followed by Metalaxyl alone (Ramachandran *et al.*, 1989). These fungicides were also tested as seed and soil treatments in pre infested soil in pot culture (Ramachandran *et al.*, 1989) Metalaxyl formulation (Ridomil 5G granules) and Ethazole (Terrazol, 35 WP) gave best control.

Rana and Sharma (1993) reported that seed treatment with fungicides was more effective in reducing ginger yellows compared to soil drenching in the field. Seed treatment with Bavistin (1g/l) was most effective followed by Dithane M-45 (2.5 g/l).

Recommendation of Dithane M-45 for seed treatment and soil drenching was made based on its performance in disease control in prolonged on farm evaluations of the fungicides at Indian Institute of Spices Research, Calicut, Kerala (Sarma, 1994). Increased germination, reduced incidence of rhizome rot and better yield was obtained with Captafol when used for seed treatment (Mathur *et al.*, 1984). Manmohandas *et al.*, (1990) recorded when four treatments viz., seed treatment with Captan, Captafol, Dithane M-45 and hot water treatment superimposed by 200 ppm Streptocycline were evaluated it was found that Captan was more effective against rhizome rot.

Thakore *et al.* (1988) evaluated six non systemic and four systemic fungicides by treating *P. aphanidermatum* inoculated ginger rhizome with respective fungicides before planting. Of these, Dithane M-45, Captafol, Ziride, Captan and Metalaxyl controlled rhizome rot incidence and increased germination of rhizomes and yield.

Rana (1991) reported that ginger yellows could be effectively checked by proper seed treatment and may be helpful only if the seed selection was proper. Rana and Sharma (1993) reported that seed treatment with fungicides was more effective in reducing ginger yellows compared to soil drenching in the field. Seed treatment with Bavistin (1g/1) was most effective followed by Dithane M-45 (2.5 g/l).

As early as 1955, Morgan and Goodman reported the in *vitro* sensitivity of plant bacterial pathogens to antibiotics. It was found that the antibiotics varied considerably in their capacity to inhibit the entire spectrum of the test organisms and none was consistently superior to the others. *R. solanacearum* was effectively inhibited by lower concentration of Aureomycin and Terramycin and relatively insensitive to the other two antibiotics, streptomycin and polymixin.

The effect of soil amendment with urea and calcium oxide on survival of *Ralstonia solanacearum* was studied by mixing urea and calcium oxide at the rate of 80: 800 kg/a.i. in the artificial infested soil with 2.83 x 10^7 cfu/ml of bacteria the population of *R. solanacearum* in the treated soil was decreased from 0.88 x 10^7 cfu/ml to 0 cfu/ml from first week to third week, where as in control has got 0.26 × 10^7 cfu/ml to 0.11× 10^6 cfu/ml from first week to third week. soil amendment with urea and calcium oxide at the rate of 80 : 800 kg/ai can decrease population of *R. solanacearum* in the infested fields for bacterial wilt control (Sasitorn Vudhivanich, 2002). The treated soil should be left at

least 3 weeks before planting a new crop to avoid toxicating to ginger Seedlings.

Rajan *et al.*, (2002) evaluated various chemicals in controlling the seed borne inoculum; all chemical treatments reduced the rhizome rot. Copper oxy chloride was more effective in the control of root rot and mortality due to different pathogens.

The efficacy of 0.2% Dithane M-45 [mancozeb], 0.3% Ridomil MZ [metalaxyl], 0.1% Bavistin [carbendazim], 0.2% SAAF, 0.2% Shield [clopyralid], 0.3% Blitox-50 [copper oxychloride] and 0.25% Dithane M-45 + 0.05% Bavistin in controlling rhizome rot of ginger caused by *Pythium aphanidermatum* under storage and field conditions was determined in experiments carried out in Bihar, India (Singh *et al.*, 2004). Under stored conditions, application of 0.3% 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%).

Venkatesh (2005) conducted *in vitro* evaluation of bactericides/ antibiotics on the growth of *Ralstonia solanancearum* out of eight compounds comprising bactericides and antibiotics, sulphamethaxazole and streptocycline were found effective at 500 and 1000 ppm respectively.

A study to find out the effect of seed treatment with five fungicides on soft rot disease of ginger was conducted at Dholi (Anon., 2006). The pooled data of three years (1997-2000) showed that, minimum disease incidence (16.40%) was recorded by one hour seed treatment with Ridomil MZ (3g/l of water) followed by Indofil M-45 seed treatment (25.30%).

Shalini, (2006) evaluated Eight organic amendments against rhizome rot of ginger, neem cake was found to be superior, which recorded least disease incidence (13.33%), with maximum germination (81.00%) and yield of 3.33 kg/pot, which was found to be significantly superior over all the treatment. This was followed by *Eupatorium* which recorded germination (78.33%), disease incidence (15.00%) and yield of 3.17 g/pot. Maximum per cent disease incidence was observed in the treatment which was amended with farm yard manure which recorded 32.00; lowest germination of 53.00 per cent and yield of 2.87 kg/plot though differed significantly over control with a per cent disease incidence, per cent germination and yield of 42.00, 57.10 and 1.17 kg/plot respectively.

Rajesh Gang and Raudhi Singh (2008) conducted an experiment to find out the effect of seed selection and seed treatment on incidence of rhizome rot in ginger, selection of healthy seed along with seed treatment by soaking in solution of Dithane M-45 (2.5g/litre) + Bavistin 1g/litre for one hour was found to be most effective in reducing the disease incidence and enhancing germination percentage, there by resulting in the higher yield.

The treatment with plant products (*Boerhaavia diffusa* root extract) might offer a practical and economical alternative for eco-friendly management of rhizome rot disease (Pandey *et al.,* 2010). Rhizomes dipped overnight in the suspension of 10.00 per cent crude root extract followed by 3 foliar sprays of the same proved quite effective in the management of the disease. Results indicated a gradual decrease in disease incidence with the corresponding increase in number of sprays and rhizome treatment with *B. diffusa* root extract.

Alcoholic leaf extracts of *Swietenia macrophylla* King, *Azadirachta indica*, *Hyptis suaveolens* (L.) Poit., *Polyalthia longifolia* (Sonn.) Thw.,

Boerhaavia epens L. var. *diffusa* (L.) Hook. f., and *Tithonia diversifolia* A. Gray. had strong inhibitory activity on the growth of benomyl sensitive and resistant isolates of *Fusarium solani* causing rhizome rot of ginger (Ramteke and Kamble, 2011).

2.4.7 Host plant resistance

The variety Maran was more resistant to soft rot of ginger caused by *P. aphanidermatum* (Balagopal *et al.*, 1975) out of 21 varieties in a screening system based on mean infection percentages of sprouts of different ages ranging from four weeks to twelve weeks. The variety Maran scored mean infection percentage of 12.6 per cent whereas, that of the other varieties ranged from 20-75 per cent (Indrasenan and Paily, 1973). Moderate resistance was reported in two varieties *viz*. Nadia and Naraspatam.

Lack of resistance or tolerance in 33 accessions of ginger including indigenous and exotic collections was also demonstrated (Sarma *et al.*, 1979). The variety Maran also expressed field tolerance against *P. apanidermatum* among 25 varieties evaluated (Nybe and Nair, 1979). Disease incidence in this variety was 3.2 per cent compared to 27.5 per cent in the most susceptible variety Rio-de Janeiro. The variety Maran has also got good agronomic characteristics.

Setty *et al*. (1995) evaluated a total of 18 cultivars of ginger in the field at Brahmavar, Karnataka during 1993-94 for resistance to rhizome rot, caused by *Pythium* spp. None of the cultivars tested were resistant to disease. The cultivars Suprabha and Himachal Pradesh demonstrated < 31 per cent disease incidence.

One hundred and thirty four ginger (*Zingiber officinale*) cultivars were screened for resistance to rhizome rot disease complex (*Pythium aphanidermatum, P. deliense, P. myriotylum, P. vexans, P. ultimum*) from

1996 to 1998 in Orissa, India (Senapati and Sugata Ghose, 2004). Only one cultivar, ZO-16, was resistant (percent disease incidence, PDI=0%), eight were moderately resistant (PDI=1-5%), 19 were tolerant (PDI=6-15%), 56 were moderately tolerant (PDI=16-25%), 39 were susceptible (PDI=26-40%) and 11 were highly susceptible (PDI>40%).

Among 148 varieties of ginger varieties viz., 72, 74, 79, 215 & 250 showed numerically less incidence of rhizome rot as compared to other varieties. This might be a reflection of some amount of tolerance of these varieties. However, wild varieties viz., Indonasian wild, zingiber species (accessions 335 & 336), Kanyakumari and Karakkal did not succumb to rhizome rot infection (Balakrishnan Panayanthatta, 2005).

Kavitha and Thomas (2007) evaluated genetic diversity and *P. aphanidermatum* resistance of 74 *Zingiber zerumbet* (L) Smith accessions belonging to 15 populations from eight districts in Kerala state, India which belongs to a wild clonal species related to the cultivated *ginger (Zingiber officinale* Rosc.), The disease index (DI) of the accessions varied from zero per cent to 72.24 per cent. More than 65 per cent of the accessions had a DI < 20%. Eight accessions were found to be immune to the infection. The relative frequency of resistant accessions was higher in the central and northern regions of Kerala. The study revealed high genetic diversity and variability for pathogen resistance among Z. *zerumbet* accessions and confirmed the value of *Z. zerumbet* as a potential donor for soft rot resistance for the genetic improvement of ginger.

Eleven genotypes of ginger were screened for reaction to soft rot and rhizome yield at AICRP on Dryland Agriculture (OUAT), Phulbani, Orissa during 2006-07. Over 8 per cent soft rot incidence was found in ACC-35, ACC-117 and SG-666 at 60 DAP. These genotypes had severe soft rot incidence at 135 DAP. Suprabha, Phulbani Local and VIC-8 were

showed minimum soft rot. Rhizome yield varied from zero (ACC-117) to 46.27 q/ha (VIC-8). However, rhizome yields of Suprabha, VIC-8 and Phulbani Local were found to be at par (Mishra *et al.*, 2008).

None of the locally available germplasm tested was found to be tolerant against rhizome rot and wilt disease complex of ginger, however, cultivar "Majauley" might considered as moderately susceptible and "Bhaisey" and "Gorubathaney" are considered as highly susceptible germplasm (Sharma *et al.*, 2011).

2.4.8 Integrated disease management of rhizome rot of ginger

Soil solarization of *Pythium* sick plot prior to planting suppressed weed growth improved the germination and yield and reduced disease incidence (Usman *et al.,* 1996). Two years of field trials showed that the isolate *T. harzianum* was efficient in controlling the disease both in solarised and non-solarized plots. The weed growth was also suppressed in the solarised plot to an extent of 40 per cent.

Ciampi *et al.* (1996) studied the effect of bio control agents for the management of bacterial wilt of tomato. They observed that *P. fluorescens* was found effective to minimize the disease. The effect of the bioagent might be attributed to the production of siderophores which have strong inhibitory effect of *R. solanancearum.*

Ram *et al.* (1999) conducted an experiment to evaluate fungal and bacterial biocontrol agents (BCA) individually and in combination and finally both BCA's in integration with fungicidal rhizome treatment. Rhizome treatment with individual BCA resulted in better germination and stand of ginger and significant suppression of the disease and increase in yield as compared to the control and these treatments were at par with the fungicides rhizome treatment. 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 treatmnents. Soil application of *T. harzianum* and rhizome treatment with *Pseudomonas* sp. and fungicides was the most effective among all the tested treatments.

Shanmugam *et al.* (1999) conducted experiment on different biocontrol and chemicals as both seed treatment and soil application. The results revealed that *T. harzianium* applied as seed treatment and soil application was equally effective to Copper oxy chloride in inducing germination and reducing percent rhizome rot incidence.

Jayasekhar *et al.,* (2000) tested fungicides and biological control agents effectiveness in the reduction of ginger rhizome rot caused by *P. aphanidermatum*. Metalaxyl MZ @ 1% at 45 and 90DAP recorded the lowest disease incidence (4.23%) and Cost: benefit ratio was highest (1:2.85) with *T. harzanium* + neem cake application followed by 0.1% Metalaxyl (1:2.71).

Maran variety showed highest percent germination and lowest per cent disease incidence when treated with Ridomil MZ 0.2% which was followed by Rio-de-jeneria and COC 0.3% showed good results (Das *et al.,* 2001).

In integrated management of ginger against *Pythium, Fusarium* and *Ralstonia,* the results indicated that mancozeb, soil solarization and hot water treatments of ginger rhizomes were effective in increasing the emergence and yield of ginger (Anon., 2005).

Mathur *et al.* (2002) conducted soil solarization using thin transparent polythene film against rhizome rot. They attempted in integration with fungicidal seed treatment and phorate as soil application in the field experiment for management of rhizome rot of ginger. All the

treatments in the solarized fields had significantly less disease as compared to the untreated control and least disease was observed in captan seed dressing + phorate soil application + metalaxyl MZ drench.

Rajan *et al*. (2002) has evaluated various chemicals against the seed borne infection of pathogens of ginger. All the chemical treatments reduced rhizome rot. Copper oxy chloride was found effective in control of root rot and mortality due to different pathogens causing rhizome rot of ginger.

Kusum Mathur *et al.* (2002) conducted soil solarization using thin transparent polythene film in integration with fungicidal seed treatment and Phorate as soil application in the field experiment for management of rhizome rot of ginger. Reddy *et al.*(2003) observed that treatments in the solarized fields had significantly less disease as compared to the untreated control and least disease was observed in Captan seed dressing+ Phorate soil application + Metalaxyl MZ drench. The combination of *Trichoderma* + Ridomil was more effective in suppressing the rhizome rot of turmeric (*F. solani*) as compared to individual inoculations of *Trichoderma* or Ridomil alone.

The combination of *Trichoderma* and Ridomil was more effective in suppressing the rhizome rot of ginger (*F. solani)* as compared to individual inoculations of *Trichoderma or* Ridomil alone (Reddy *et al.* 2003*).*

Solarization of soil by mulching with polythene sheet of 100 micron thick increased the soil temperature by 6.0 to 12.7 ^{0} C more as compared to non-mulched soil (Balakrishnan *et al.*, 1996). This heating of soil was found to be effective in controlling the disease, due to greater reduction in soil propagules of *F. oxysporum f. sp. zingiberi.* In solarized plots, there was a considerable increase in seed germination, plant height and yield

and greater reduction in disease incidence (88.18%) over solarised plots was observed.

Fungicidal seed treatment with supplementary soil drenching protects ginger from rhizome rot by reducing pre-emergence rot and disease incidence. Among fungicides, captafol, metalaxyl-mancozeb and mancozeb are most effective. Integrated management practices consisting of soil disinfestations by solarization, seed treatment with fungicide which is compatible with biocontrol agent (*T. harzianum*) and soil application of neem oil cake in combination with *T. harzianum* were found promising for effective management of rhizome rot of ginger (Balakrishnan Panayanthatta, 2005).

The trials conducted at Kumarganj for management of rhizome rot of ginger, minimum incidence and maximum yield was observed in the treatment seed treatment with hot water at 51°C for 10 minutes and *Trichoderma harzianum* for 30 minutes with neem cake (Anon., 2006). A study to find out the effect of seed treatment with five fungicides on soft rot disease of ginger was conducted at Dholi (Anon., 2006). The pooled data of three years(1997-2000) showed that, minimum disease incidence (16.40%) was recorded by one hour seed treatment with Ridomil MZ (3g/l of water) followed by Indofil M-45 seed treatment (25.30%).

A field experiment was conducted during kharif 2004 on the integrated management of rhizome rot in the farmer's field located at the hilly tracts of Uttara kannada district of Karnataka, where the soil was infested with *P. aphanidermatum* and *F. solani* (Shalini, 2006). Among different treatments, Rhizomes dipped in 0.6% metalaxyl MZ for 30 min and Soil application of tender Eupatorium plants @ 10 t/ha + Soil application of *Trichoderma harzianum* @ 10 Kgs mixed with 25t FYM /ha + One drench with copper oxy chloride @ 0.3%, immediately after the

onset of the disease was found to be efficient in reducing the disease with higher B:C ratio and yield (10150kg/ha) when compare to the control.

Rhizome treated with soil solarization + rhizome treatment with metalaxyl MZ @ 0.3% + soil application of *T. harzianum* @10kg along with *Eupatorium*@ 10t/ha recorded highest per cent germination(92.66) when compared to the control (59.33) which was on par with the soil solarization + Rhizome dipped in metalaxyl MZ @ 0.3 % + Soil application of *T. harzianum* @ 10 kg along with 25t FYM /ha + COC @ 0.3 % drenching (45 DAP immediately after the onset of the diseases) (Srikanth Kulkarni, 2011) and there was a significant reduction in the disease incidence in sterilized plot when compare to non-sterilized soil.

An experiment was conducted by Ajit Kumar Singh, (2011) during 2005–08 to study the management practices to control rhizome rot caused by *Pythium, Fusarium* and *Ralstonia* in ginger. The seed treatment with Ridomil MZ 72% WP (Metalaxyl 8% + Mancozeb 64% (1.25 g /litre) found 81.6 per cent of plant survival and maximum yield of 10.2 tonnes/ha, followed by the treatment with *T. harzianum* 72.05 per cent plant survival and 7.6 t/ha of yield.

The lowest disease incidence (2.77%) over untreated control were counted in treatment Poultry waste + Bavistin 50 WP followed by poultry waste + Ridomil gold MZ 72 and poultry waste + Alamanda leaf extract at 240 days after sowing (DAP) (Ziaur Rahman Bhuiyan *et al.*, 2013). The highest number of tillers (60) per hill, the highest plant height (65.20 cm) the highest weight (3039 g) of the healthy rhizome and that (307.3 g) of infected rhizome was recorded in poultry waste + Bavistin 50WP. The highest rhizome yield (16.73 t/ha^{-1}) was achieved in poultry waste + Bavistin 50 WP which was 172.92% higher over the untreated control

Material and Methods

III. MATERIAL AND METHODS

The present investigations were carried out in the laboratory and field during 2011-12 and 2012-13. All the laboratory studies were undertaken at Plant Pathology Laboratory of Organic Farming Research Centre (OFRC) ZARS, Shimoga, while field experiments were conducted at farmer's field in Shimoga district, Karnataka. The details of the materials used and methodology followed during the course of investigation are described here under.

3.1 Survey for rhizome rot incidence and collection of diseased samples

Roving method of survey was conducted to record the incidence of rhizome rot disease during *Kharif* 2011 and 2012 in ginger growing areas malnad districts of Karnataka *viz*., Shimoga, Chikkamagalore, Hassan, Kodagu and Uttara Kannada. Details of locations surveyed and samples collected are tabulated.

a) Kharif-2011

Name of the District	Name of the taluk	No. of fields visited
Shimoga	Shimoga	21
	Shikaripura	13
	Sagara	07
	Soraba	14
	Hosanagara	08
Chikkamagalore	Chikkamagalore	05
	N.R. Pura	13
Hassan	Alur	10
	Sakaleshapura	17
Coorg	Virajpete	13
	Somavarapete	15
Uttara Kannada	Sirsi	14

b) Kharif-2012

Name of the District	Name of the taluk	No. of fields visited
Shimoga	Shimoga	23
	Shikaripura	16
	Sagara	07
	Soraba	18
	Hosanagara	07
Chikkamagalore	Chikkamagalore	24
	N.R. Pura	22
Hassan	Alur	15
	Sakaleshapura	16
Coorg	Virajpet	14
	Madikeri	10
	Somavarapete	15
Uttara Kannada	Sirsi	15

During survey diseased fields and infected ginger were carefully observed and farmer's opinion about the constraints of ginger production, their knowledge about the disease were recorded and disease samples of ginger rhizome and pseudostem with adhering soil from each field were collected. These samples were brought to laboratory for isolation of pathogens. Disease incidence in the fields was calculated by using following formula.

$$\text{Per cent Disease Incidence: } \frac{\text{No. of plants infected}}{\text{Total no. of plants observed}} \times 100$$

Processing of Soil Sample

The soil samples collected were dried inside the laboratory at 28^0 C. Each sample was sieved through a 1000µ mesh to remove the bigger

soil particles and debris. The dried and sieved soil samples were used for further analysis.

Analysis

Physico-chemical properties of collected infested soils *viz.*, pH, Electrical conductivity, Organic matter content, N-content, P-content, and K-content were analyzed with standard soil analytical methods.

Determination of soil pH

The pH meter (Elico) was standardized with a standard buffer solution of pH (4.0, 7.0, and 9.2) by changing the function switch to a particular pH range (0-7 or 7-14) and adjusting the standardization knob till the pointer read the correct pH value of the buffer solution.

Twenty grams of air dried soil which passed through two mm sieve was weighed and transferred to a clean 100 ml beaker. Fifty ml of distilled water was added and the content was stirred intermittently by using glass rod and allowed to stand for 30 min.

The electrode of the pH meter were washed carefully with a jet of distilled water and wiped with a piece of filter paper. The electrodes were immersed into the beaker containing soil water suspension which was stirred just before taking the reading. The function switch was changed to the particular pH range and the meter reading was recorded.

Determination of soil Electrical Conductivity (EC)

The conductivity bridge was switched on for 10 min. The instrument was checked with saturated $CaSO_4$ solution and 0.1 N KCl solution. The EC of $CaSO_4$ and KCl solution should be 2.2 and 1.41 dSm^{-1}, respectively.

Soil water suspension used for measuring soil pH was also used for estimation of EC. The content was stirred and allowed to settle for 30 min. The electrodes were immersed into the soil solution supernatant after washing the knob with distilled water then the readings were noted down.

Estimation of organic carbon

Two mm sieved soil sample was ground using augate pestle and mortar to pass through 0.2 mm sieve, known weight of sample was treated with standard $K_2Cr_2O_7$ and H_2SO_4. The untreated $K_2Cr_2O_7$ was estimated by back titration with standard ferrous ammonium sulphate using Orthophosphoric acid and indicator (Diphenyl amine). A blank without soil was carried out. Using these values the percent organic carbon was computed (Jackson, 1973).

Estimation of available Phosphorus

Available P content was extracted by using 0.5M $NaHCO_3$. The P content in the extract was determined by chloromolybdic blue colour method using spectrophotometer (Make-U model). The intensity of blue colour was determined at 660 nm. The available P content was computed and expressed in kg ha^{-1} (Jackson, 1973).

Estimation of available Potassium

Available K_2O content was extracted using neutral N NH_4OAC as described by Schollenberger and Simon (1945). The concentration of K in the extractant was determined by flame photometer (Mc Lean *et al.*, 1982).

Isolation and identification of causal agent/ agents

Glassware Cleaning

Borosil and Corning glassware were used for all the laboratory experimental studies. They were kept for a day in the cleaning solution containing 60 g Potassium dichromate ($K_2Cr_2O_7$), 60 ml of concentrated sulphuric acid (H_2SO_4), in one liter of water. Then they were cleaned by washing with detergent solution followed by rinsing several times in tap water and finally with distilled water allowed the washed materials to air dry.

Sterilization

All the glassware used in the studies were sterilized in an autoclave at 1.1 kg/cm^2 pressure for 20 min and kept in hot air oven at 60^{0}C for one hour. Both solid and liquid media were sterilized at 1.1 kg/cm^2 pressure for 15 minutes. Plant materials were surface sterilized using 0.1 per cent mercuric chloride solution ($HgCl_2$) for 30 seconds and then washed in sterile water for thrice.

Laminar air flow chamber was used for isolation and inoculation of pathogens for various studies to maintain the aseptic conditions. Laminar air flow chamber was sterilized for 15 minutes with UV-light, immediately before the start of work. The working bench and working hands were also sterilized by swabbing 70 per cent ethanol. The blades, forceps, inoculation needles cork borer etc were sterilized by dipping in ethanol and heated in the flame. The mouth of flask and culture tubes were opened close to the flame before inoculation and replaced properly near the flame to avoid the contaminations.

Potting mixture

For all the pot experiment studies, potting mixture was sterilized by autoclaving at 1.1 kg/cm^2 pressure for 60 minutes for three consecutive days.

Media preparation

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

Potato Dextrose Agar

Readymade dehydrated media formulation supplied by the M/s Hi-media Laboratories Pvt. Ltd Bangalore was used. Forty grams of the medium was rehydrated and made up to 1000ml with distilled water. Potato dextrose agar was used as growth medium for *Pythium aphanidermatum* (Edson) Fitzp., *Fusarium solani* (Martius) Sacc. and *Sclerotium rolfsii* Sacc.

Potato dextrose agar supplemented with antibiotics (Tsao and Ocana, 1969) for isolation of *Pythium sp.*

Potato dextrose agar was prepared as above. Hundred ml stock solution of pimaricin and vancomycin was made by weighing 12.2mg of pimaricin (purity 90.5%) and 220 mg of vancomycin (purity 100%) respectively. Pimaricin was dissolved in 5 ml of dimethyl sulphoxide (DMSO) in a sterile amber-coloured bottle and then 95 ml of sterile distilled water was added. To this solution vancomycin was added and mixed. The stock solution was added to PDA while pouring to plates @ 10% v/v. The stock solution stored under refrigeration upto one month. This medium was used for selective isolation of *Pythium aphanidermatum* from soil or host tissue.

Sucrose peptone agar for isolation of *Ralstonia solanacearum* (Mehan, 1995)

Sucrose ($C_{12}H_{22}O_{11}$)	20 g
Dipotassium Hydrogen phosphate (K_2HPO_4)	1.0 g
Peptone	5.0 g
Magnesium chloride ($MgCl_2$)	0.5 g
Distilled water	1000ml
Agar-agar	20 g
pH	7.2

Just before pouring in to the plates 500µl of stock solution of filter sterilized 2, 3, 5- Triphenyl Tetrazolium Chloride (Stock 10 mg/ml).

Enumeration of pathogen population from disease infested soil

Pythium sp. were enumerated by using *Pythium* specific medium potato dextrose agar medium (PDA) supplemented with pimaricin and vancomycin for isolation of *Pythium* spp.) developed by Tsao and Ocana, (1969). Ten grams of soil sample was taken separately and suspended in 90 ml of sterile water and stirred well to get 1:10 dilution (10^{-1}). One ml from this was transferred to test tube containing 9ml of sterile distilled water to get 1:100 (10^{-2}) dilution. Likewise the dilution of the sample was prepared up to 1:10000 (10^{-3}). One ml of the final dilution of each soil sample was aseptically pipetted out into each sterile petri plate separately to which a quantity of 15-20 ml of sterilized and cooled *Pythium* medium was poured and gently rotated for uniform mixing, the plates were incubated at 28 ± 1°C for about 5-10 days. They were observed daily for appearance of *Pythium* colonies.

PDA supplemented with streptocycline was used for enumeration of *Fusarium, Sclerotium* other fungal pathogens by using dilution plate

technique. Numbers of colonies were counted and the population was expressed cfu g^{-1} of soil. Enumeration of bacteria was done by sucrose using Tetrazolium chloride medium (TZC) by using 10^{-3} diluted suspension. Numbers of colonies were counted and the population was expressed cfu g^{-1} of soil. The population was expressed cfu g^{-1} of soil by using following formula.

$$\text{Pathogen population (cfu } g^{-1}) = \frac{\text{Mean plate count x dilution factor}}{\text{Weight of soil (g)}}$$

Isolation of fungal pathogens from infected plant parts

Infected specimens were washed in tap water and roots, rhizomes and pseudo stems were cut into small pieces. The pieces were surface sterilized in 0.1 per cent mercuric chloride solution for 20- 30 seconds. Ten pieces each of different plant parts were placed on potato dextrose agar medium (PDA) supplemented with pimaricin and vancomycin for isolation of *Pythium* spp. and only PDA for other fungi. Later the fungus was purified by single spore isolation.

Purification by single spore isolation

Ten ml of clean filtered two per cent sterile agar solution was poured into sterile petri plates and allowed to solidify. The spore suspension was prepared in sterile distilled water from five days old culture of *Pythium* and *Fusarium*. One ml of spore suspension was spread uniformly on solidified water agar plates. The excess of suspension was aseptically drained off. After 24 hours of incubation at 25 ± 1^0C, the plates were examined and germinated spore were located. Single isolated and germinated spore was marked with ink on the lower side of Petri plate. The portion of the agar directly above the ink mark was cut and transferred to fresh PDA slants in such a way that the mycelium bearing surface is in contact with PDA surface and incubated

at 25 ± 1°C. The pure culture of the fungus was obtained and preserved in refrigerator and sub cultured once in a month.

Maintenance of the culture

The fungus was subcultured on potato dextrose agar slants and allowed to grow at 25°C for 15 days and such slants were preserved in a refrigerator at 4°C and sub cultured once in 30 days. Such culture was used throughout the study.

Identification

Fungi belonging to the genus *Pythium* were identified using the methodology and description of Van der Plaats- Niterink (1981). Other fungi were identified using standard and reference books (Ainsworth, 1971).

The identification of *Fusarium* was done based on the spore morphology and colony characters of the fungus by referring to the 'Illustrated genera of Imperfect fungi" (Barnett and Hunter, 1972). The cultures of *Pythium* and *Fusarium* isolated from the infected rhizome were identified and species were confirmed from Agharkar Research Institute, Pune, Maharashtra. The pure culture of the fungus was obtained by further growing the culture and following hyphal tip culture under aseptic conditions. Such culture tubes were preserved in a refrigerator at 5^0 C and used for further studies.

Mass multiplication of isolated fungi

Sand corn meal medium was prepared in the proportion of 95:5 in order to get maximum inoculum of the fungus. About 400 g of sand-maize meal medium was taken in 1000 ml flasks and watered to 20 per cent of its weight and sterilized at 1.33 kg/cm^2 pressure for one hour. The pure cultures of *P. aphanidermatum* and *F. oxysporum* were

inoculated separately to different flasks under aseptic conditions and incubated at 25±1^{0}C for 20 days. The flasks were shaken on alternate days to get uniform growth. The giant cultures so obtained were used for preparing sick pot to study the pathogenicity and interaction among the different pathogens.

Isolation of bacterium from infected plant parts

Four pieces of pseudo stem cut at six cm away from the collar was surface sterilized in 0.1 per cent mercuric chloride solution for 30 seconds washed in sterile distilled water thrice and placed in 15 ml of sterile distilled water in screw-capped tubes for 30 minutes. If the solution turned turbid, it was used for isolation of bacterium. Four such pieces were used for isolation from four pseudo stem of an infected clump.

A loopful of turbid solution was streaked on sucrose peptone agar in Petri plates and the plates were incubated at 25^{0}C. *Ralstonia solanacearum* colonies appeared after 36 h of incubation at 25^{0}C. The colonies were typical white fluidal with spiral pink centre. Discrete colonies were purified by sub-culturing successively for four times on nutrient agar. From the last plate, individual colonies were picked up and transferred to sucrose peptone agar medium slants. A loopful of bacterial growth was suspended in sterile distilled water and kept at 4^{0}C for short-term storage, while at –20^{0}C in 20 per cent glycerol for long term storage.

Identification of the bacterial isolates by Morphological, Physiological and Biochemical characters

Identification of the bacteria isolated from ginger was based on morphological, physiological, cultural, biochemical and pathogenicity studies as described by Kelman (1954), Buddenhagen *et al.* (1962) and

Schaad (1992). The cultural characteristics of the isolates were studied based on their colony morphology on TZC medium (Kelman, 1954).

All physiological and biochemical tests *viz.,* gram staining, capsule staining, oxidase test, starch hydrolysis, gelatin hydrolysis, catalase test, were carried out as per the methods described in the Manual of Microbial methods (Anon, 1957) and Laboratory guide for identification of Plant pathogenic bacteria (Schaad, 1992).

Oxidase test: Freshly grown (24 to 48 hr) cultures from nutrient agar with 1% glucose were patched onto a filter paper moistened with a fresh oxidase reagent (1% w/v aqueous solution of tetramethyl-para18 phenylene diamine dihydrochloride) using a wooden stick. A purple reaction in 30 seconds was recorded as oxidase positive (Sands, 1990).

Starch hydrolysis: Nutrient agar plates containing 0.2% soluble starch (w/v) were streaked by the test strains and incubated at 30°C until heavy growth occurred. Then plates were flooded with IKI solution (iodine 1 g; potassium iodide 2 g; distilled water 100 ml). A clear zone around a colony was recorded as positive reaction (Sands, 1990).

Gelatin hydrolysis: For this test, nutrient agar with 0.4% (w/v) gelatin was poured into Petri dishes, cooled and dried over night. The following day strains were inoculated on to each plate and incubated at 30°C for 3 days. When good growth was observed, the plate surfaces were flooded with 5 ml of mercuric chloride solution ($HgCl_2$, 12 g; distilled water 80 ml; concentrated HCl 16 ml). A clear zone surrounding bacterial growth indicates positive reaction for the test (Sands, 1990).

Fluorescens test on King's B medium

Fluorescence pigmentation was tested on King's B medium (King *et al.,* 1954) containing protease peptone (Difco) 20 g, $K_2HPO_4.3H_2O$ 2.5 g,

$MgSO_4$. $7H_2O$ 6.0 g, agar 15 g, glycerol 15 ml, and distilled water 1 l. Strains were incubated on this medium at 30°C for 48 h and after 48 h colonies were examined in the dark for fluorescence with a UV lamp (366 nm) according to Sands (1990).

Proving the pathogenicity of rhizome rot pathogens

Sprouts of ginger were raised by planting 20g bits of seed rhizomes in steam sterilized standard potting media consisting of soil: sand: farm yard manure in 3:1:1 ratio. Forty five days old plants were used for inoculation of *Pythium aphanidermatum*, *Fusarium oxysporum*, *Sclerotium rolfsii* and *Ralstonia solanacearum*. A control treatment was maintained without inocula.

Giant cultures of *Pythium aphanidermatum* (20.60 x 10^4 cfu/ml), *Fusarium oxysporum* (23.65 x 10^4 cfu/ml) and *Sclerotium rolfsii* (23.65 x 10^4 cfu/ml) were inoculated to susceptible ginger variety Himachal.

Pathogenicity tests of *Ralstonia solanacearum* (16.5 x 10^6 cfu/ml) was conducted by preparing aqueous suspension of the bacteria grown on sucrose peptone broth medium. Twenty ml of the suspension was poured at the base of ginger plants which were artificially injured by using sterile needle in sterilized plastic pots.

All the pots were maintained at 50 per cent moisture holding capacity and the moisture loss was maintained by adding water on weight basis. Observations were made every alternate day regarding development of wilt symptoms. When the plants showed wilt symptoms such plants were carefully uprooted and the pathogens were reisolated by standard tissues isolation method. The pathogens reisolated were compared with original cultures.

Standardization of inoculum density

The mycelial suspension of the *P. aphanidermatum* and *F. oxysporum* were prepared by harvesting the mycelial mats from a seven day old culture raised on Potato dextrose broth. The mats were homogenized in a blender for one minutes and strained through double layered muslin cloth and diluted with sterile distilled water in such a manner to contain $5x10^2$, $5x10^3$, $5x10^4$, $5x10^5$, $5x10^6$ and $5X10^7$ cfu/ml of mycelial suspension. The inoculum was added to 45 days old healthy plants raised in sterilized pots at different concentrations. Healthy plant was maintained as control. Three replications were maintained for each treatment. Observations like per cent disease incidence and per cent rhizome rot incidence were recorded. Per cent rhizome rot was assessed by the following formula.

$$\text{Per cent rhizome rot} = \frac{\text{No. of fingers infected}}{\text{Total no. of fingers}} \times 100$$

CULTURAL STUDIES

The growth characters of *P. aphanidermatum, F. oxysporum* and *S. rolfsii* were studied on following sixteen different solid media and the best media for growth of these fungus were identified.

1. Asthana and Hawks agar
2. Sabouraud's agar
3. Czapek's agar
4. Elliot's agar
5. Glucose asparagine agar
6. Richards's agar
7. Oat meal agar
8. Potato dextrose agar
9. Yeast extract agar

10. Host extract agar
11. Ashby's mannitol agar
12. Tochina agar
13. Sach's agar
14. Corn meal agar
15. Potato carrot agar
16. Browns agar

The composition and preparation of the above mentioned synthetic and non-synthetic media were obtained from Ainsworth and Bisby's dictionary of fungi as follows.

1. Asthana and Hawker's medium (Tuite, 1969)

Glucose ($C_6H_{12}O_6$)	5.0 g
Potassium nitrate (KNO_3)	3.5 g
Potassium di-hydrogen phosphate (KH_2PO_4)	1.75 g
Magnesium sulphate ($MgSO_4.\ 7H_2O$)	0.75 g
Agar-agar	15.0 g
Distilled water	1000 ml

Agar-agar was melted in 400 ml of distilled water. The other ingredients were dissolved in 400 ml of distilled water. The two solutions were mixed thoroughly and the volume was made upto 1000 ml by adding distilled water and sterilized.

2. Sabouraud's agar

Dextrose ($C_6H_{12}O_6$)	20 g
Peptone	10 g
Agar-agar	20 g
Distilled water	1000 ml

Agar-agar was melted in 500 ml of distilled water. All the ingredients were mixed thoroughly. The volume was made up to 1000 ml and sterilized.

3. Czapek's agar (Tuite, 1969)

Sucrose ($C_{12}H_{22}O_{11}$)	30 g
Sodium nitrate ($NaNO_3$)	2 g
Potassium dihydrogen phosphate (K_2HPO_4)	1 g
Magnesium sulphate ($MgSO_4.7H_2O$)	0.5 g
Potassium chloride (KCl)	0.5 g
Ferrous sulphate ($FeSO_4.7H_2O$)	0.01 g
Agar-agar	20 g
Distilled water	1000 ml

Agar-agar was melted in 500 ml of distilled water. All the ingredients were mixed thoroughly. The volume was made up to 1000 ml and sterilized.

4. Elliott's agar medium

Asparagine ($C_3H_3O(NH_2)_2$ COOH)	1 g
Dextrose ($C_6H_{12}O_6$)	5 g
Magnesium sulphate ($MgSO_4.7H_2O$)	0.5 g
Potassium dihydrogen phosphate (KH_2PO_4)	1.36 g
Sodium carbonate (Na_2CO_3)	1.06 g
Agar-agar	20 g
Distilled water	1000 ml

All the ingredients were mixed thoroughly. The volume was made up to 1000 ml and sterilized at 15 lbs and 121°C for 15 min.

5. Glucose asparagine agar

Glucose ($C_6H_{12}O_6$)	30 g
Magnesium sulphate ($MgSO_4.7H_2O$)	0.5 g
Potassium dihydrogen phosphate (KH_2PO_4)	1.5 g
Asparagine ($C_3H_3O(NH_2)_2COOH$)	1 g
Agar-agar	20 g
Distilled water	1000 ml

Agar-agar was melted in 500 ml of distilled water. All the ingredients were mixed thoroughly. The volume was made up to 100 ml and sterilized.

6. Richards's agar (Ainsworth, 1971

Sucrose ($C_6H_{12}O_6$)	50 g
Potassium dihydrogen phosphate (KH_2PO_4)	5 g
Potassium nitrate (KNO_3)	10 g
Magnesium sulphate ($MgSO_4.7H_2O$)	2.5 g
Ferric chloride ($FeCl_3.6H_2O$)	0.02 g
Agar-agar	20 g
Distilled water	1000 ml

All the above ingredients except potassium dihydrogen phosphate and agar-agar were dissolved in 450 ml of distilled water. Agar-agar was melted separately in 500 ml of distilled water and was mixed with the above solution. The volume was made upto 950 ml. Potassium dihydrogen phosphate was dissolved in 50 ml of distilled water. The two solutions were autoclaved and subsequently mixed together.

7. Oat meal agar (Tuite, 1969)

Oat flakes	60 g
Agar-agar	20 g
Distilled water	1000 ml

Oat flakes were boiled in 500 ml of distilled water for 20 min and the extract was filtered through a muslin cloth. Agar-agar was melted separately in 500 ml of distilled water. Both the solutions were mixed thoroughly. The volume was made up to 1000 ml with distilled water and sterilized.

8. Potato dextrose agar

As mentioned earlier.

9. Yeast extract agar medium

Soluble starch	10.00 g
Yeast extract	1.00 g
Agar- agar	20 g
Distilled water	1000 ml

Twenty gram of the yeast extract was dissolved in 400 ml distilled water and in other 400 ml distilled water 20 gram agar-agar was dissolved and both the solutions were mixed together. The volume was made up to 1000 ml then subjected to sterilization.

10. Host extract agar medium

Healthy ginger rhizomes	200 g
Agar- agar	20 g
Distilled water	1000 ml

Ginger rhizome washed thoroughly and cut into small pieces then boiled in 500 ml distilled water for 15min. The extract was collected by filtering through the muslin cloth. The agar was melted in 500 ml distilled water both the solutions were mixed together. The volume was made up to 1000ml then subjected to sterilization.

11. Ashby's mannitol agar

Mannitol	20 g
Dipotassium phosphate	0.2 g
Magnesium sulphate	0.2 g
Sodium chloride	0.2 g
Potassium sulphate	0.1 g
Calcium carbonate	5.0 g
Agar	20 g
Final pH (at 25°C)	7.4±0.2

Agar-agar was melted in 500 ml of distilled water. All the ingredients were mixed thoroughly. The volume was made up to 1000 ml and sterilized.

12. Tochina agar

Potassium nitrate	30.00 g
Potassium di-hydrogen phosphate	0.50 g
Di- potassium hydrogen phosphate	0.50g
Magnesium sulphate	0.10 g
Ferric chloride trace	0.10 g
Sucrose	30.00 g
Agar- agar	20 g
Distilled water	1000 ml

All the above ingredients except potassium di-hydrogen phosphate and agar-agar were dissolved in 450 ml of distilled water. Agar-agar was melted separately in 500 ml of distilled water and was mixed with the above solution. The volume was made up to 950 ml. Potassium dihydrogen phosphate was dissolved in 50 ml of distilled water. The two solutions were autoclaved and subsequently mixed together.

13. Sach's agar

Di- potassium hydrogen phosphate	0.25 g
Calcium nitrate	1.00 g
Magnesium sulphate	0.25 g
Ferric chloride trace	0.25 g
Calcium carbonate	4.00 g
Agar- agar	20 g
Distilled water	1000 ml

All the above ingredients except potassium di-hydrogen phosphate and agar-agar were dissolved in 450 ml of distilled water. Agar-agar was melted separately in 500 ml of distilled water and was mixed with the above solution. The volume was made up to 950 ml. Potassium dihydrogen phosphate was dissolved in 50 ml of distilled water. The two solutions were autoclaved and subsequently mixed together

14. Corn (maize) meal agar

Maize	30 g
Agar-agar	20 g
Distilled Water	1000 ml

Maize meal was boiled in distilled water and the extract was collected by filtering through a muslin cloth. Agar-agar was melted separately in distilled water. The corn extract was mixed in the molten agar and volume was made up to 1000 ml with distilled water and sterilized.

15. Potato carrot agar

Potato	20 g
Carrot	20 g
Agar-agar	20 g
Distilled water	1000 ml

Grated vegetables were boiled for 1 h in distilled water. This was strained through fine sieve. Agar-agar was melted separately in distilled water. Both the solutions were mixed thoroughly. Volume was made upto 1000 ml with distilled water and sterilized.

16. Browns agar

Sucrose	2.00 g
Asparagine	2.00 g
Potassium di-hydrogen phosphate (KH_2PO_4)	1.25 g
Magnesium sulphate ($MgSO_4$. $7H_2O$)	0.75 g
Agar-agar	20 g
Distilled water	1000 ml

All the above ingredients except potassium di-hydrogen phosphate and agar-agar were dissolved in 450 ml of distilled water. Agar-agar was melted separately in 500 ml of distilled water and was mixed with the above solution. The volume was made upto 950 ml. Potassium dihydrogen phosphate was dissolved in 50 ml of distilled water. The two solutions were autoclaved and subsequently mixed together.

Twenty ml of each medium listed above was poured in to 90 mm Petri plates. Such plates were inoculated with five mm discs of test fungi cut from periphery of actively growing culture and incubated at 25±1°C. Each treatment was replicated thrice. Observations on colony diameter were recorded by averaging in two directions for each plate. The fungus colony, surface elevation and sporulation were also recorded. The data on radial growth were analysed statistically. The sporulations were graded as follows.

Sl. No.	Score	Grade	Description (Spore/microscopic field)
1	++++	Excellent	>150
2	+++	Good	101-150
3	++	Fair	51-100
4	+	Poor	1-50
5	-	No sporulation	-

Survival of pathogen in infected rhizome

Fungal pathogen culture disc were placed in both sterilized and unsterilized pots, whereas bacterial suspension of 25 ml of an aqueous suspension containing 10^8cfu/ml was poured sterilized and unsterilized pots to study survivability in soil. Infected rhizomes of ginger collected from the field were placed in a clean place to study survival ability in rhizomes. Presence of pathogen in rotten tissue was confirmed for every fifteen days by isolation on selective medium.

Interaction among the pathogens

Pot culture tests were conducted to investigate the interaction among the rhizome rot pathogens viz., *P. aphanidermatum*, *F. oxysporum*, *S. rolfsii,* and *R. solanacearum*. The details of the experimentation are presented here under.

Details of the experiment

1) *Pythium aphanidermatum* alone (P)
2) *Fusarium oxysporum* alone (F)
3) *Sclerotium rolfsii* alone (S)
4) *Ralstonia solanacearum* alone (R)
5) P+F

6) P+S

7) P+R

8) F+ S

9) F+R

10) S+R

11) P +F+S

12) P + F +R

13) F+S+R

14) S+R +P

15) P+F +S+R

16) Control

Three replications were maintained for each treatment. The experiment was conducted at 30, 60, 90 and 120 DAP.

Treatments were

P. aphanidermatum : Mycelial suspension @ 50 ml/pot ($4.5x10^6$ cfu/ml)

F. oxysporum : Mycelial suspension @ 50 ml/pot ($6.5x10^6$ cfu/ml)

S. rolfsii : Mycelial suspension @ 50 ml/pot ($5.5x10^6$ cfu/ml)

R. solanacearum : Cell suspension @ 50ml/pot ($5.5x10^6$ cfu/ml)

To prepare inoculum of *P. aphanidermatum, F. oxysporum,* and *S. rolfsii* 100 ml potato dextrose broth were seeded with mycelial discs from 48 h old culture and incubated for seven days. The mycelium was washed, suspended in sterile tap water and homogenized in a blender at low speed for five minutes. The suspension was diluted to 400 ml. Fifty ml of the suspension was used for inoculation purpose. To prepare cell suspension of *R. solanacearum* cultures were grown on nutrient broth for 36 h. Bacterial growth was then suspended in 10 ml of sterile water. Fifty

millilitre of the suspension was applied at the base of the plant. Pathogens were inoculated to 45 days old healthy plants raised in sterilized pots. The ginger variety Himachal was used for the study.

Disease incidence was recorded from the day when symptoms appeared and continued until fresh infections ceased to appear. Observations like per cent disease incidence and per cent rhizome rot were recorded. Later pathogens were detected for each treatment.

In-vitro evaluation of chemicals and bioagents

Chemicals

The efficacy of non-systemic fungicides (at the concentrations of 0.2 and 0.3 per cent), systemic fungicides (at the concentration of 0.05 and 0.1 per cent) and Combi products (@ 0.1 and 0.2 per cent products were assayed). The fungicides used are given here under.

Fungicides used under *in-vitro* evaluation

Sl. No.	Common name	Chemical name	Trade name
Non systemic fungicides			
1	Copper Oxy Chloride	Copper oxy chloride	Blitox 50 % WP
2	Mancozeb	Manganese and Zinc ethylene bis-dithiocarbonate + Zinc	Indofil M-45 75% WP
3	Methoxyethyl mercury chloride	2- methoxyethyl mercury chloride	Emisan
4	Thiram	Tetramethyl thiuram disulphide	Thiram 75WP
5	Captan	N-trichloromethyl mercapta 4-Cyclolexene-1-2- dicarboximide-Ntrichloromethyl thiotetrahydropthalamide	Captaf 50% WP

Systemic fungicides			
1	Carbendazim	2-(Methoxy-Carbomyl) – benzimidazole	Bavistin 50% WP
2	Metalaxyl MZ	Methyl N-(2-methoxyacetyl)-N-(2.6,xylyl)-DL-alaninate)	Ridomil MZ 75 WP
3	Tridemorph	2,6-dimethyl-4-tridecylmorpholine	Calixin 80% EC
4	Hexaconazole	2-(2,4-dichlorophenyl)-1-(1H-1,2,4-triazol-1-yl)hexan-2-ol	Sabizole 5% EC
Combi products			
1	(Carbendazim 12% + ancozeb 63% WP)	Manganes zinc ethylene bisdithiocarbamate +2-(Methoxy carboryl) – benzimidazole	SAAF
2	(Metalaxyl MZ+ Mancozeb)	Methyl N-(2-methoxyacetyl)-N-(2.6,xylyl)-DL-alaninate) + Manganese and Zinc ethylene bis dithiocarbonate + Zinc	Ridomil gold
3	Cymoxanil 8% + Mancozeb 64%	2-cyano-N-[(ethylamino)carbonyl] -2-(methoxyimino)acetamide + Manganese and zink ethylene bis dithocarbonate	Curzate M8

The fungicides were tested against *P. aphanidermatum* and *F. solani* by adopting 'Poisoned food technique'. The required concentrations of chemicals were prepared and incorporated into sterilized, cooled potato dextrose agar. Twenty ml of cooled medium was poured into 90 mm sterilized Petri plates and all plates were inoculated with actively growing five mm mycelial disc of *P. aphanidermatum* and *F. solani* separately. Three replications were maintained for each treatment. These plates were incubated at 25+ 2^{O}C for seven days, and colony diameter was recorded. Per cent inhibition of mycelial growth over control was calculated by using the formula of Vincent (1947).

$$I = \frac{(C-T)}{C} \times 100$$

Where,

I = Per cent inhibition

C = Growth of fungal plant pathogens in control (mm)

T = Growth of fungal plant pathogens in dual culture plate (mm)

CULTURAL PRACTICES

Date of Planting

The experiment on effect of date of sowing/planting was conducted at farmer's field at Chikmarasa, Shimoga taluk during Kharif 2012. The treatments details are as follows.

Treatments

1 Planting in March first week

2 Planting in April first week

3. Planting in May first week

4. Planting in June first week

5. Planting in July first week

Plot size : 2m x 2 m

Design : RCBD

Replications : 4

Treatments : 5

Screening of ginger cultivars against rhizome rot complex

Five major ginger cultivars grown in malnad areas were screened in sick soil that is in the field where in the last crop was ginger and diseased. Each variety was sown in a row with 20 rhizomes/row.

Observation like per cent germination, per cent disease incidence and yield (fresh weight) were taken.

T1 –Himachal

T2- Reo-de-jeneria

T3- Maran

T4- Varada

T5- Humnabad local

Integrated management of rhizome rot disease of ginger under field conditions

An experiment was conducted during *Kharif* 2012 on the integrated management of rhizome rot of ginger in the farmer's field located at Chikamarasa (Shimoga taluk) and at Nimbegundi (Shikaripura taluk) Shimoga district of Karnataka. Treatment details of field trial on rhizome rot management in ginger were presented in Table 2.

Observations on germination, growth parameters (plant height and number of tillers per plant) and disease incidence at 30 days interval and yield were recorded.

Statistical analysis

The data obtained in the present investigations for various parameters were subjected to ANOVA for a completely randomized design for *in vitro* studies and randomized complete block design for *in vivo* studies by using M-STATC programme.

Table 2: Treatment details of field trial on rhizome rot management in ginger

Sl. No.	Treatment details
T1	Rhizomes dipped in 0.2% Curzate M8 for 30 min + One drench with same solution, immediately at the onset of the disease.
T2	Rhizomes dipped in 0.2% Mancozeb for 30 min + One drench with same solution immediately at the onset of the disease.
T3	Rhizome treatment with *Trichoderma viride* @ 10 g/Kg + Soil application of *Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha.
T4	Rhizome treatment with *Pseudomonas fluorescens* @ 10 g /Kg + Soil application of *P. fluorescens* @ 10 Kg mixed with 25t FYM /ha.
T5	Rhizomes dipped in 0.3% Copper Oxy Chloride +0.05% streptocycline for 30 min + One drench with same solution, immediately at the onset of the disease
T6	Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha.
T7	Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease.
T8	Control

Plot size: 4m x 5m Design: RCBD Treatments: 8 Replications: 3

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the investigations on rhizome rot of ginger with reference to survey, isolation of pathogens associated with rhizome rot complex, interactions among different pathogens causing rhizome rot and management of disease in the field conditions conducted during 2011-12 and 2012-13 are presented in this chapter.

Symptomatology

Rhizome rot is commonly used for all rhizome diseases irrespective of pathogen involved. The ultimate result is either partial or total loss of rhizome. The major diseases identified were the soft rot caused by *Pythium spp.,* wet rot caused by *Fusarium spp.,* bacterial wilt caused by *Ralstonia solanacearum, Sclerotium* rot caused by *Sclerotium rolfsii* and root knot caused by *Meloidogyne spp.* The individual pathogen infection may lead to rhizome rot or in combination of pathogens leading to rhizome rot complex.

a) Soft rot

present investigation revealed that, *Pythium spp.* often infects immature and undifferentiated parts of the host plant as both pre-emergence and post-emergence rhizome rot, yellowing of foliage was clearly seen starting from the margins of the lower most leaf and later progresses upwards. The rotted tissues of immature plants emit foul smell. Whereas in the mature plant, foliar yellowing and stunted growth of the plants was common along with the rotting of rhizome (Plate1).

b) Wet rot/ Yellows

Wet rot is confirmed to be caused by *Fusarium spp.* The infected plants exhibited foliar yellowing. The affected plants wilted and dried up, but didn't fall on the ground in contrast to soft rot and bacterial wilt



Water soaked lesions
at collar region



Post emergence damping
off in field condition



Foliar yellowing &
stunted growth



Rotted rhizome

Plate 1. Symptoms of soft rot of ginger caused by *Pythium aphanidermatum*

affected ginger. Affected rhizome showed a creamy discoloration of the vascular system and cortical rot. Rhizomes showed varying degrees of decay finally leading to wet rot symptoms (Plate 2).

d) Sclerotium rot

Sclerotium rot is confirmed to be caused by *Sclerotium rolfsii.* This usually occurs during the maturity of the crop, *i.e*. December- January. Foliar yellowing and drying up of foliage was observed. When rhizomes were examined, white mycelial growth and formation of mustard like brown coloured sclerotial bodies were observed (Plate 3).

d) Bacterial wilt

Bacterial wilt is confirmed to be caused by *Ralstonia solanacearum.* Water soaked patches on the collar region of the pseudostem were observed. Later, leaves became flaccid with intense yellowish colour and drooped. Leaves showed roll up symptoms and the whole plant dried up. Pseudostem came off easily with a gentle pull. Such rhizomes when pressed exhibited oozing of bacterial exudate and in the advanced stages, decaying of whole rhizome leaving only skin was seen (Plate 4).

e) Root knot of ginger

Infected plants in the field showed stunted and chlorotic symptoms. Small galls were seen on the roots of infected plants. The galls resembled bead-like structures. The galls were seen alternatively on the roots. The pathogen was identified as *Meloidogyne incognita* (Plate 5).

4.1 Survey for rhizome rot incidence

Survey was conducted during *Kharif* seasons of 2011 and 2012 in major ginger growing areas of malnad district *viz.*, Shimoga, Coorg, Chikkamagalore, Hassan and Uttara Kannada to find out the prevalence of rhizome rot and also to know the other problems of ginger cultivation





Yellowing of lower leaves



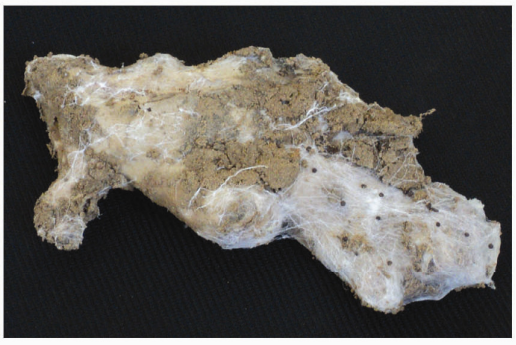
Discoloured rhizome

Plate 2. Symptoms of wet rot of ginger caused by *Fusarium oxysporum*



White mycelial growth





Sclerotial bodies



Plate 3. Symptoms of Sclerotium rot of ginger caused by *Sclerotium rolfsii*



Plate 4. Symptoms of bactireal wilt of ginger caused by *Ralstonia solanacearum*



Plate 5. Symptoms of root knot and rhizome fly of ginger

as explained in material and methods. The results of the survey are presented in the Table 3 and 4.

During Kharif 2011 disease incidence was noticed in all locations surveyed and it ranged from 3.5 at N.R. Pura to 56.00 per cent at Anavatti (Table 3). In Shimoga district maximum average disease incidence observed in Shikaripura taluk (34.13 %) and minimum average disease incidence was observed at Sagara taluk (16.50%). In Chikkamagalore district highest disease incidence was recorded at Chikkamagalore taluk (32.50%) and lowest was recorded in N.R. Pura taluk (19.33%).

In coorg district among the surveyed taluks average disease incidence was 19.74 (Virajpet) followed by 22.50 per cent (Somavarpet). Whereas in Hassan district, disease incidence ranged from 11.25 (Alur taluk) to 17.60 per cent (Sakaleshpura taluk). In Uttara kannda Sirsi taluk being the major ginger growing area where the average rhizome rot incidence was 34.90 per cent.

During Kharif 2012 intensive survey was conducted in malnad districts of Karnataka to know the incidence of ginger rhizome rot. Disease incidence was ranged from 5.24 per cent at Rothur to 52.50 per cent at Doddinathale (table 4). In Shimoga district, average disease incidence was maximum in Soraba taluk (33.49) which was followed by Hosanagara (26.80%), Sagara taluk (24.17%), Shimoga (23.15%) and minimum incidence was recorded in Shikaripura (18.72%).

In Uttara Kannada district, Varada was the major variety cultivated by many farmers and rhizome rot incidence was ranged from 18.50 to 25.50 per cent in Sirsi taluk. In Chikkamagalore district, highest average incidence was recorded at Chikkamagalore taluk (31.48%) and lowest was at N. R pura taluk (19.09%).

Table 3: Survey for incidence of rhizome rot complex of ginger in malnad districts of Karnataka during 2011

District	Taluk	Place	Cultivar grown	Age of the crop (months)	DI (%)	Remarks by the farmer/ observations
Shimoga	**Shimoga**	Ayanur	Himachal	4.5	08.50	Leaf spot was severe
		Choradi	Himachal	4.0	25.00	Disease started at 3.5 months after planting and spread rapidly
		Konagavalli	Maran	5.2	22.50	Wilting started at 3.5 months after planting
		Thyajavalli	Himachal	5..0	12.50	Very good drainage was provided to crop
		Sevalal nagar	Maran	6.0	35.50	Gray leaf spot about 40%, rhizomes was infected by rhizome fly
		V. Benavalli	Rio-de- Janero	5.0	22.50	Jambittige soil
		Chikmarasa	Himachal	5.0	34.40	Very poor drainage was provided
		Kumsi	Himachal	4.0	17.50	Good tillering and crop stand
				Mean	**21.44**	
	Shikaripur	Udugani	Rio-de- Janero	3.5	20.00	Poor plant stand, 10-15% gray spot
		Hosur	Himachal	3.5	28.50	Heavy black soil with poor drainage
		Nimbegondi	Himachal	4.5	32.50	Leaf spot was severe
		Shiralkoppa	Rio-de- Janero	3.0	55.50	Black soil with poor drainage
				Mean	**34.13**	
	Sagara	Chennakopa	Himachal	5.50	18.50	Disease starts at the onset of rain
		Anandapura	Rio-de- Janero	2.0	23.50	Jabittige soil
		Korgi	Himachal	3.0	07.50	Applied Ridomil MZ as rhizome treatment
				Mean	**16.50**	
	Soraba	Mavalli	Rio-de- Janero	5.1	15.50	Disease starts at the onset of rain
		Uluvi	Local variety	3.5	12.00	Rhizome treated with metalaxyl
		Anavatti	Himachal	5.5	56.00	They does't know about seed treatment, leaf spot, root knot and rhizome fly infections were observed

		Kadakani	Rio-de- Janero	5.0	28.50	Converted paddy field
		Hodabetta	Rio-de- Janero	5.5	30.50	Disease starts at the onset of rain
		Hirekasavi	Himachal	3.5	32.50	Disease starts at the onset of rain
				Mean	**29.17**	
	Hosanagar	Ripponpet	Maran	3.5	35.50	Very poor drainage has been provided
		Arasal Benvalli	Maran	3.5	30.00	Root knot nematode was observed
		Tammadikoppa	Maran	4	28.50	Root knot nematode was observed
				Mean	**31.33**	
Chikka magalore	**Chikkamagalore**	Punduru	Maran	5.0	32.50	Infected with rhizome fly
	Mudigere	Mudigere	Himachal	5.5	30.00	-
	N.R. Pura	N.R. Pura	Maran	4.5	3.50	Very good crop stand, Cloropyriphos and neem cake
		Gubbiga	Local variety	5.5	26.00	Poor drainage
		Hansur	Local variety	3.5	29.50	Bacterial infection was very high
		Mugathihalli	Local variety	4.4	22.00	-
		Sringeri	Local variety	2.5	18.50	Root knot nematode was observed
		Balehonnur	Maran	3.0	16.50	Rhizome treated with Mancozeb
				Mean	**19.33**	
Coorg	**Virajpet**	Virajpet	Local variety	4.0	16.00	Disease starts at the onset of rain
		Napoklu Kademallur	Rio-de- Janero	3.5	18.50	Disease starts at the onset of rain
		Haabyatmangala	Rio-de- Janero	5	22.00	Disease starts at the onset of rain
		Virajpet	Local variety	5.5	25.80	Sclerotial bodies were seen on infected rhizome
		Balele	Local variety	4.5	16.50	Root knot nematode was observed
				Mean	**19.74**	
	Somavarapete	Ganagur	Local variety	5.0	28.50	Disease starts at the onset of rain
		Shantha	Local variety	4.5	19.00	Applied neem cake as basal dose
		Bettadahally	Local variety	5.0	15.00	Disease starts at the onset of rain
		Negrugalale	Local variety	4.5	22.00	-
		Uugur	Rio-de- Janero	7.5	26.00	Disease starts at the onset of rain
		Kodige	Local variety	5.5	24.50	Disease starts at the onset of rain
				Mean	**22.50**	**-**

Hassan	**Alur**	Alur	Maran	5.0	10.50	Good crop stand
		Bhairapura	Himachal	5.5	12.75	Disease starts at the onset of rain
		Heddurga	Himachal	6.5	07.50	applied Ridomil and neemcake
		Palya	Himachal	3.5	14.25	Rhizome treated with Ridomil MZ
				Mean	**11.25**	
	Sakaleshapura	Hanbal	Himachal	5	22.50	Infected by rhizome fly
		Hebsale	Local variety	4	18.50	Disease starts at the onset of rain
		Heggatte	Varada	4	16.00	Sclerotial bodies were observed
		Janekere	Varada	6	18.50	Poor drainage
		Sakaleshapura	Varada	5	12.50	Rhizome treated with metalaxyl
				Mean	**17.60**	
Uttara kannada	**Sirsi**	Banvasi	Local variety	6.5	33.50	Disease starts at the onset of rain
		Katranji			18.50	-
		Maduravalli	Varada	4	45.50	Disease starts at the onset of rain
		Koralakatte	Himachal	-	52.00	Grey spot was about 15-20%
		Bhashi	Varada	4.5	25.00	Disease starts at the onset of rain
				Mean	**34.90**	

Table 4: Survey for Incidence of rhizome rot complex of ginger in malnad districts of Karnataka during 2012

Name of the District	Taluk	Place	Cultivar grown	Age of the crop (month)	DI (%)	Remarks
Shimoga	Shimoga	Mandaghatta	Local variety	6.5	29.00	Jambittige soil
		Chennahalli	Himachal	6.0	23.56	Jambittige soil
		Tyavarekoppa	Himachal	4.5	32.60	Jambittige soil
		Hosahalli	Himachal	5.5	20.10	Jambittige soil with poor drainage
		Sakrebailu	Himachal	3.5	22.30	Jambittige soil, severe gray spot
		V. Benavalli	Himachal	3.6	19.00	Root knot nematodes were observed
		Jananpura	Himachal	4.0	24.50	Hasiru kole is the major problem
		Ayanur	Himachal	4.0	18.00	Rhizome treated with chlorpyriphos and metalaxyl
		Surulihalli	Himachal	5.0	22.50	Jambittige soil with poor drainage
		Ganedaalu	Himachal	3.5	25.10	Disease started after germination itself
		Kakanahasudi	Himachal	4.5	18.00	Leaf spot problem
				Mean	**23.15**	
	Shikaripur	Manchikoppa	Himachal	2.0	20.00	Sprayed metalaxyl at the base of plant
		Hirejambure	Himachal	4.5	18.00	Black soil, disease started after two months of planting
		Chennahalli	Himachal	5.0	22.50	Severe gray leaf spot
		Shiralkoppa	Himachal	5.0	15.5	Sclerotial bodies seen
		Balligvi	Himachal	4.5	17.60	
				Mean	**18.72**	
	Sagara	Ikkeri	Local variety	-	38.50	Rhizome emits foul smell
		Anandapur	Himachal	4.5	26.50	Leaf spot major disease
		Korgi	Local variety	-	07.50	Crop was provided with good drinage
				Mean	**24.17**	

	Soraba	Mavalli	Himachal	3.5	40.25	Disease started after first month of planting, drenching done with Metalaxyl
		Togarsi	Local variety	4.5	38.25	-
		Anavatti	Himachal	4.5	36.25	Metalaxyl drenching done
		Kadakani	Local variety	5.0	35.50	-
		Hodabetta	Rio-de- Janero	4.0	26.80	Poor drainage
		Hirekasavi	Rio-de- Janero	6.0	23.90	Poor crop stand
				Mean	**33.49**	
	Hosanagara	Ripponpet	Rio-de- Janero	4.5	25.50	Disease starts at the onset of rain
		Hirejenni	Himachal	3.5	24.90	Sclerotial bodies were observed
		Chikkajenni	Himachal	3.5	30.00	Poor drainage
		Tammadikoppa	-	4.0	26.80	Rhizome treated with metalaxyl
				Mean	**26.80**	
Uttara kannada	**Sirsi**	Sirsi	Varada	3.5	25.50	Jambittige soil
		Karekoppa	Varada	3.5	23.60	Poor drainage
		Navangere	Varada	4.0	20.50	Disease started after 2 months of planting
		Siddapura	Varada	4.0	19.00	-
		Balegeri	Varada	5.0	18.50	Poor drainage
				Mean	**21.42**	
Chikka magalore	**Chikka magalore**	Muthinakoppa			31.00	
		Kusuburu	Varada	5.5	32.00	
		Doddinathale	Local variety	6.0	52.50	Poor drainage
		Makod	Himachal	4.5	33.00	Poor crop stand
		Mallikoppa	-	-	31.00	-
		Kanaburu colony	-	-	32.00	-
		Sathgoli	-	-	27.50	-
		Agalamane	Rio-de- Janero	3.5	12.80	Applied copper sulphate ($cuso_{4)}$
				Mean	**31.48**	

	Mudigere	Mudigere	Local variety	5.5	25.00	Foul smell was emitted from rhizome
		Balekoppa	Local variety	6.0	23.00	
		Badagabailu	Local variety	3.5	21.00	Applied copper sulphate ($cuso_{4)}$
		Menasuru	Local variety	6.0	13.50	-
				Mean	**20.63**	
	N.R.Pura	N.R.Pura	-	3.5	50.00	Poor drainage
		Mudabagilu	-	4.0	21.00	Poor drainage
		Nelagadde	Rio-de- Janero	4.0	18.00	Applied copper sulphate ($cuso_{4)}$
		Kolale	Rio-de- Janero	3.5	10.00	Applied copper sulphate ($cuso_{4)}$
		Balehonnuru	Rio-de- Janero	5.0	08.00	Sandy loam soil with good drainage
		Kadabagere	-	3.2	16.00	Converted paddy field
		Allduru	-	4.6	28.00	Converted paddy field
		Kuduvalli	-	-	6.00	Applied neem cake
		Vasthare	Himachal	4.5	15.00	Infected with shoot borer
		Aldagudde	Local variety	5.0	13.00	-
		Rampura	Local variety	5.0	25.00	-
				Mean	**19.09**	
Coorg	**Virajpet**	Kademallur	Local variety	4.5	22.50	-
		Kadanga	Local variety	3.5	18.00	Very poor drainage has been provided
		Nellinakere	Local variety	3.5	14.02	Root knot nematode was observed
		Haabyatmangala	Rio-de- Janero	4.0	12.54	Root knot nematode was observed
		nariyandada	Local variety	4.0	31.45	Infected by rhizome fly
		Balele	Local variety	3.5	28.14	Infected by rhizome fly
				Mean	**21.11**	
	Madikeri	Panane	Himachal	4.5	13.25	Very good crop stand, applied neem cake
		Kakkabe	Local variety	5.0	16.50	-
		Ballananatti	Local variety	5.0	9.50	-
		Rothur	Sirsi variety	4.0	5.24	Rhizome treated with metalaxyl
				Mean	**11.12**	

	Somavarapet	Ganagur	Rio-de- Janero	5.0	28.5	Root knot nematode was observed
		Shanthalli	-	-	19.0	-
		Bettadahally	Rio-de- Janero	5.0	15.0	Rhizome treated with Mancozeb
		Dundalli	Maran	3.5	22.0	Disease starts in july- August
		Neragalale	Rio-de- Janero	4.5	26.0	Disease starts at the onset of rain
		Netha	Rio-de- Janero	4.0	24.5	Disease starts at the onset of rain
				Mean	**22.50**	
Hassan	**Alur**	Alur		4.5	10.5	-
		Kundur	-	3.5	12.75	
		Magge	Rio-de- Janero	3.5	07.50	Sclerotial bodies were seen on infected rhizome
		Holebellur	Local variety	4.0	14.25	-
		Kenchana hoskote	Local variety	5.5	12.5	-
				Mean	**11.50**	
	Sakaleshapur	Sakaleshapura	Local variety	4.5	22.5	Sclerotial bodies were seen on infected rhizome
		Mallipatna	Local variety	3.5	18.5	-
		Doddamagge	Himachal	6.0	16.0	Rhizome treated with Mancozeb
		Holenarasipura	Local variety	6.0	18.50	-
		Sakaleshapura	Himachal	5.5	12.5	Rhizome treated with Mancozeb
				Mean	**17.50**	

DI-Disease incidence

In coorg district, rhizome rot was ranged from 11.12 to 22.50 per cent at Madikeri and Somavarpet taluks respectively. In Hassan, minimum incidence of 11.50 per cent was observed at Alur taluk and maximum incidence of 17.50 per cent was observed at Sakaleshpura taluk.

During survey diseased fields and infected ginger were carefully observed and farmer's opinion about the constraints of ginger production, soil type and their knowledge about disease management were recorded and presented in the table 3 and 4 as remarks by farmers/ observations. Which implies the following observations.

Himachal, Rio-de-Janero, Varada and Maran were major varieties popular in all the five surveyed districts of Karnataka. Most of the farmers were not aware of seed borne nature of the disease and the importance of seed treatment. Rhizome rot was the major constraint of ginger cultivation which was followed by grey leaf spot caused by *Phyllosticta zingiberi* which was becoming severe in the recent years. Most of the ginger cultivating soils were converted paddy fields and were plinthite (Jambittige soil) with very poor drainage.

Most of the farmers were of the opinion that disease starts after the onset of rain. Maggots of rhizome fly were found in rhizomes of wilting plants this would enhance the attack of other soil borne pathogens and saprophytes. Root knot nematode was observed at Balele (Virajpet taluk) during 2011 and Ganagur (Somavarpet taluk), Habyathmangala and Nellinakere (Virajpet taluk), V. Benavalli (Shimoga taluk) during 2012.

Consolidated district wise rhizome rot incidence data (Table 5) indicated that, disease incidence was more during Kharif 2011 (24.68 %) than Kharif 2012 (20.80 %). Average rhizome rot incidence in malnad districts during 2011 and 2012 was 22.74 per cent (Figure 1).

Table 5: Survey for incidence of rhizome rot in malnad districts of Karnataka during 2011 and 2012

District	Taluk	Average PDI (%)		
		2011	**2012**	**Mean**
Shimoga	Shimoga	21.44	23.15	22.29
	Shikaripur	34.13	18.72	26.42
	Sagara	16.50	24.17	20.33
	Soraba	29.17	33.49	31.33
	Hosanagara	31.33	26.80	29.07
	Mean	**26.51**	**25.27**	**25.89**
Uttara Kannada	**Sirsi**	**34.90**	**21.42**	**28.16**
Chikkamagalore	Chikkamagalore	32.50	28.12	30.31
	Mudigere	30.00	20.63	25.32
	N. R. Pura	19.33	19.09	19.21
	Mean	**25.92**	**23.60**	**24.76**
Hassan	Alur	11.50	13.40	12.45
	Sakaleshpura	18.42	17.50	17.96
	Mean	**14.96**	**15.45**	**15.20**
Coorg	Virajpete	19.76	21.11	20.43
	Somvarapete	22.50	22.50	16.81
	Madikeri	-	11.12	22.50
	Mean	**21.13**	**18.24**	**22.69**
Average of districts	**Grand mean**	**24.68**	**20.80**	**22.74**

PDI- per cent disease incidence

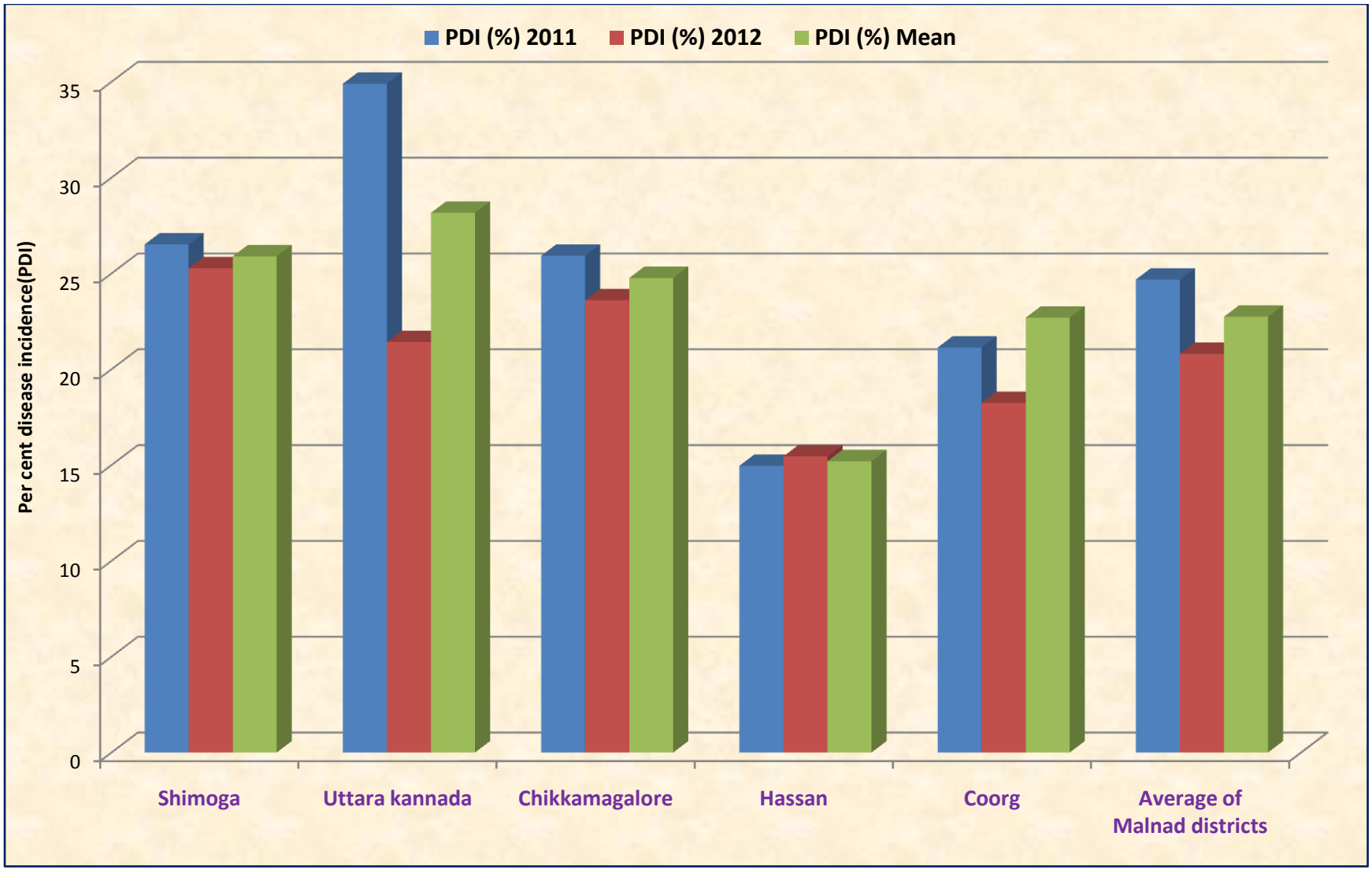


Fig. 1: Survey for incidence of rhizome rot in malnad districts of Karnataka during 2011 and 2012

4.1.1 Relationship between soil physicochemical parameters and disease incidence

Disease infected soils were analysed for soil physicochemical parameters *viz.*, Hydrogen ion concentration (pH), electrical conductivity (EC), organic carbon content (OC), nitrogen content, phosphorus content, and potassium contents and are presented in Table 6 along with the disease incidence of their respective place.

The physicochemical parameters of ginger growing soils having different degrees of rhizome rot complex were put to correlation and regression analysis as independent variables and DI (%) as a dependent variable. Correlation matrix is presented in Table 7. Correlation results indicated that, per cent disease incidence have got significant negative correlation with pH, OC and N- content with correlation coefficient of -0.784, -0.518 and -0.544, respectively. Other parameters such as EC, P and K-content didn't show any significant correlation with per cent disease incidence.

Further, R^2 (co-efficient of determination) was found out to be 0.713 (Table 9), which implies that 71.30 per cent variation in the disease development as explained by all the six independent variables *i e.*, pH, EC, OC, N,P, and K content in the soil. Some Parameters have shown high correlation within themselves that is independent variables considered here do have some amount of interdependence. So step wise regression analysis was performed to eliminate parameters having interdependence to find out the most important determinants contributing to the disease incidence.

Regression model with soil physicochemical parameters which have significant correlations is presented in Table 8. In the first step, three parameters were dropped keeping only pH, OC and N. The R^2 value

Table 6: Relationship of disease incidence with pH, EC, Organic carbon, N, P and K in different locations

Sl. No.	Place	pH	EC (dSm^{-1})	OC (%)	N-content ($kg\ ha^{-1}$)	P-content ($kg\ ha^{-1}$)	K-content ($kg\ ha^{-1}$)	Disease incidence (%)
1.	Surali halli	5.84	0.02	0.94	344.96	58.97	126.45	22.50
2.	Umble bailu	6.86	0.04	1.11	232.06	49.20	62.83	15.00
3.	Mallikoppa	6.90	0.02	0.97	128.58	39.29	77.62	31.00
4.	Doddinathale	4.60	0.04	0.45	100.35	44.72	101.92	52.50
5.	Kanabur colony	5.26	0.04	0.93	106.62	25.45	79.86	32.00
6.	Sathgoli	6.92	0.01	1.03	132.71	22.12	10.64	27.50
7.	Balekoppa	5.74	0.02	1.57	282.24	92.56	122.98	23.00
8.	N.R. pura	5.09	0.03	0.46	100.35	78.79	64.06	50.00
9.	Vasthare	6.30	0.02	1.00	225.79	32.17	24.64	15.00
10.	Aladagudde	7.84	0.02	0.68	219.52	37.19	75.82	13.00
11.	Mudabagilu	5.94	0.03	1.00	169.34	92.23	497.84	21.00
12.	Badaga bailu	5.33	0.04	0.98	181.89	37.87	231.73	21.00
13.	Huluguthuru	7.64	0.04	1.52	178.75	80.01	108.64	14.50
14.	Uchangi	6.88	0.04	2.20	344.96	80.96	93.52	12.34
15.	Moodahalli	7.32	0.02	2.13	131.71	82.79	112.34	13.50
16.	Chikmarasa	5.60	0.26	1.51	213.25	35.15	126.78	34.50
17.	Shimoga	5.76	0.03	0.54	132.71	11.67	22.85	27.65
18.	Jannapura	5.00	0.04	0.57	119.17	22.06	19.82	24.50
19.	Abbalagere	5.40	0.02	0.46	203.84	16.90	6.08	26.50
20.	Basavagangur	6.67	0.03	1.20	181.89	34.54	19.04	18.50
21.	Gerukoppa	6.14	0.04	1.11	206.98	23.48	47.60	20.50
22.	Channapura	5.80	0.02	0.68	106.62	46.28	21.06	32.50
23.	Mavalli	4.68	0.19	o.51	100.35	30.00	11.80	40.25
24.	Audige	7.10	0.26	2.09	282.24	55.92	21.06	13.50
25.	Uraganahalli	5.64	0.17	1.28	181.89	26.20	10.64	17.50
26.	Jade	5.20	0.10	0.47	119.17	12.76	18.03	32.50
27.	Sirsi	6.12	0.19	0.88	137.98	31.49	84.34	21.24
28.	Banavasi	6.88	0.22	1.28	119.17	15.34	4.00	35.50
29.	Ramanapura	5.90	0.04	0.91	132.71	33.12	67.87	27.50
30.	Gomala	7.50	0.02	1.05	156.80	77.09	12.10	12.67
31.	Anavatti	4.99	0.18	0.68	103.49	51.85	14.78	36.50
32.	Thavarekatte	7.04	0.02	0.83	344.96	46.42	5.89	13.40
33.	Kodakani	5.10	0.28	0.97	103.49	32.17	3.45	35.50
34.	Doddanudi	7.76	0.18	0.91	147.39	33.25	2.50	10.50
35.	Ayanur	8.00	0.02	0.34	564.48	24.70	45.81	8.52
36.	Choradi	5.90	0.32	1.18	128.58	31.49	15.34	25.80
37.	Channakoppa	6.88	0.02	1.05	125.44	80.62	2.89	18.50
38.	Anandapura	5.88	0.14	0.83	125.44	94.19	17.81	23.50

39.	Hodabetta	5.60	0.22	0.80	119.17	51.85	56.56	30.50
40.	Udugani	6.88	0.02	1.11	128.58	85.78	126.45	20.50
41.	Konegavalli	6.00	0.02	0.71	131.71	32.71	62.83	22.50
42.	Udugani	6.82	0.26	0.60	119.17	21.31	77.62	20.10
43.	Nimbegundi	5.60	0.03	1.00	106.62	33.39	101.92	32.50
44.	Sevalalnagar	6.92	0.02	1.04	125.44	83.06	79.86	35.50
45.	Kumsi	6.88	0.02	0.81	175.62	82.66	10.64	17.50
46.	Shiralkoppa	4.88	0.02	0.44	100.35	32.10	122.98	55.50
47.	Balehonnur	7.10	0.02	1.54	98.76	33.19	104.90	16.50
48.	Mavinakere	7.80	0.14	2.34	100.35	83.36	80.86	10.20
49.	Allduru	6.10	0.04	0.57	128.58	22.06	19.82	28.50
50.	Ikkeri	4.94	0.02	0.46	125.44	16.90	105.50	38.50
51.	Ripponpet	5.78	0.03	0.87	100.35	34.54	19.04	25.50
52.	Thavanandi	7.88	0.42	1.03	344.96	45.60	55.10	10.50

Table 7: Correlation matrix of six independent variables (soil physico-chemical parameters) with the dependent variable disease incidence (DI %)

	pH (X1)	EC (X2)	OC (X3)	N-content (X4)	P-content (X5)	K-content (X6)	DI (%) Y
X1	1	.014	.462	.420	.291	-.079	-.784**
X2		1	.149	-.008	-.163	-.186	-.057
X3			1	.130	.457	.137	-.518**
X4				1	.074	.039	-.544**
X5					1	.336*	-.237
X6						1	-.008
Y							1

**. Correlation is significant at the 0.01 level.

*. Correlation is significant at the 0.05 level.

Table 8: Coefficient of regression model to estimate the DI (%) based on different ginger growing soils physico-chemical properties independent variable at different steps

Steps	pH (X1)	EC (X2)	OC (X3)	N-content (X4)	P-content (X5)	K-content (X6)	Interception	DI (%) Y
I	-6.538	-	-5.228	-0.034	-	-	76.501	0.708
II	-7.806	-	-	-0.032	-	-	78.866	0.670
III	-9.076	-	-	-	-	-	81.392	0.614

Table 9: Multiple regression analysis for prediction of ginger rhizome rot complex

Stepwise prediction equation	R^2 value
Y= 77.072- 6.743(X1) – 1.116(X2) -5.693(X3) – 0.033 (X4) +0.033 (X5) – 0.005 (X6)	0.713
Y=78.866-7.806(X1) -0.032(X4)	0.670
Y= 76.501-6.538(X1) -5.228(X3) – 0.034(X4)	0.708
Y= 81.392-9.076(X1)	0.614

is 0.708 which means that 70.08 per cent variation in the disease development as explained by pH, OC and N.

In the second step, four parameters were dropped keeping only pH and N-content, the R^2 value is 0.670 which means that 67.00 per cent variation in the disease development as explained by pH and N. In last step five parameters were dropped keeping only pH, the R^2 value is 0.614 which means that 61.40 per cent variation in the disease development as explained by pH alone. With the value of interception obtained multiple regression analysis disease prediction equation was developed and presented in Table 9.

4.2 Isolation and identification of pathogens associated with rhizome rot complex

Standard tissue isolation technique was followed for the isolation of pathogens associated with diseased rhizomes which were collected during survey. Pathogens isolated in rhizome rot, were *viz.*, *Pythium aphanidermatum, Fusarium oxysporum, Sclerotium rolfsii* and *Ralstonia solanacearum.* They were purified by single spore isolation as explained in material and methods. Further they were identified based on morphological and cultural characters (Table 10).

1. *Pythium aphanidermatum* (Edson) Fitz.

Pythium aphanidermatum was isolated on specific medium potato dextrose agar supplemented with pimarcin and vancomycin as described in Material and Methods (Plate 6). Hyphal tip of mycelium was cut and transferred on potato dextrose agar slants for the growth. Mycelium was colourless, coenocytic and sometimes lustrous, occasionally slightly brownish due to abundant oospores or hyphal swellings. Oogonia terminally formed, smooth, Antheridia mostly intercalary. Oospore size varied from 18.50 to 20.20 µm (Plate 6).

2. *Fusarium oxysporum* Trujillo.

On potato dextrose agar, growth was rapid. Colonies were woolly to cottony mycelium. Hyphae were septate and hyaline and produced both macro and microconidia. Macroconidia were moderately curved, stout, thick-walled, usually 2-5 septate, measure 10.47 to 29.72 µm long, Microconidia were one to two-celled, 2-5 x 8-16 µm long. Chlamydospore were present, formed both terminally and intercalary. The species identification of both *Fusarium* and *Pythium* was confirmed by Agharkar Research Institute, Pune (Plate 7).

3. *Sclerotium rolfsii* Sacc.

The infected rhizomes showing symptoms like growth of white cottony mycelium or presence of sclerotial bodies. Culture of *S. rolfsii* by standard tissue isolation technique as described in Material and Methods. The fungus produced white, dense, radiating and thread like mycelial growth on potato dextrose agar medium. In early stages, the fungus produced silky white mycelium and gradually lost its lustre and became dull in appearance.

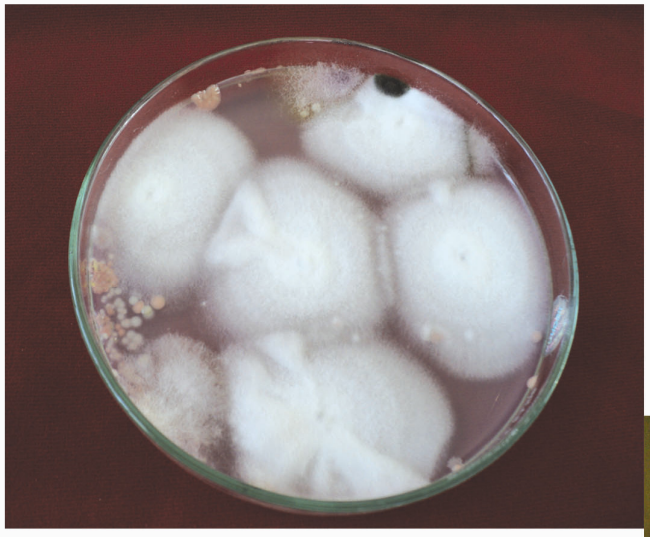
Aerial hyphae were not uniformly distributed, Initiation of sclerotial bodies were obtained from sixth day after inoculation. In the beginning, the sclerotial bodies were white but gradually turned to buff brown colour and then to chocolate brown at maturity. The fully matured sclerotial bodies were spherical to ellipsoidal and measured 1.5 mm in diameter. The fungus obtained from the affected plant tissue was compared with species originally described and it was found resembling S. *rolfsii* in all morphological characters (Plate 7).

3. *Ralstonia solanacearum* (Smith) Yabuuchi

Ralstonia solanacearum was isolated from wilted ginger plant on sucrose peptone agar medium supplemented with Tetrazolium chloride

Table 10: Morphological features of ginger rhizome rot pathogens

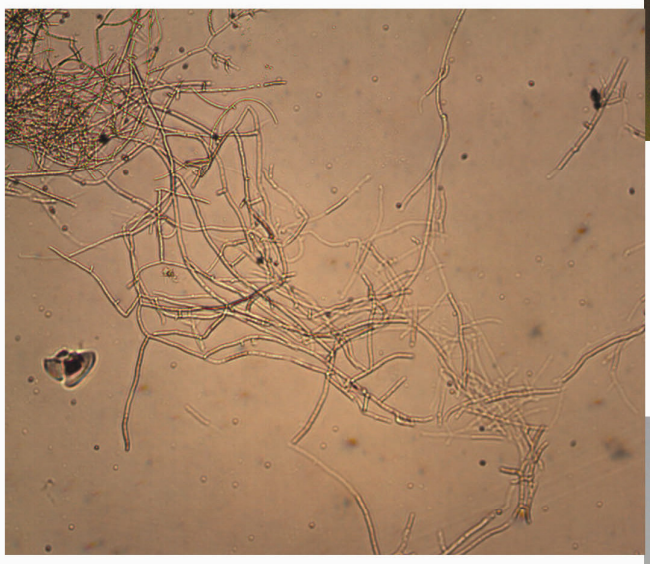
Pathogen	Mycelial Character	Spore Characters
Pythium aphanidermatum	Aseptate and hyaline	Oospore size varied from 18.5 to 20.2µm
Fusarium oxysporum	Septate and hyaline	Conidia varied from 2 to 5 septations with size from 10.47 µm to 29.72 µm in length. Chlamadospores were seen both terminal and intercalary
Sclerotium rolfsii	Septate and hyaline	Large sclerotial bodies are formed in the plates after 8 to days after plating



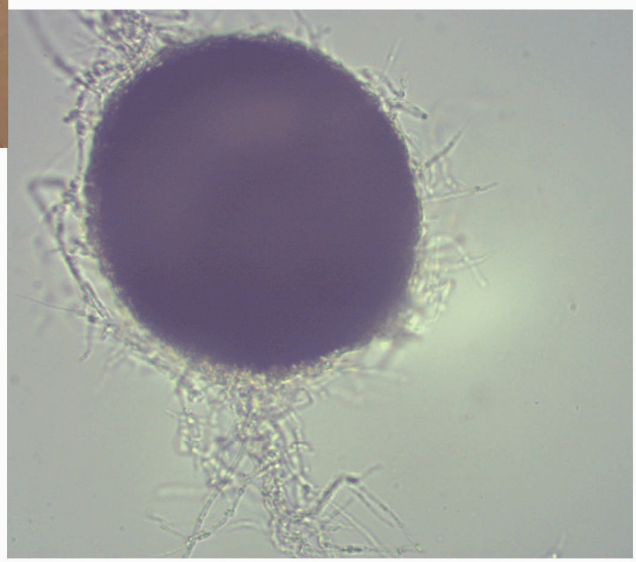
Isolation of *Pythium aphanidermatum* on specific medium



Pure culture of *Pythium aphanidermatum*



Coenocytic mycelium



Oospore

Plate 6. Cultural characteristics of *Pythium aphanidermatum*

as described in 'Material and Method'. The colonies appeared after 36 hrs of incubation at 28^0C. Typical white fluidal round to irregular colonies with spiral pink to red centre. Such colonies were purified and transferred into sucrose peptone agar medium and further tested for the race and biovar by different methods.

Bacterial isolates were identified based on the morphological, biochemical and physiological characteristics which are presented in the Table 11 and 12. Among twelve isolates studied for their morphological characteristics, most of them were irregularly shaped, fluidal dull white coloured with pink canter, their shape varied from small to medium rods (Table 11 and Plate 8).

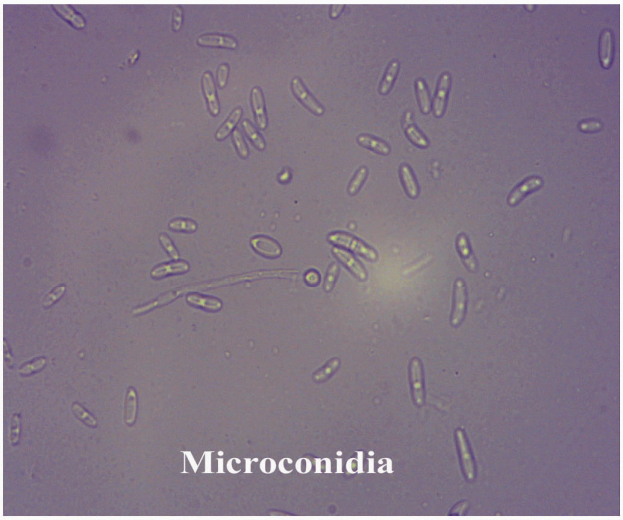
All isolates were formed gram negative, oxidase positive, hydrolyses the starch and doesn't produce fluorescens pigment in the Kings B medium. Catalase test was positive for all the isolates except RS7 and RS8. All the 12 isolates are capable of gelatine hydrolysis except two isolates RS7 and RS9 (Table 12). Isolate RS3 which was isolated from Mallikoppa (Chikkamagalore district) used for the further studies.

Proving Pathogenicity

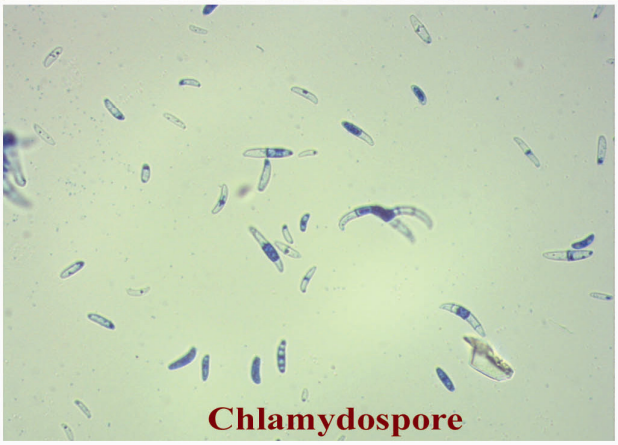
Pathogenicity test for *P. aphanidermatum, F. oxysporum*, *S. rolfsii* and *R. solanacearum* was carried out as described in Material and Methods. The symptoms produced were similar to the one described in the symptomatology (Plate 9).

Foliar yellowing was clearly seen starting from the margins of the lower most leaf and later progressed upwards. The affected rotted tissues emitted foul smell in case of *P. aphanidermatum* and able to kill plants within 10 days.

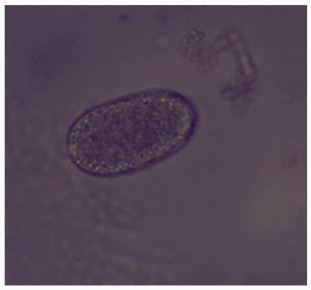












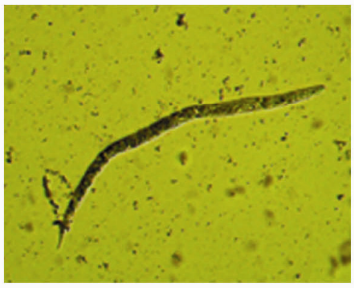


Plate 7. Cultural characteristics of *Fusarium oxysporum*, *Sclerotium rolfsii and Meloidogyne incognita*

Table 11: Morphological characteristics of *R. solanacearum isolates*

Sl. No.	Isolated from	Isolate code	Characters	
			Colony characters on TZC	Shape
1	Suralihalli	Rs 1	Irregularly shaped, fluidal, white coloured with dark pink canter	Small rods
2	Umblebailu	Rs 2	Irregularly shaped, fluidal, dull white coloured with pink to red canter	medium rods
3	Mallikoppa	Rs 3	Regularly shaped, slimy dull white coloured with light pink canter	Small rods
4	Doddinathale	Rs 4	Irregularly shaped, fluidal, white coloured with yellowish pink canter	medium rods
5	Kanabur colony	Rs 5	Irregular, fluidal, slimy, dull white coloured with pink to red canter	medium rods
6	Sathgoli	Rs 6	Regularly shaped, smooth colony, slimy, white coloured with pink canter	medium rods
7	Shimoga	Rs 7	Irregular, fluidal, viscous, slimy with pink centre	Small rods
8	Chikmarasa	Rs 8	Irregularly shaped, viscous, slimy, dull white colored with pink to red canter	Small rods
9	Gerukoppa	Rs 9	Irregularly shaped, slimy, dull white coloured with pink to red canter	medium rods
10	Ramanapura	Rs 10	Irregular, fluidal, viscous, slimy, dull white coloured with pink to red canter	medium rods
11	Channakoppa	Rs 11	Irregular, slimy, white coloured with pink to red canter	Small rods
12	Udugani	Rs 12	Dull white colonies with light pink canter and highly fluidal	Small rods

Table 12: Biochemical characterization of *Ralstonia solanacearum*

Sl. No.	Isolate code	Gram test	Oxidase test	Starch hydrolysis	Gelatin hydrolysis	Fluorescens Pigment production	Catalase test
1	Rs 1	-	+	+	+	-	+
2	Rs 2	-	+	+	+	-	+
3	Rs 3	-	+	+	+	-	+
4	Rs 4	-	+	+	+	-	+
5	Rs 5	-	+	+	+	-	+
6	Rs 6	-	+	+	+	-	+
7	Rs 7	-	+	+	-	-	-
8	Rs 8	-	+	+	+	-	-
9	Rs 9	-	+	+	-	-	+
10	Rs 10	-	+	+	+	-	+
11	Rs 11	-	+	+	+	-	+
12	Rs 12	-	+	+	+	-	+

+ = positive reaction

- = negative reaction

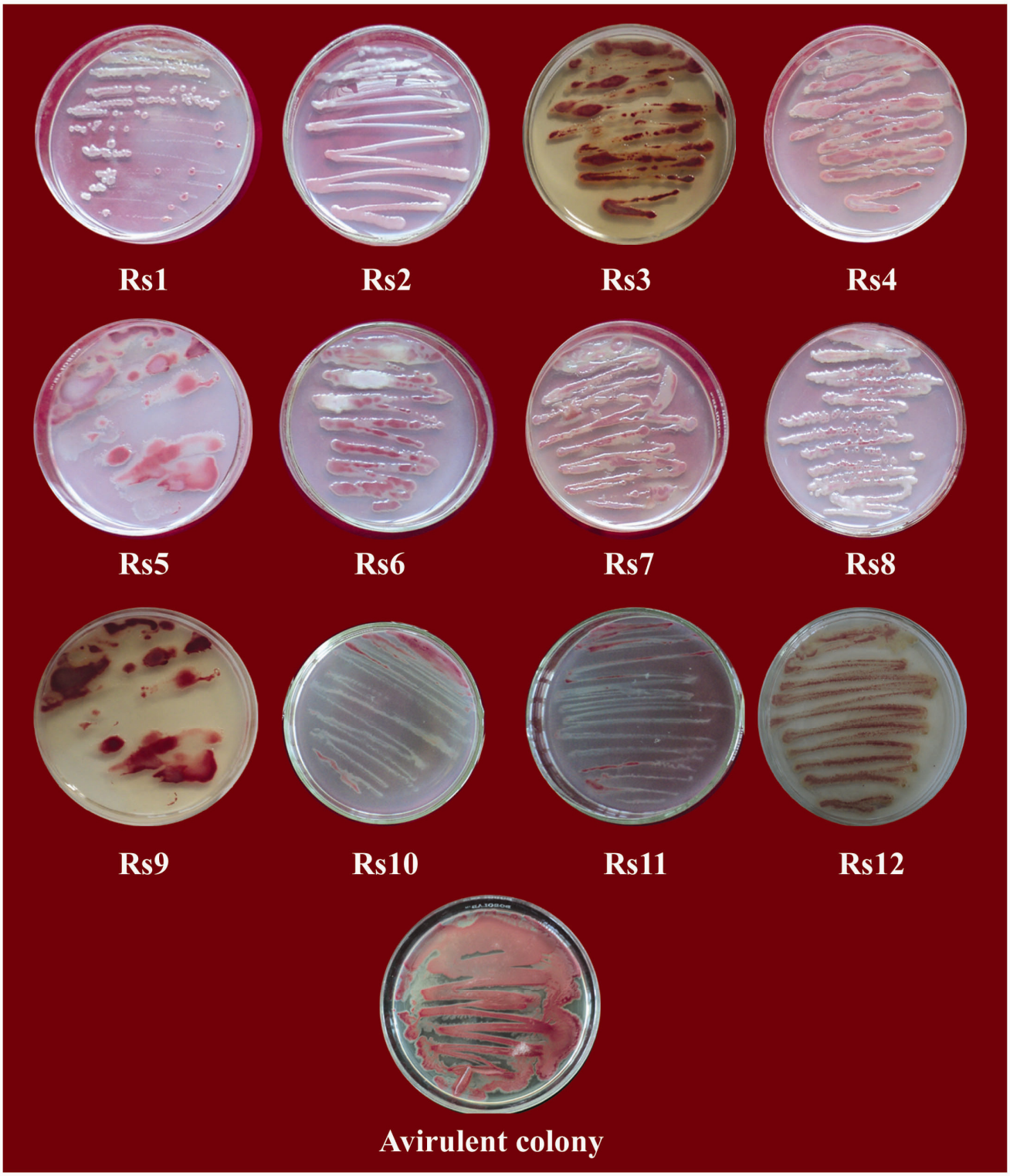


Plate 8. Morphological characteristics of *R. solanacearum* isolates on TZC medium



Healthy



R. solanacearum
(16.5x 10 ^{6} cfu/ml)



F. oxysporum
(23 x10^{4} cfu/ml)



S. rolfsii
(23x10^{4} cfu/ml)



P. aphanidermatum
(20 x10 ^{4} cfu/ml)

Plate 9. Pathogenicity test of ginger rhizome rot causing pathogens

The affected plants wilted and dried up. Affected rhizomes became soft and watery. The pseudostem came off from mother rhizome with a gentle pull. Affected rhizomes showed a creamy discoloration of the vascular system and cortical rot in case of *F. oxysporum* and it took 18 days for complete wilting of the plant.

S. rolfsii causes symptoms that could be confused with other pathogens. Yellowing and wilting of lower leaves and show die back from the tips. The fungus typically attacks the plant just under or at the soil line.

In case of *R. solanacearum,* water soaked patches or linear streaks on the collar region of the pseudostem were observed. Later, leaves became flaccid with intense yellowish bronze colour and drooped. The leaves showed roll up symptoms and the whole plant dried up. Such rhizomes when pressed, bacterial cell mass oozed out. All pathogens were reisolated from the infected plants and found similar to the original culture.

Enumeration of associated pathogens in the diseased soil samples

The enumerations of pathogen population present in the infested soil are presented in the Table 13. Data indicates that out of 52 infested soil samples tested for the pathogen populations, only three samples (Sathgoli, Chikkamarasa and Mavalli) have yielded all the four rhizome rot pathogens that are *P. aphanidermatum, F. oxysporum*, *S. rolfsii* and *R. solanacearum*. Fourteen samples had association with any three pathogens, twenty two samples were associated with any two pathogens and thirteen samples found associated with any one pathogen.

With respect to individual pathogens, 38 samples had *R. solanacearum*, 33 samples had *F. oxysporum*, 22 samples had *P. aphanidermatum* and only 9 samples had *S. rolfsii*. Hence the association

Table 13: Estimation of pathogen population in rhizome rot affected soil

Place	*P. aphanidermatum* (cfu x10^2)	*F. oxysporum* (cfu x10^2)	*S. rolfsii* (cfu x10^2)	*R. solanacearum* (cfu x10^3)	DI (%)
Surali halli	4.50	6.10	0.00	22.45	22.50
Umble bailu	2.30	5.88	0.00	21.20	15.00
Mallikoppa	0.00	0.00	0.00	17.54	31.00
Doddinathale	0.00	6.33	0.00	14.80	52.50
Kanabur colony	5.80	0.00	4.5	15.02	32.00
Sathgoli	1.20	15.10	3.21	17.10	27.50
Balekoppa	15.10	0.00	0.00	3.20	23.00
N.R. pura	12.10	0.00	0.00	2.56	50.00
Vasthare	0.00	12.55	0.00	1.50	15.00
Aladagudde	3.00	14.3	0.00	0.00	13.00
Mudabagilu	0.00	2.55	0.00	0.00	21.00
Badaga bailu	0.00	3.11	0.00	0.00	21.00
Huluguthuru	4.80	4.22	0.00	6.55	14.50
Uchangi	6.40	0.00	0.00	9.45	12.34
Moodahalli	0.00	14.12	7.40	8.56	13.50
Shimoga	17.00	8.55	2.50	41.58	34.50
Chikmarasa	18.00	14.00	0.00	10.12	27.65
Jannapura	0.00	0.00	0.00	28.30	24.50
Abbalagere	0.00	0.00	0.00	13.40	26.50
Basavagangur	0.00	9.50	0.00	0.00	18.50
Gerukoppa	2.10	0.00	7.10	12.10	20.50
Channapura	3.30	18.54	0.00	0.00	32.50
Mavalli	6.55	21.44	1.55	3.10	40.25
Audige	0.00	26.55	2.10	0.00	13.50
Uraganahalli	0.00	12.55	0.00	0.00	17.50
Jade	0.00	1.00	0.00	0.00	32.50
Sirsi	0.00	1.44	0.00	2.10	21.24
Banavasi	5.10	18.22	0.00	2.50	35.50
Ramanapura	3.20	1.25	0.00	26.00	27.50
Gomala	5.10	12.42	0.00	8.21	12.67
Anavatti	7.10	0.00	0.00	7.65	36.50
Thavarekatte	0.00	14.21	0.00	2.33	13.40
Kodakani	0.00	14.20	9.33	2.45	35.50
Doddanudi	1.10	0.00	0.00	1.79	10.50
Ayanur	1.40	0.00	0.00	0.00	8.52
Choradi	0.00	17.25	0.00	0.00	25.80
Channakoppa	4.80	16.22	0.00	17.18	18.50
Anandapura	0.00	3.55	0.00	12.04	23.50
Hodabetta	0.00	14.22	0.00	6.55	30.50
Udugani	0.00	10.21	24.33	17.45	20.50
Konegavalli	0.00	0.00	1.88	1.46	22.50
Udugani	0.00	0.00	0.00	2.55	20.10
Nimbegundi	3.10	0.00	0.00	15.25	32.50
Sevalalnagar	0.00	3.66	0.00	1.00	35.50
Kumsi	0.00	2.11	0.00	5.22	17.50
Shiralkoppa	0.00	5.44	0.00	0.00	55.50
Balehonnur	0.00	6.11	0.00	24.50	16.50
Mavinakere	0.00	8.54	0.00	0.00	10.20
Allduru	0.00	0.00	0.00	12.50	28.50
Ikkeri	0.00	0.00	0.00	10.00	38.50
Ripponpet	0.0	12.5		15.6	25.50
Thavanandi	9.50	0.00	0.00	9.88	10.50

of *R. solanacearum* was dominating in malnad districts of Karnataka which was followed by *F. oxysporum* and *P. aphanidermatum*.

With respect to population count, highest number of 41.58 x 10^3 cfu of *R. solanacearum* was recorded at Shimoga and lowest number of 1.0 x 10^3 Sevalalnagar. Maximum *P. aphanidermatum* population at Chikmarasa (18.00 x 10^2) and minimum at Doddanudi(1.1 x 10^2). *F. oxysporum* population ranged from 1.0x10^2 to 26.55x10^2 at Jade and Audige respectively.

Cultural studies

Cultural characters for *P. aphanidermatum, F. oxysporum* and *S. rolfsii* were studied on 16 different solid media so as to identify the best media for growth and sporulation. The radial growth of the pathogens was measured when the maximum growth was attained in any of the media tested. Observations on various cultural characters were recorded as described in Material and Methods. The results are presented in Tables 14, 15 and 16. There was significant difference between 16 different solid media on the growth and sporulation of the pathogens tested.

In case of *P. aphanidermatum,* maximum radial growth was observed in potato dextrose agar (82.33 mm) which was on par with the potato carrot agar (81.33 mm), Sach's agar (79.67 mm), Ashby's mannitol agar (76.67 mm), oat meal agar (75.00 mm) and Sabouraud's agar (75.00 mm). Oospore production was maximum on Sabouraud's, potato dextrose and potato carrot agar. There was no oospore production on host extract and Tochina agar (Plate 10) and (Figure 2).

In case of *F. oxysporum,* maximum radial growth was observed in Tochina agar (89.33 mm) followed by Czapek's (89.00 mm), Richards's agar (88.33 mm), Glucose asparagine agar (88.00 mm) and Asthana and

Table14: Effect of different solid media on growth of *Pythium aphanidermatum*

Sl. No.	Media	Mean colony diameter (mm)	Colony characteristics	Sporulation
1	Asthana and Hawks agar	32.33	Milky white colony, flattened growth with irregular margin	++
2	Sabouraud's agar	75.00	white colony, flattened growth with round margin	++++
3	Czapek's agar	50.00	Milky white, raised growth with irregular margin	++
4	Elliot's agar	16.67	Milky white, raised growth with irregular margin	+
5	Glucose asparagine agar	26.00	Milky white, raised growth with round margin	+
6	Richards's agar	50.33	White, raised growth with round margin	+++
7	Oat meal agar	75.00	Dark cream coloured, flattened with round margin	+++
8	Potato dextrose agar	82.33	Creamy mycelia, flattened with round margin	++++
9	Yeast extract agar	71.00	White mycelia, flattened with round margin	+++
10	Host extract agar	16.33	Creamy white**,** flattened with round margin	-
11	Ashby's mannitol agar	76.67	Milky white, flattened with round margin	++
12	Tochina agar	29.33	White, flattened with round margin	-
13	Sach's agar	79.67	White, flattened with round margin	+++
14	Corn meal agar	56.33	Dark grey coloured, flattened with round margin	++
15	Potato carrot agar	81.33	Dark at centre and white at borders, flattened with round margin	++++
16	Browns agar	28.00	White, raised with irregular margin	+
	S. Em	2.40	-	
	CD at 1%	9.31	-	

Sporulation: ++++ = Excellent, +++ = good, ++ = Fair, + = poor, - = no sporulation

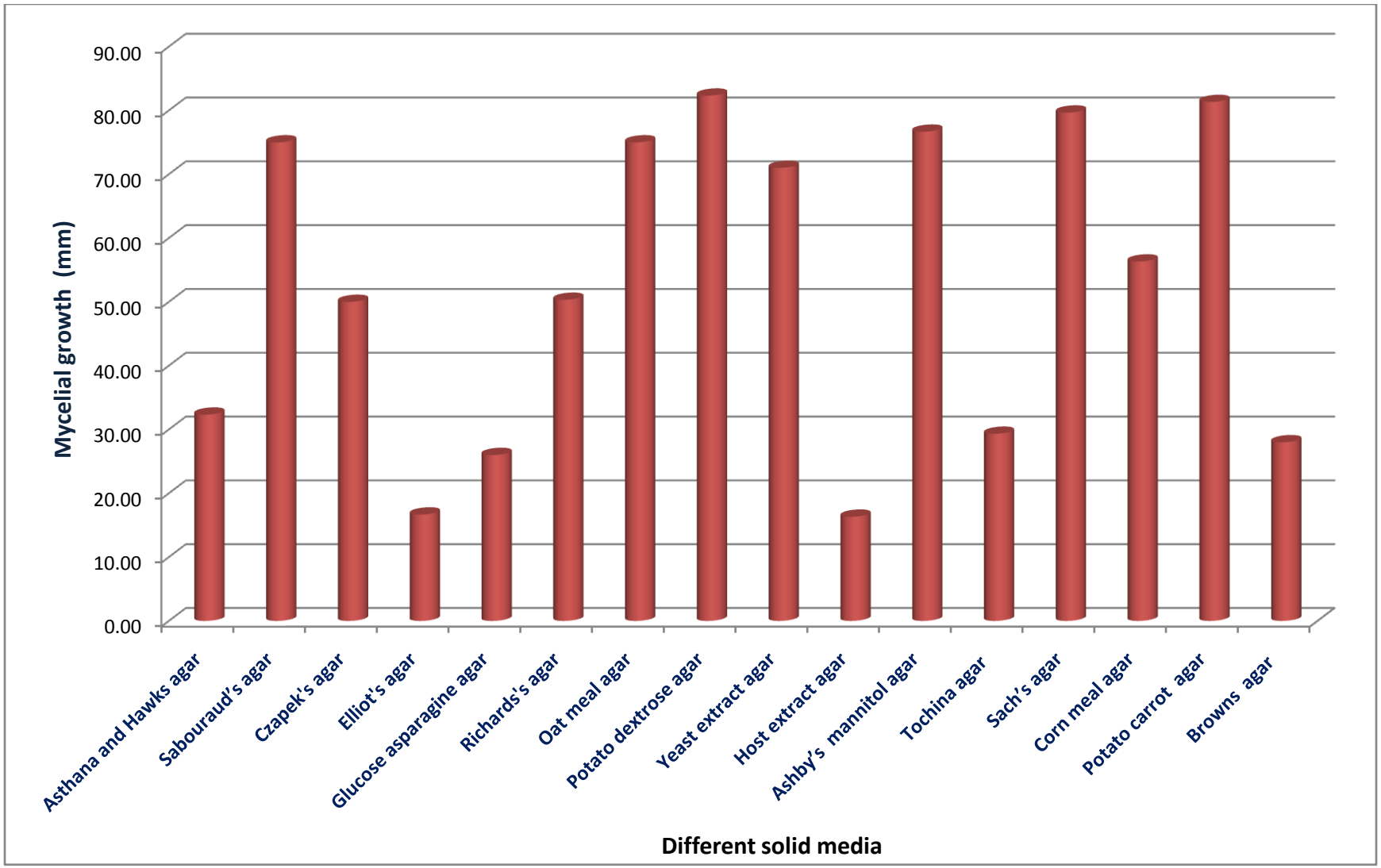
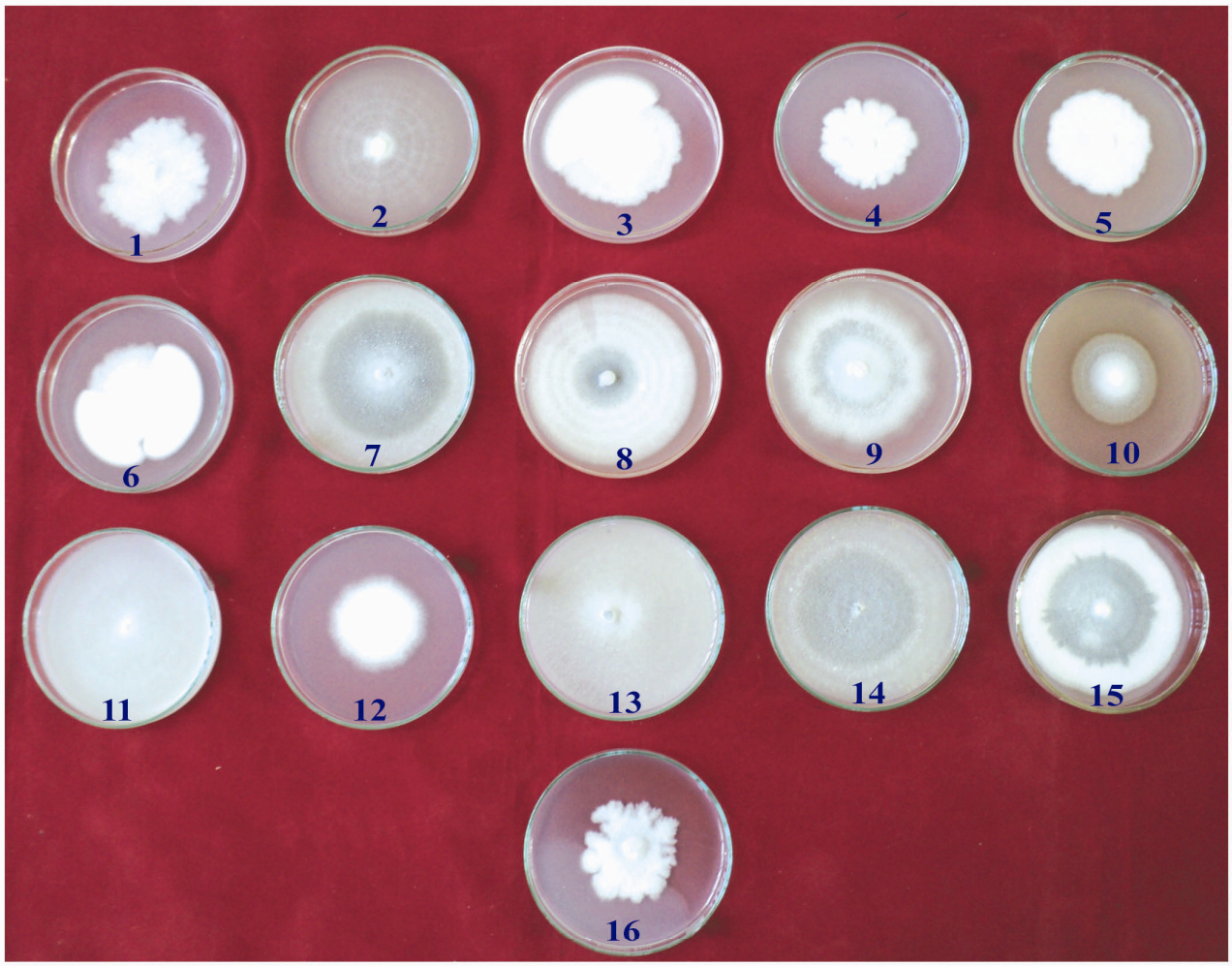


Fig. 2: Effect of different solid media on growth of *Pythium aphanidermatum*



1 - Asthana and Hawks agar
2 - Sabouraud's agar
3 - Czapek's agar
4 - Elliot's agar
5 - Glucose asparagine agar
6 - Richards's agar
7 - Oat meal agar
8 - Potato dextrose agar
9 - Yeast extract
10 - Host extract agar
11 - Ashby's mannitol agar
12 - Tochina agar
13 - Sach's agar
14 - Corn meal agar
15 - Potato carrot agar
16 - Browns agar

Plate 10. Effect of different solid media on growth of *Pythium aphanidermaturm*

Table 15: Effect of different solid media on growth of *Fusarium oxysporum*

Sl. No.	Media	Mean colony diameter (mm)	Colony characteristics	Sporulation
1	Asthana and Hawks agar	84.33	White colour mycelia, flattened with round margin	++++
2	Sabouraud's agar	17.67	Very poor growth	+
3	Czapek's agar	89.00	Milky white mycelia, raised with round margin	++
4	Elliot's agar	64.00	Sparse growth with raised mycelia	+++
5	Glucose asparagine agar	88.00	Light pink, raised, with round margin	+++
6	Richards's agar	88.33	Light coloured, raised at centre with round margin	++
7	Oat meal agar	60.00	White, flattened with round margin	++
8	Sach's agar	48.33	White, mycelia has formed concentric rings	+
9	Yeast extract agar	60.67	Dark pink, flattened with round margin	++
10	Host extract agar	32.00	Creamish, flattend growth	+
11	Ashby's mannitol agar	06.33	Poor growth	-
12	Tochina agar	89.33	Creamish thread like mycelia	++
13	Potato dextrose agar	86.67	Yellowish cream, raised with round margin	++++
14	Corn meal agar	02.33	Very poor growth	-
15	Potato carrot agar	16.33	White, flattened with round margin	-
16	Browns agar	50.00	Pink coloured, raised with round margin	++
	S.Em	2.11		
	CD at 1%	8.13		

Sporulation: ++++ = Excellent, +++ = good, ++ = Fair, + = poor, - = no sporulation

Table 16: Effect of different solid media on growth of *Sclerotium rolfsii*

Sl. No.	Media	Mean colony diameter (mm)	Colony characteristics	No. of sclerotial bodies per plate
1	Asthana and Hawks agar	80.00	Flattened, sparse	++++
2	Sabouraud's agar	45.00	Flattened, Light mycelia, irregular margin	+++
3	Czapek's agar	87.67	Flattened growth	++++
4	Elliot's agar	69.00	Raised at centre, fluffy mycelia	+++
5	Glucose asparagine agar	46.67	Mycelia concentrated at the centre	+++
6	Richards's agar	89.00	Flattened, medium to sparse white mycelia	++++
7	Oat meal agar	90.00	Raised with milky white colony	++++
8	Potato dextrose agar	90.00	Fluffy, milky white colony with irregular margin	++++
9	Yeast extract agar	77.00	Raised, cottony growth	++
10	Host extract agar	65.00	Flattened, raised at centre with regular margin	+
11	Ashby's mannitol agar	20.00	Poor growth	-
12	Tochina agar	36.67	Poor growth	-
13	Sach's agar	11.33	Creamy mycelial threads	+
14	Corn meal agar	90.00	Thick thread like mycelia, flattened mycelia	+++
15	Potato carrot agar	90.00	Flattened at centre and raised at margins	++++
16	Browns agar	69.33	Light coloured mycelia with flattened growth	++
	S. Em	02.59		
	CD at 1%	10.03		

Sclerotial bodies: ++++ = Excellent, +++ = good, ++ = Fair, + = poor, - = no formation of sclerotial bodies.

Hawks agar (84.33 mm). Minimum radial growth was observed in corn meal agar (2.33 mm). Conidial production was maximum and got correlation with the one having higher radial growth. Other colony characteristics were presented in the Table 15, Plate 11 and Figure 3.

The pathogen *S. rolfsii* was capable of growing well in most of the media tested such as Oat meal agar, Potato dextrose agar, Corn meal agar, Potato carrot agar, Richards's agar all were on par with cent per cent growth in the petri plate. Whereas, Ashby's mannitol agar (20.00 mm) has minimum growth. Production of Sclerotial bodies was correlated with one which were having highest radial growth (Table 16, Plate 12 and Figure 4).

Survival of pathogens in the sterilized and unsterilized soils and infected ginger under laboratory conditions

The survival ability of all the four pathogens described in Material and Methods was tested. Presence of the fungus was confirmed by isolating the fungus at every fifteen days on selective medium and is given in the Table 17 and 18. Presence of *P. aphanidermatum* was isolated from the culture discs up to 22 weeks in unsterilized soil whereas, in sterilized soil, it was detected up to 26 weeks.

In case of *F. oxysporum,* it was detected up to 22 weeks in unsterilized soil whereas in sterilized it was recovered from up to 28 weeks. *S. rolfsii* was capable of surviving up to 32 weeks in unsterilized soil whereas in sterilized it was alive up to 36 weeks. In case of *R. solanacearum* also it was detected up to 14 weeks in both unsterilized and sterilized soils.

P. aphanidermatum can survive up to 30 weeks, *F. oxysporum* can survive up to 34 weeks, *S. rolfsii* can survive up to 40 weeks and *R.*

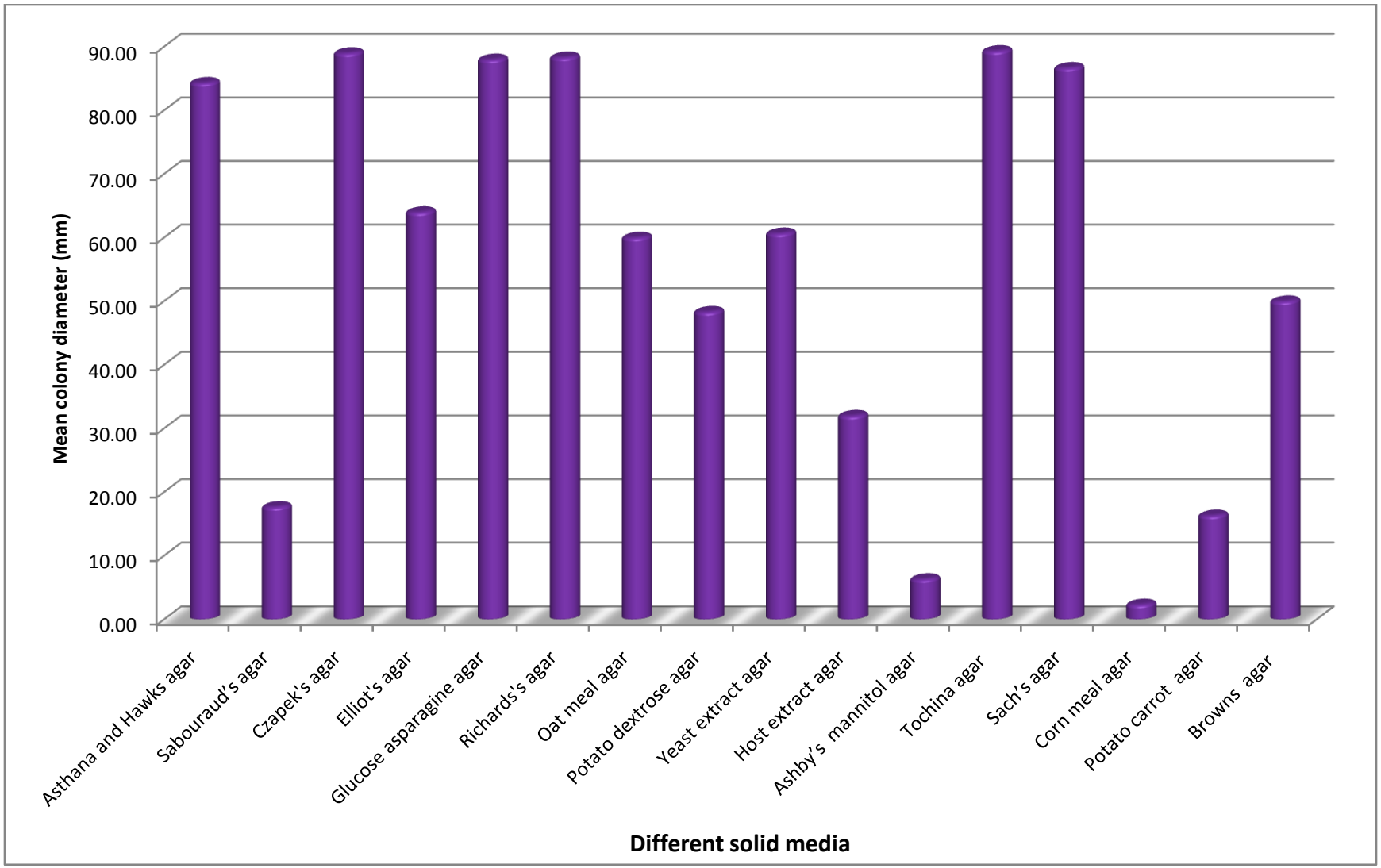


Fig. 3: Effect of different solid media on growth of *Fusarium oxysporum*

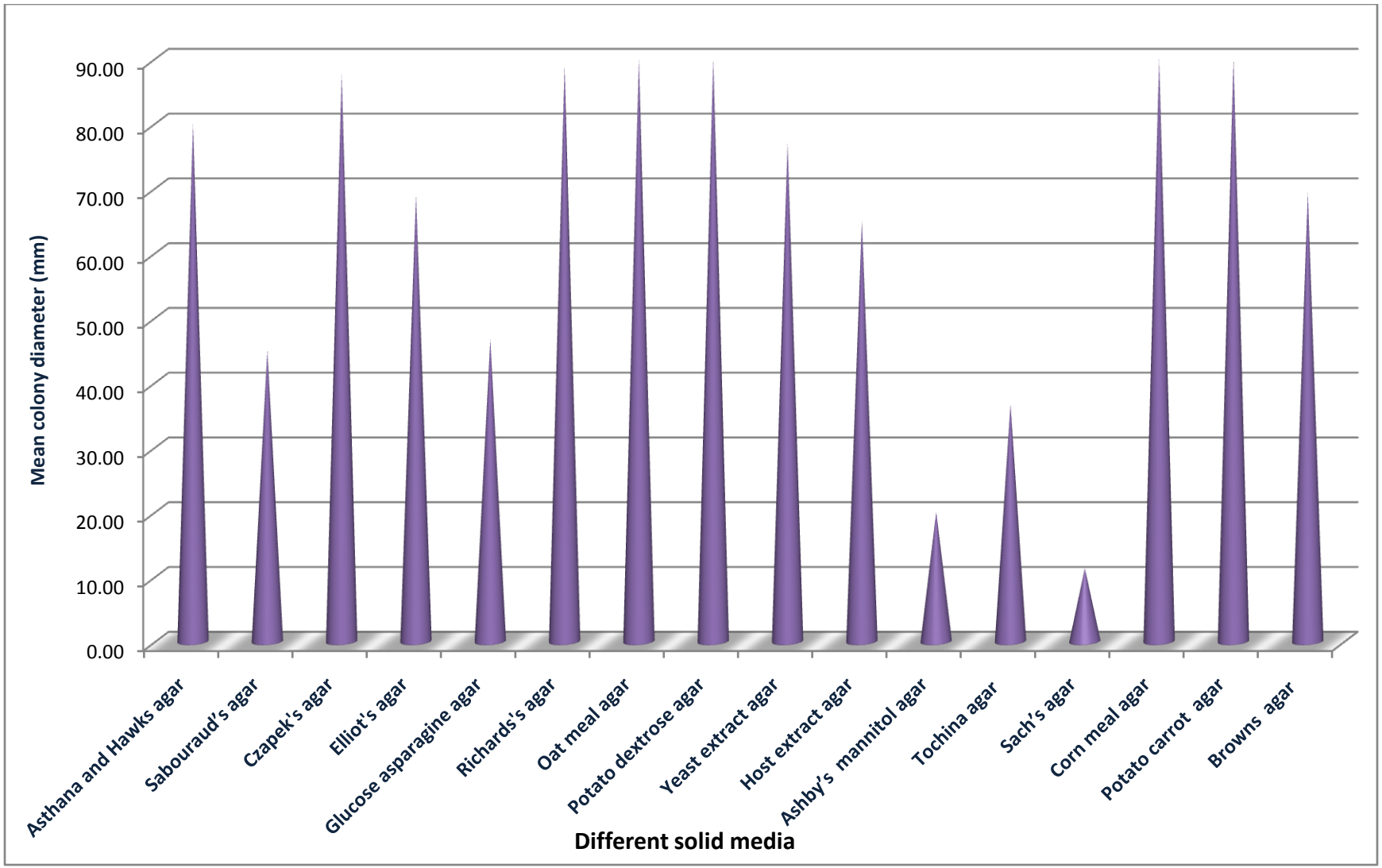
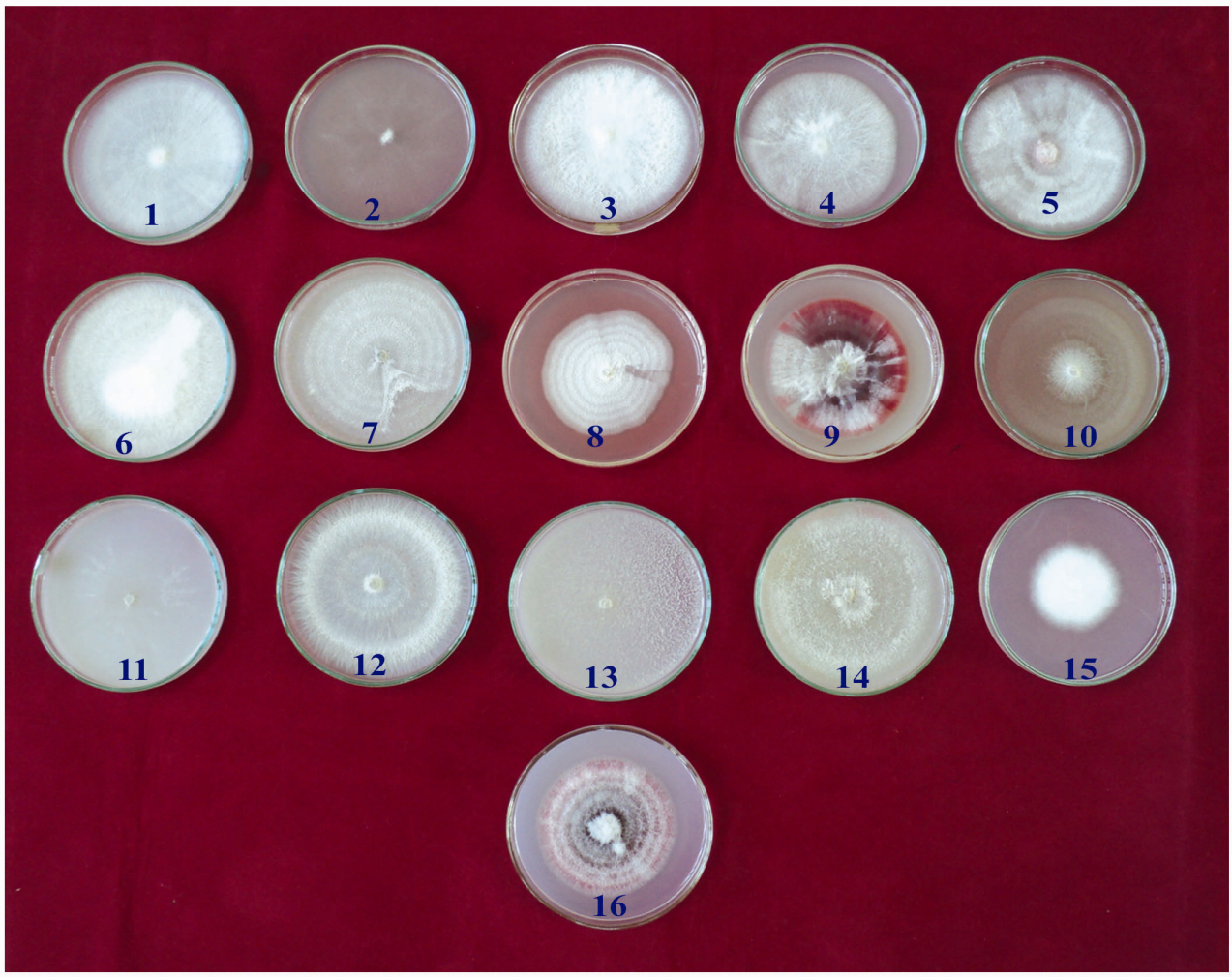


Fig. 4: Effect of different solid media on growth of *Sclerotium rolfsii*



1 - Asthana and Hawks agar
2 - Sabouraud's agar
3 - Czapek's agar
4 - Elliot's agar
5 - Glucose asparagine agar
6 - Richards's agar
7 - Oat meal agar
8 - Potato dextrose agar
9 - Yeast extract
10 - Host extract agar
11 - Ashby's mannitol agar
12 - Tochina agar
13 - Sach's agar
14 - Corn meal agar
15 - Potato carrot agar
16 - Browns agar

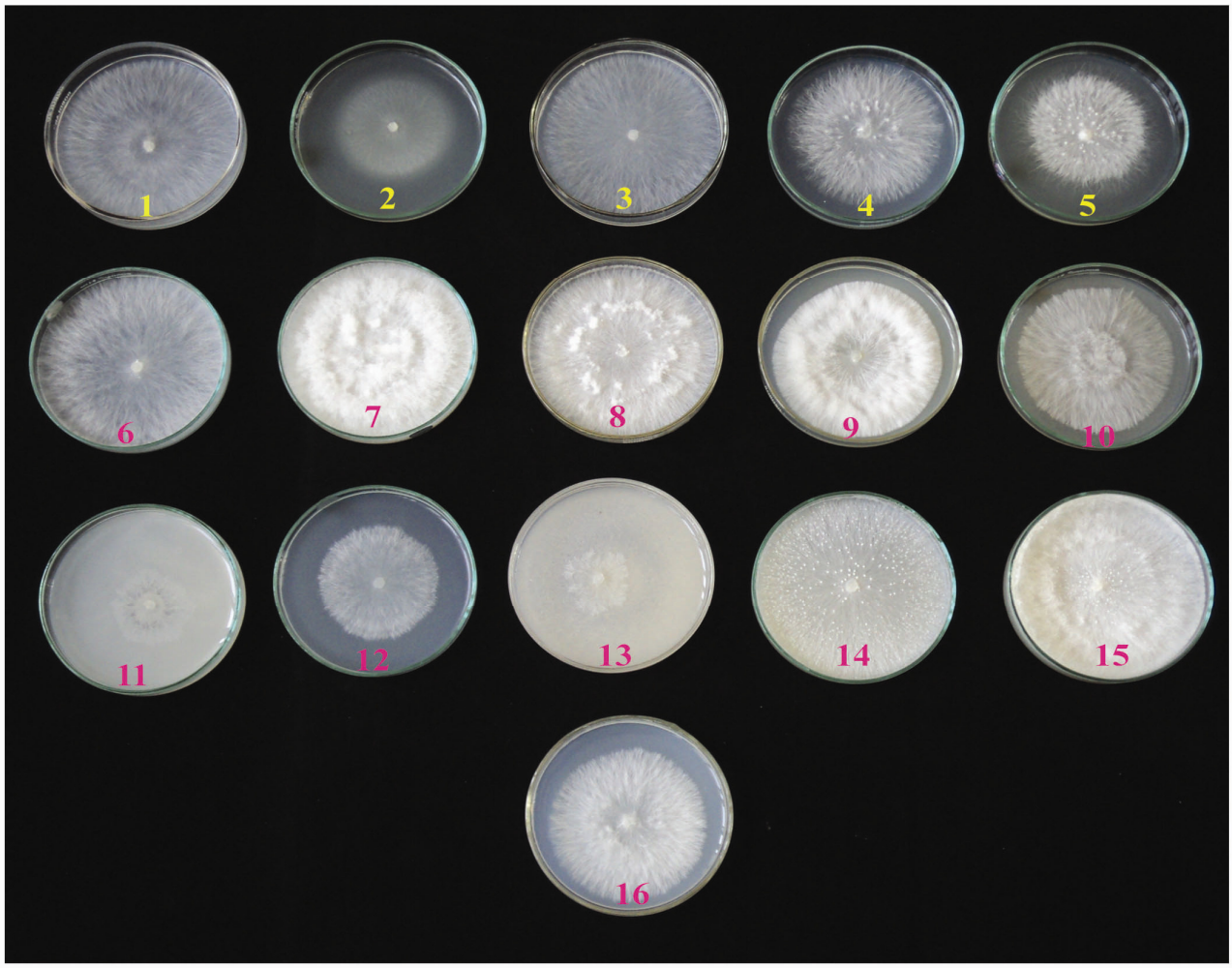
Plate 11. Effect of different soild media on growth of *Fusarium oxysporum*

Table 17: Survival of ginger rhizome rot causing pathogens in soil under Laboratory conditions

Sl. No.	Week	*P. aphanidermatum*		*F. oxysporum*		*S. rolfsii*		*R. solanacearum*	
		Sterilized soil	Unsterilized soil	Sterilized soil	Unsterilized soil	Sterilized soil	Unsterilized soil	Sterilized soil	Unsterilized soil
1	2	+	+	+	+	+	+	+	+
2	4	+	+	+	+	+	+	+	+
3	6	+	+	+	+	+	+	+	+
4	8	+	+	+	+	+	+	+	+
5	10	+	+	+	+	+	+	+	+
6	12	+	+	+	+	+	+	+	+
7	14	+	+	+	+	+	+	+	+
8	16	+	+	+	+	+	+	-	-
9	18	+	+	+	+	+	+	-	-
10	20	+	+	+	+	+	+	-	-
11	22	+	+	+	+	+	+	-	-
12	24	+	-	+	-	+	+	-	-
13	26	+	-	+	-	+	+	-	-
14	28	-	-	+	-	+	+	-	-
15	30	-	-	-	-	+	+	-	-
16	32	-	-	-	-	+	+	-	-
17	34	-	-	-	-	+	-	-	-
18	36	-	-	-	-	+	-	-	-
19	38	-	-	-	-	-	-	-	-
20	40	-	-	-	-	-	-	-	-

Table 18: Survival of ginger rhizome rot causing pathogens in infected rhizomes

Sl. No.	Week	*P. aphanidermatum*	*F. oxysporum*	*S. rolfsii*	*R. solanacearum*
1	2	+	+	+	+
2	4	+	+	+	+
3	6	+	+	+	+
4	8	+	+	+	+
5	10	+	+	+	+
6	12	+	+	+	+
7	14	+	+	+	+
8	16	+	+	+	+
9	18	+	+	+	+
10	20	+	+	+	+
11	22	+	+	+	+
12	24	+	+	+	-
13	26	+	+	+	-
14	28	+	+	+	-
15	30	+	+	+	-
16	32	-	+	+	-
17	34	-	+	+	-
18	36	-	-	+	-
19	38	-	-	+	-
20	40	-	-	+	-



1 - Asthana and Hawks agar
2 - Sabouraud's agar
3 - Czapek's agar
4 - Elliot's agar
5 - Glucose asparagine agar
6 - Richards's agar
7 - Oat meal agar
8 - Potato dextrose agar
9 - Yeast extract
10 - Host extract agar
11 - Ashby's mannitol agar
12 - Tochina agar
13 - Sach's agar
14 - Corn meal agar
15 - Potato carrot agar
16 - Browns agar

Plate 12. Effect of different solid media on gowth of *Sclerotium rolfsii*

solanacearum can survive up to 22 weeks in the infected rhizomes (Table 18).

Standardization of inoculum density of rhizome rot causing pathogens

Inoculum concentrations of approximately $5x10^2$, $5x10^3$, $5x10^4$, 5 $x10^5$, 5 x 10^6 and 5 X 10^7 cfu/ml of suspension of all the pathogens were prepared and inoculated to 45 days ginger plants to know the inoculum potential as explained in Material and Methods. The results are presented in Table 19, Figure 5 and Plate 13.

At zero per cent inoculum level, the per cent rhizome rot incidence recorded was zero, but increase in per cent inoculum levels leads to significant increase in the per cent rhizome rot incidence (Table 18). At $5x10^4$ highest disease incidences of fungal pathogen was noticed further there was no significant increase was observed. Minimum pathogenic concentration of *R. solanacearum* was found to be $5x10^6$ where it has produced 98.33 per cent rhizome rot further increased concentrations are on par with this concentration.

Interaction among the pathogens

Pot culture tests were conducted to investigate the interaction among the rhizome rot pathogens *viz.*, *P. aphanidermatum*, *F. oxysporum*, *S. rolfsii*, and *R. solanacearum* applied to plants individually and also in combinations. Observations like number of days taken to symptom induction, per cent rhizome rot incidence and detection of pathogen were recorded and presented in the Table 20, 21 and 22 at different stages of crop growth *i e.*, 15, 45, 75, 105 and 135 Days after planting (DAP) (Figure 6).

Table 19: Evaluation of minimum inoculum level of pathogens causing rhizome rot of ginger

Pathogen	***P. aphanidermatum***	***F. oxysporum***	***S. rolfsii***	***R. solanacearum***
Inoculum concentration	**Rhizome rot (%)**			
0	0 (0)	0(0)	0(0)	0(0)
5x 10^2	14.45 (22.34)	23.59(29.06)	29.54(32.92)	10.63(19.03)
5x10^3	55.73(48.29)	53.90(47.24)	73.68(59.14)	30.20(33.34)
5x10^4	98.33(82.58)	96.67(79.48)	100.00(90.00)	49.82(44.90)
5x10^5	100.00(90.00)	100.00(90.00)	100.00(90.00)	79.95(63.40)
5x10^6	100.00(90.00)	100.00(90.00)	100.00(90.00)	98.33(82.58)
5X10^7	100.00(90.00)	100.00(90.00)	100.00(90.00)	100.00(90.00)
S.Em	1.93	2.15	0.79	1.57
CD at 1%	8.12	9.06	3.31	6.62

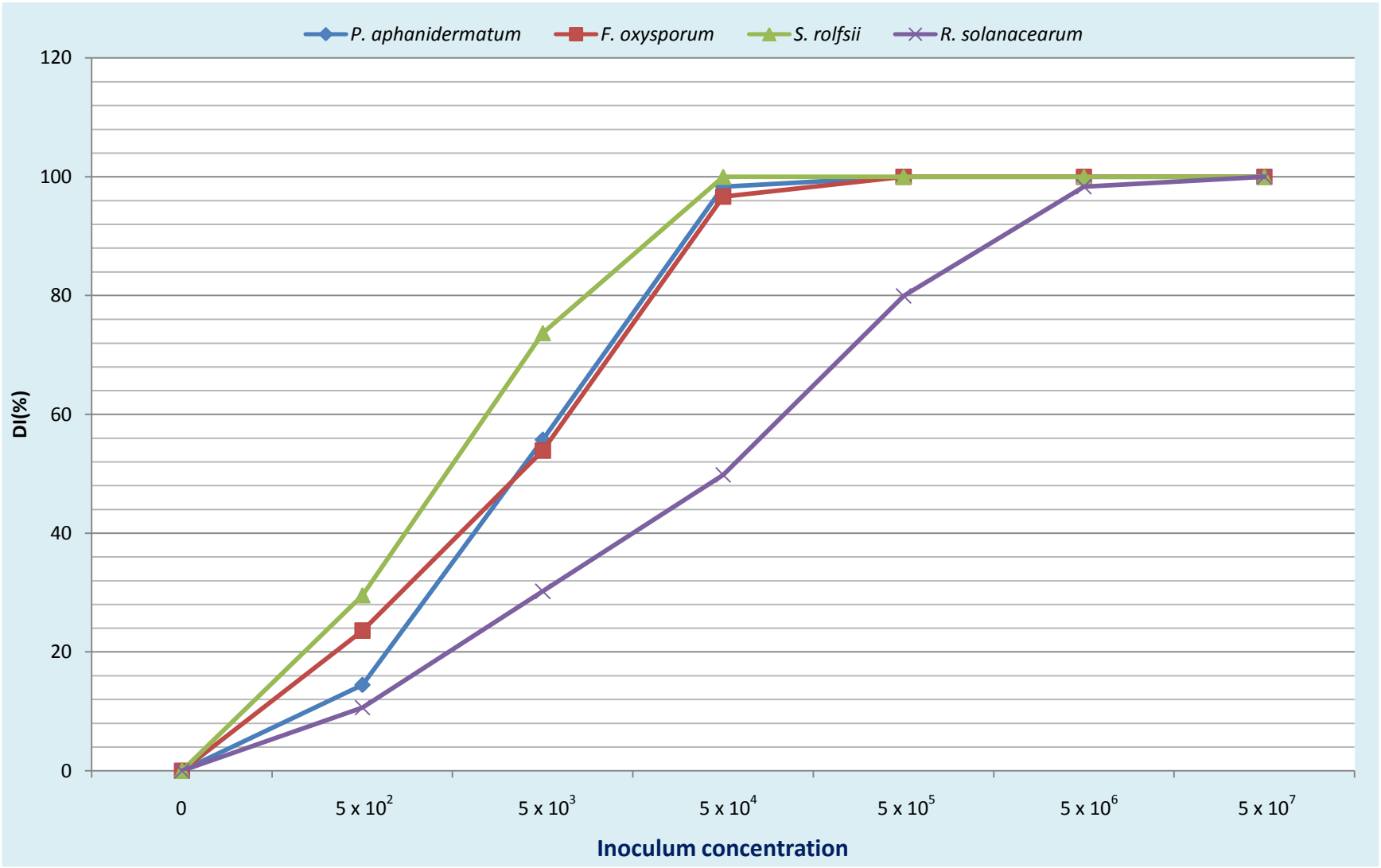
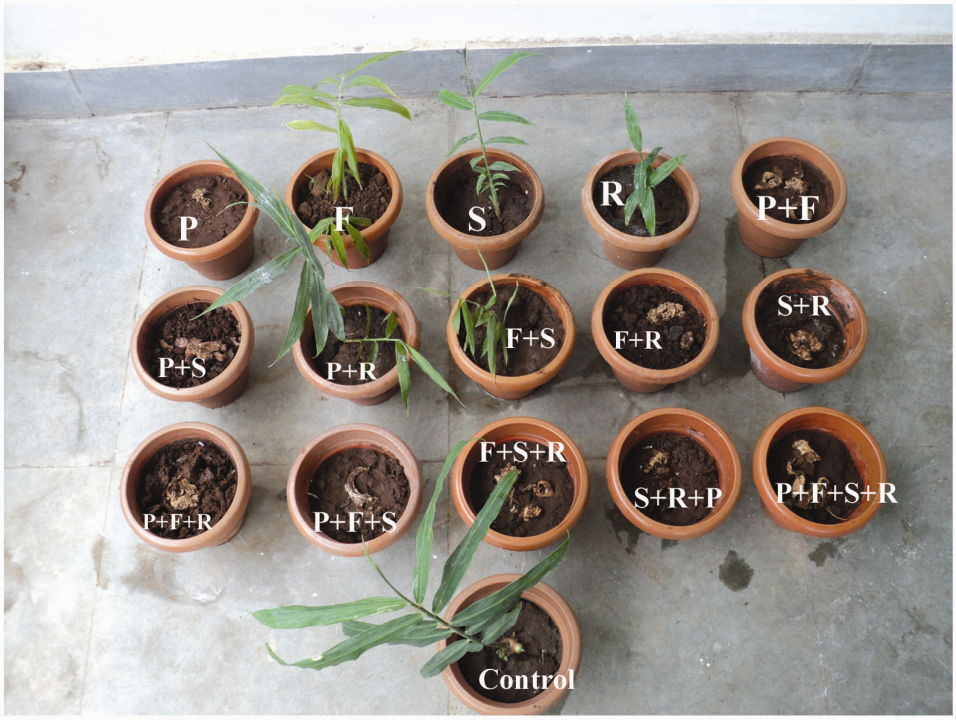


Fig. 5: Evaluation of minimum inoculum level of pathogens causing rhizome rot of ginger



Plate 13. Evaluation of inoculum levels of pathogens of Ginger rhizome rot



Rotted rhizome

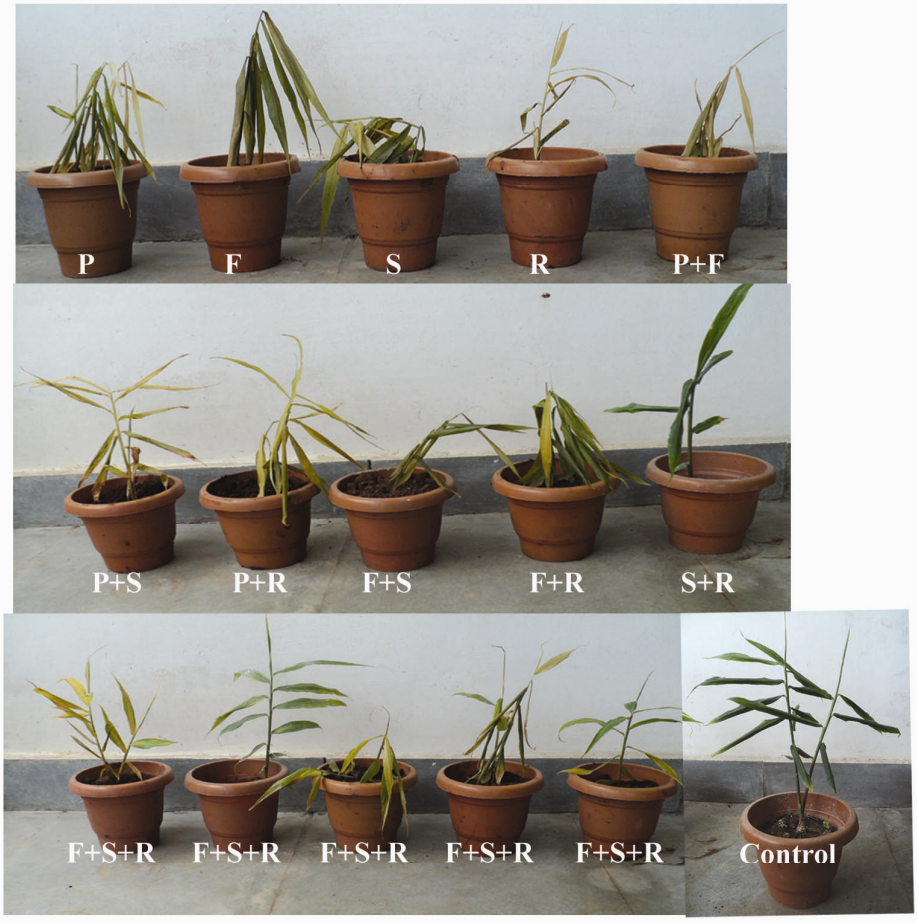


Plate 14. Interaction among different pathogens of rhizome rot of ginger at 15 and 45 DAP

Inoculation at 15 Days after planting

When pathogens inoculated individually at 15 DAP, in case of *P. aphanidermatum* inoculated treatment rhizome rotted at sprouting stage with typical pre-emergence damping off, in case of *F. oxysporum* inoculated treatment there was a delayed germination (55 days) of rhizome and started yellowing at 2 leaf stage itself and then wilted, in case of *S. rolfsii* and *R. solanacearum* stunted growth was observed compare to untreated control.

With the combined inoculation of pathogens, in most of the combinations rhizomes rotted before germination. Some were capable of germinating but could not survive more than 20 days after germination, except in treatment *S. rolfsii* alone and S+R combination lower Rhizome rot percentage recorded (Table 20 and Plate 14).

Inoculation at 45 Days after planting

Among the individual pathogens inoculated to the ginger plants, Plants inoculated with *R. solanacearum* showed early symptoms *i.e.*, at 10.5 days which was followed by *P. aphanidermatum* (12 days), *Sclerotium rolfsii* (18 days) but *F. oxysporum* took longer time (21 days). Rhizome rot incidence was maximum in plants inoculated with *R. solanacearum* (79.97 %) and minimum in *F. oxysporum* inoculated plants (39.95 %).

In case of combined inoculation of pathogens S+R combination has took very less time to produce symptoms, plants exhibited yellow to bronze colouration of the margins of the lower most leaves, which gradually progressed upwards. Whereas, F+S has took longer time (24.5 days).

Table 20: Interaction among different pathogens of rhizome rot on ginger at 15 DAP

Treatment		Rhizome rot incidence	Detection of pathogen
P. aphanidermatum alone (P)	Rotted at sprouting stage	98.17 (86.97)*	P
F. oxysporum alone (F)	Germinated after 55 days	84.67 (66.96)	F
S. rolfsii alone (S)	Germinated but stunted growth	51.17 (45.67)	S
R. solanacearum alone (R)	Stunted growth	80.50 (63.80)	R
P+F	Post emergence damping off	96.77 (86.97)	P F
P+S	Rotted before germination	99.17 (86.9)	P S
P+R	Stunted growth	70.50 (57.10)	P R
F+ S	Stunted growth	81.67 (64.66)	F S
F+R	Stunted growth	84.67 (66.96)	F R
S+R	Stunted growth	45.50 (42.42)	S R
P + F+R	Rotted before germination	99.17 (86.97)	P F R
P +F+S	Rotted before germination	99.17 (86.97)	P F S
F+S+R	Stunted growth	74.67 (59.79)	F R
S+R +P	Rotted before germination	100.00 (90.00)	P R
P+F +S+R	Rotted before germination	100.00 (90.00)	P F S R
Control	Normal growth	0.00 (0.00)	-
S.Em		2.05	
CD at 1%		7.92	

* Figures in the parentheses indicate arcsine transformed values.

Highest rhizome rot incidence 94.33 per cent was recorded at P+F+R combination which was on par with the P+F+S+R (94.00%) and F+R (89.37 %) combination. There was increase in the disease incidence in combined inoculation of pathogens when compare to individual inoculation.

When pathogens were reisolated from the disease rhizomes, it was found that in most of the combinations *S. rolfsii* was not detected (Table 21, Plate 15).

Inoculation at 75 Days after planting

Among the individual inoculation of pathogens *R. solanacearum* has taken only 8.5 days to initiate the symptoms which was followed by *P. aphanidermatum* (15 days), *S. rolfsii* (18 days) and *F. oxysporum* took longer time (25 days). Rhizome rot incidence was maximum in plants inoculated with *R. solanacearum* (71.00 %) and minimum in *S. rolfsii* inoculated plants (45.33 %). All pathogens were detected with their respective inoculation.

In case of combined inoculations of pathogens P+R combination has took only 7 days to produce symptoms, Whereas, F+S has took longer time (22 days). Highest rhizome rot incidence of 94.33 per cent was recorded at P+F+R combination. There was increase in the disease incidence in combined inoculation of pathogens when compare to individual inoculation except in combination S+R (46.36 %). When pathogens were re-isolated from the diseased rhizome, it was found that in most of the combinations *S. rolfsii* was not detected (Table 21).

Inoculation at 105 Days after planting

In case of individual inoculation pathogens, *R. solanacearum* incited the diseased symptoms at earliest *i e.,* 12 days after the



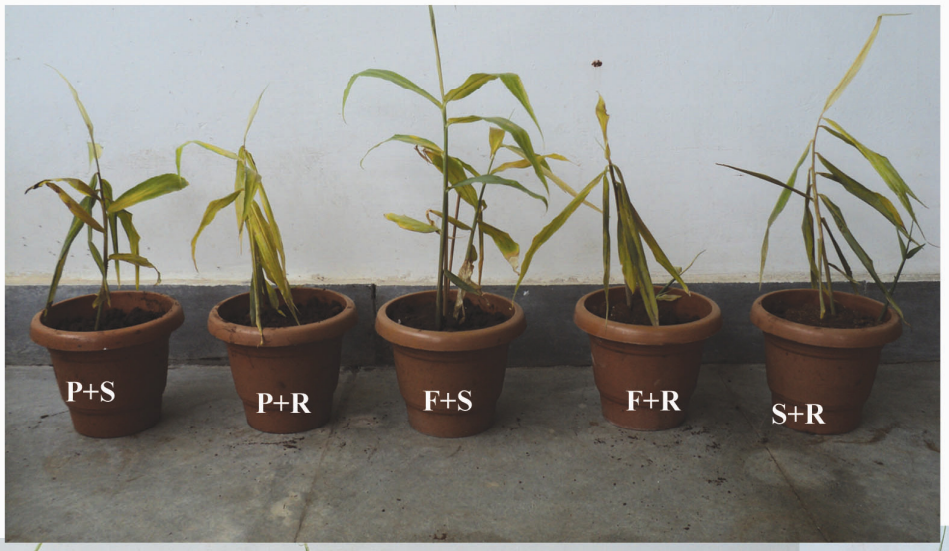




Plate 15. Interaction among different pathogens of rhizome rot of ginger at 75 DAP

Table 21: Interaction among different pathogens of rhizome rot on ginger at 45 and 75 DAP

Treatment	45 DAP			75 DAP		
	Days Taken For Symptom Induction	**Rhizome rot incidence (%)**	**Detection of pathogen**	**Days Taken for Symptom Induction**	**Rhizome rot incidence (%)**	**Detection of pathogen**
P. aphanidermatum alone (P)	12	67.03 (55.07)*	P	15	59.67 (50.59)*	P
F. oxysporum alone (F)	21	39.95 (39.19)	F	25	50.00 (44.99)	F
S. rolfsii alone (S)	18	43.50 (41.24)	S	18	45.33 (42.32)	S
R.solanacearum alone (R)	10.5	79.97 (63.51)	R	8.5	71.00 (57.51)	R
P+F	10.15	69.54 (56.53)	P F	14.5	53.93 (47.29)	P
P+S	14.25	64.90 (53.68)	P	15	67.94 (55.53)	P S
P+R	8.5	68.00(55.66)	P R	7	51.57 (45.90)	P R
F+ S	24.5	70.90 (67.60)	F	22	52.83 (46.65)	F S
F+R	21	89.37 (71.18)	F	18	74.03 (60.72)	F R
S+R	7.5	45.27 (42.27)	P F R	10	46.36 (42.86)	R
P + F +R	14.5	94.33 (78.74)	P S	15	94.33 (79.694)	P S
P +F+S	9.5	80.00 (63.55)	P F	9	80.30 (63.76)	F S
F+S+R	8.6	61.67 (51.95)	F R	12	68.56 (55.96)	R
S+R +P	15.4	77.63 (61.79)	P S R	17	73.97 (59.39)	R
P+F +S+R	10.5	94.00 (78.73)	P S R	8	80.62 (64.68)	P S R
Control		0.00	-	-	0.00	
S.Em		3.17			3.63	
CD at 1%		12.29			14.07	

* Figures in the parentheses indicate arcsine transformed values.

inoculation whereas *F. oxysporum* took longer time (35 days). Rhizome rot incidence was maximum in plants inoculated with *R. solanacearum* (66.33 %) and minimum in *S. rolfsii* inoculated plants (40.67 %). All pathogens were detected with their respective inoculation.

In case of combined inoculations of pathogens P+F+S+R combination took only 12 days as that of *R. solanacearum* alone produce symptoms, Whereas F+S took longer time (30.50 days). Highest rhizome rot incidence 80.93 per cent was recorded at P+F+R combination which was on par with the P+F+S+R (75.96%) and P+F+S (75.63%) combination. There was increase in the disease incidence in combined inoculation of pathogens when compare to individual inoculation except in combination S+R (41.69%). When pathogens were re-isolated from the disease rhizome, it was found that in most of the combinations *P. aphanidermatum* was not detected (Table 22, Plate 16).

Inoculation at 135 Days after planting

Among the individual pathogens inoculated to the ginger plants, Plants inoculated with *R. solanacearum* showed early symptoms at 15 days which was followed by *P. aphanidermatum* (20 days), *Sclerotium rolfsii* (22 days) but *F. oxysporum* took longer time (32 days). Rhizome rot incidence was maximum in plants inoculated with *F. oxysporum* (9.90%), *R. solanacearum* and *P. aphanidermatum* both failed in causing rhizome rot. In case of combined inoculation of pathogens, P+F+S+R have given highest rhizome rot (48.87%) and there was no infection in plants inoculated with P+R. In almost all the treatments *Pythium* was not detected (Table 22).

S+R combination took very less time to produce symptoms, plants exhibited yellow to bronze colouration of the margins of the lower most

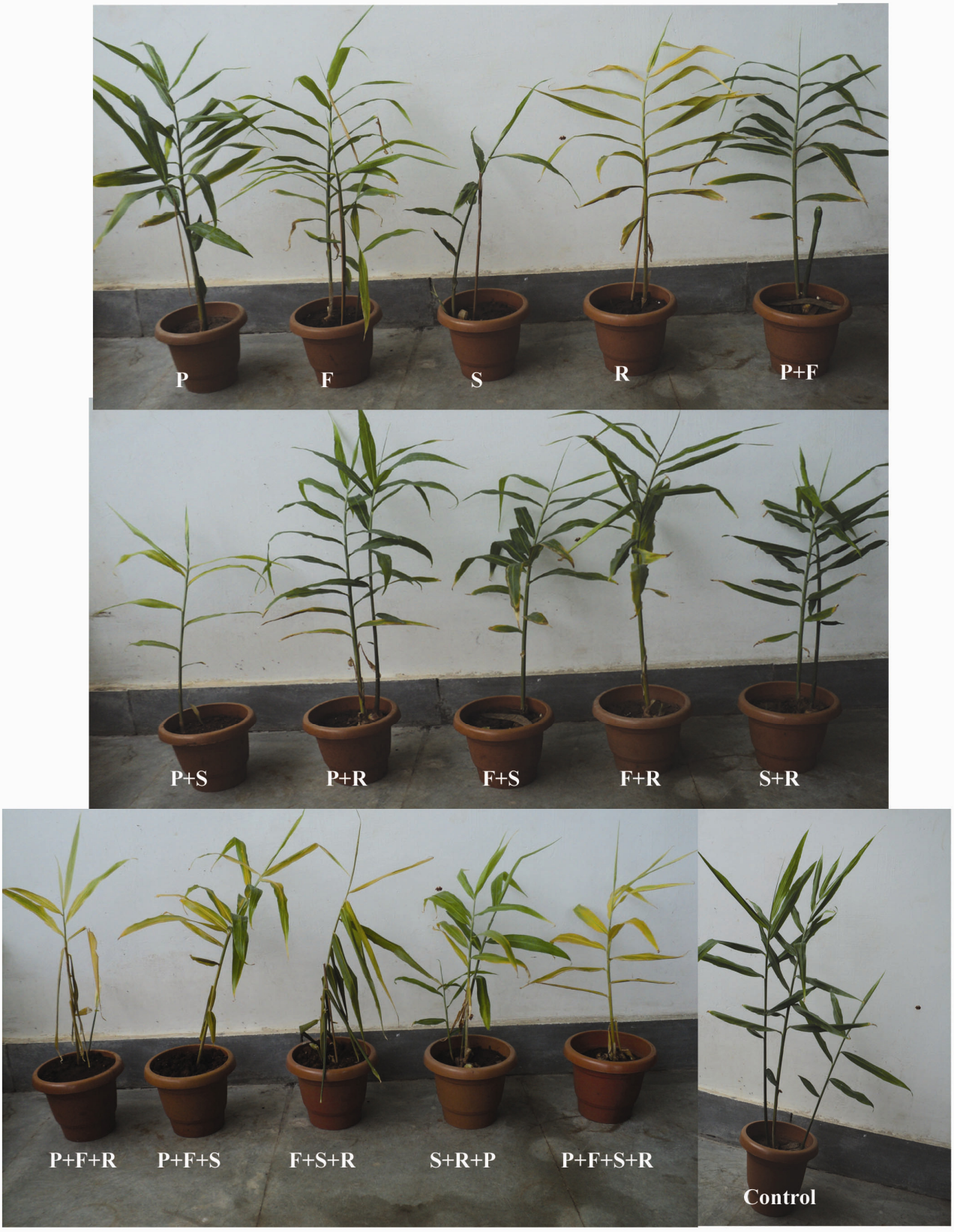


Plate 16. Interaction among different pathogens of rhizome rot of ginger at 105 DAP

Table 22: Interaction among different pathogens of rhizome rot on ginger at 105 and 135 DAP.

Treatment	105 DAP			135 DAP		
	Days taken for symptom induction	**Rhizome rot incidence (%)**	**Detection of pathogen**	**days taken for symptom induction**	**Rhizome rot incidence (%)**	**Detection of pathogen**
P. aphanidermatum alone (P)	22	20.03 (26.47)*	P	20	1.83 (4.52)*	
F. oxysporum alone (F)	35	45.33 (42.31)	F	32	9.90 (15.05)	F
S. rolfsii alone (S)	21	40.67 (39.60)	S	22	8.93 (14.30)	S
R. solanacearum alone (R)	12	66.33 (54.56)	R	15	2.50 (7.33)	R
P+F	25	49.27 (44.58)	F	24	1.99 (5.93)	F
P+S	17	63.27 (52.71)	S	20	5.17 (10.60)	S
P+R	13	46.05 (42.72)	R	16	0.00(0.00)	-
F+ S	30.5	48.17 (43.94)	F S	0	35.05 (36.17)	F S
F+R	24.5	66.49 (54.74)	F R	13	07.83 (13.34)	R
S+R	15	41.69 (40.20)	R S	19	13.97 (21.92)	R S
P + F +R	16	80.93 (64.21)	P S F	16	09.87 (18.04)	P S F
P +F+S	13.5	75.63 (60.48)	R F	13.5	10.63(18.82)	R F
F+S+R	17.4	70.83 (57.35)	R	20	21.87 (27.30)	R S
S+R +P	15	69.31 (56.39)	R S P	18	35.30 (36.36)	R S P
P+F +S+R	12	75.96 (60.70)	R F	15	48.87 (44.32)	R F
Control	-	0.00	-	-	0.00	-
S.Em	-	1.76	-	-	4.39	-
CD at 1%	-	6.82	-	-	17.01	-

* Figures in the parentheses indicate arcsine transformed values.

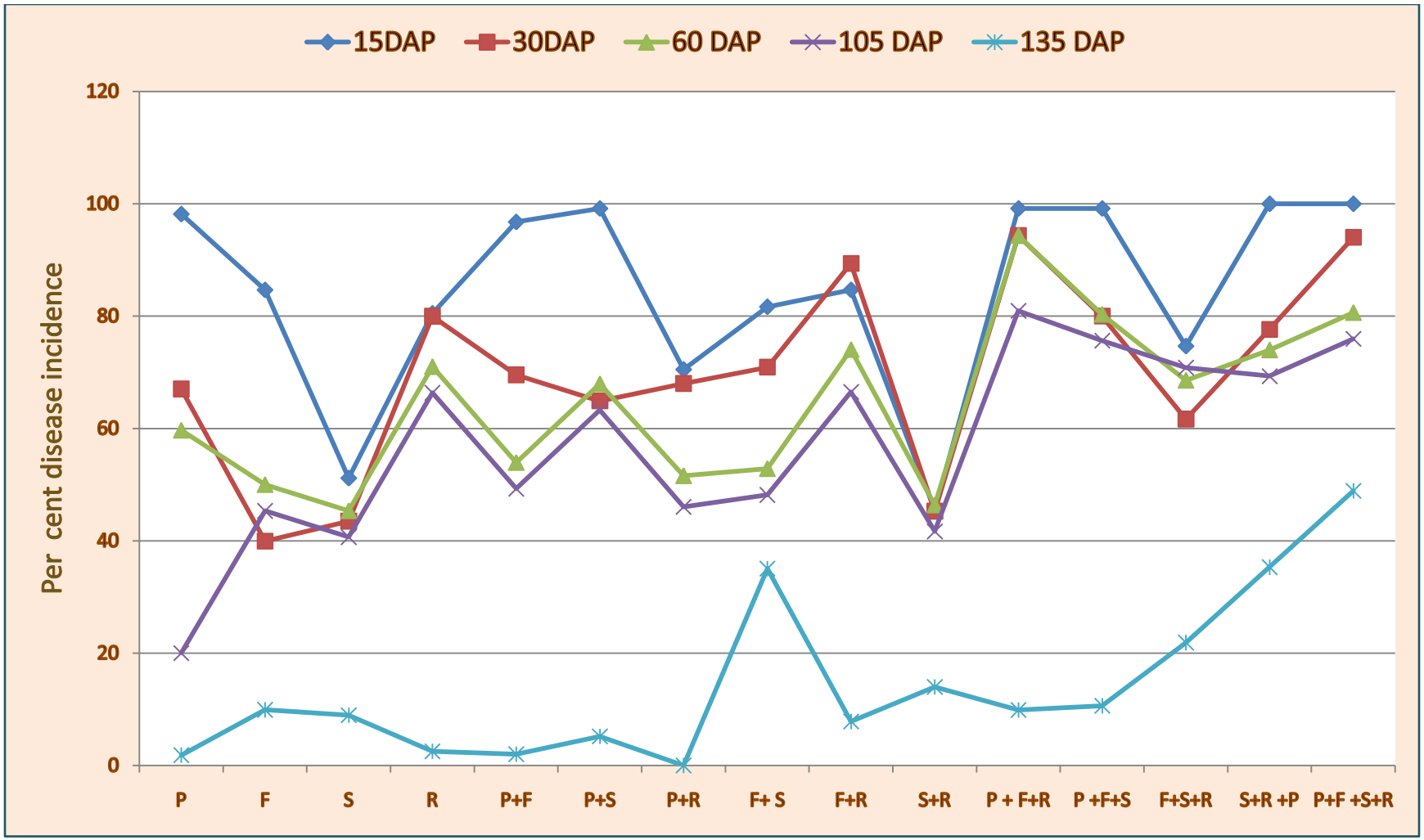


Fig. 6: Interactions among different pathogens of rhizome rot in ginger at different crop growth stages

(DAP= Days after planting, P= *Pythium aphanidermatum*, F- *Fusarium oxysporum*, S= *Sclerotium rolfsii*, R= *Ralstonia solanacearum*)

leaves, which gradually progressed upwards. Whereas, P+F has took longer time (24.0 days).

Highest rhizome rot incidence 48.87 per cent was recorded at P+F+S+R combination which is on par with the S+R+P (35.30%) and F+S (35.05%) combination. There was increase in the disease incidence in combined inoculation of pathogens when compare to individual inoculation.

When pathogens were re isolated from the disease rhizome, it was found that in most of the combinations *S. rolfsii* was not detected (Table 22) and (Plate 17).

***In vitro* evaluation of fungicides by Poisoned food technique**

Efficacy of systemic and non- systemic and some combi-products of fungicides were tested at different concentrations by Poisoned food technique against fungal pathogens of rhizome rot and the results are presented in the Table 23.

All the combi-products tested were capable of cent per cent inhibition of all the three pathogens at both the concentration tested.

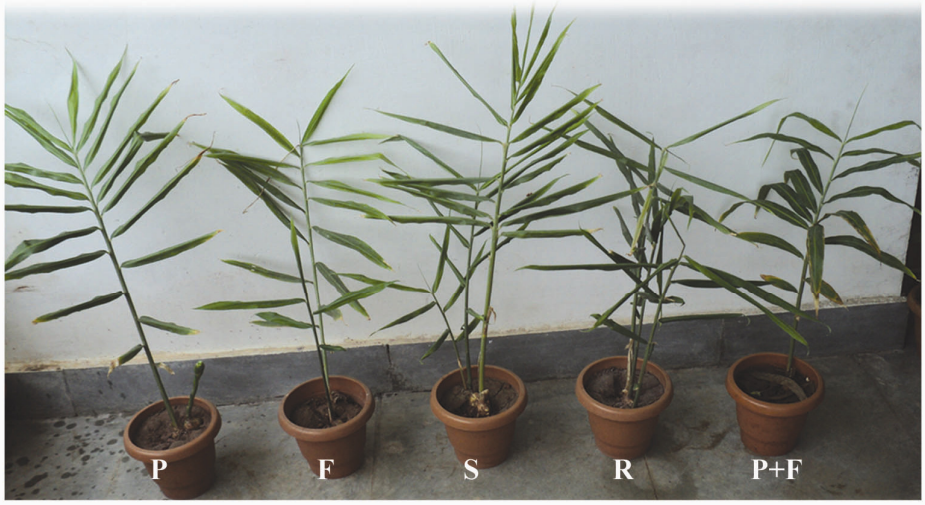
All tested systemic fungicides were capable of inhibiting the mycelial growth to the extent of cent per cent in case of *P. aphanidermatum* except Tridemefon (74.07 @ 0.05%), 95.00 per cent in case of *F. oxysporum* except Metalaxyl (81.92 @ 0.05%) and upto cent per cent in case of *S. rolfsii* except Carbendazim at both the concentrations and Metalaxyl @0.1% (91.11%).

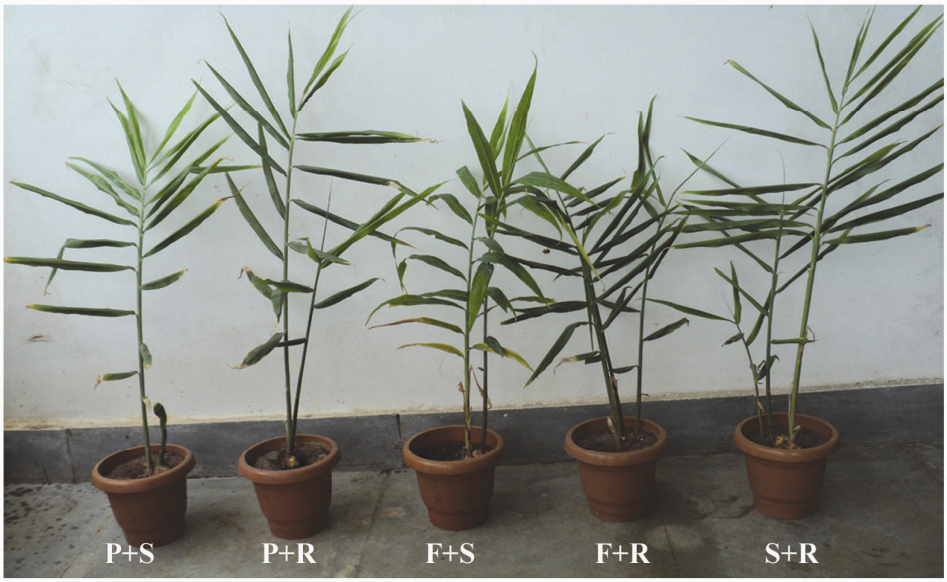
Cent per cent inhibition of mycelial growth was observed in case of *P. aphanidermatum* and *F. oxysporum* with non systemic fungicides (COC, mancozeb and emisan) whereas thiram recorded less inhibition. In

Table 23: Effect of different fungicides on mycelial growth of rhizome rot causing fungal pathogens

Fungicides	Per cent inhibition		
	S. rolfsii	***F. oxysporum***	***P. aphanidermatum***
Non-systemic			
COC @0.2%	13.70 (21.66)	100 (90.00)	100 (90.00)
COC @0.3%	37.03 (37.39)	100 (90.00)	100 (90.00)
Mancozeb @0.2%	100 (90.00)	100 (90.00)	100 (90.00)
Mancozeb @0.3%	100 (90.00)	100 (90.00)	100 (90.00)
Emisan @ 0.2%	91.11 (72.74)	100 (90.00)	100 (90.00)
Emisan @ 0.3%	100 (90.00)	100 (90.00)	100 (90.00)
Thiram @0.2%	75.55 (60.39)	61.11 (51.44)	13.70 (21.66)
Thiram @0.3%	84.81 (67.08)	60.37 (51.00)	42.59 (40.60)
Capton @0.2%	52.96 (46.70)	64.07 (53.18)	82.59 (65.45)
Capton @0.3%	70.00 (56.80)	78.88 (62.71)	94.44 (76.41)
Systemic			
Carbendazim @0.05 %	0.00	88.51 (70.49)	100 (90.00)
Carbendazim @0.1 %	7.40 (15.57)	95.00 (76.41)	100 (90.00)
Metalaxyl @0.05%	100 (90.00)	95.00 (90.00)	100 (90.00)
Metalaxyl @0.1%	91.11 (72.73)	81.92 (90.00)	100 (90.00)
Triademefon 0.05%	100 (90.00)	95.00 (90.00)	74.07 (59.73)
Triademefon @0.1%	100 (90.00)	95.00 (90.00)	79.25 (62.96)
Hexaconazole@ 0.05%	100 (90.00)	95.00 (70.93)	100 (90.00)
Hexaconazole@ 0.1%	100 (90.00)	95.00 (74.68)	100 (90.00)
Combi product			
Ridomil gold @0.05%	100 (90.00)	100 (90.00)	100 (90.00)
Ridomil gold @0.1%	100 (90.00)	100 (90.00)	100 (90.00)
SAAF @0.05%	100 (90.00)	100 (90.00)	100 (90.00)
SAAF @0.1%	100 (90.00)	100 (90.00)	100 (90.00)
Curzate @ 0.05%	100 (90.00)	100 (90.00)	100 (90.00)
Curzate @ 0.1%	100 (90.00)	100 (90.00)	100 (90.00)
Control	0	0	0
S.Em	0.92	0.88	1.41
CD at 1%	3.51	3.36	5.35

* Figures in the parentheses indicate arcsine transformed values.





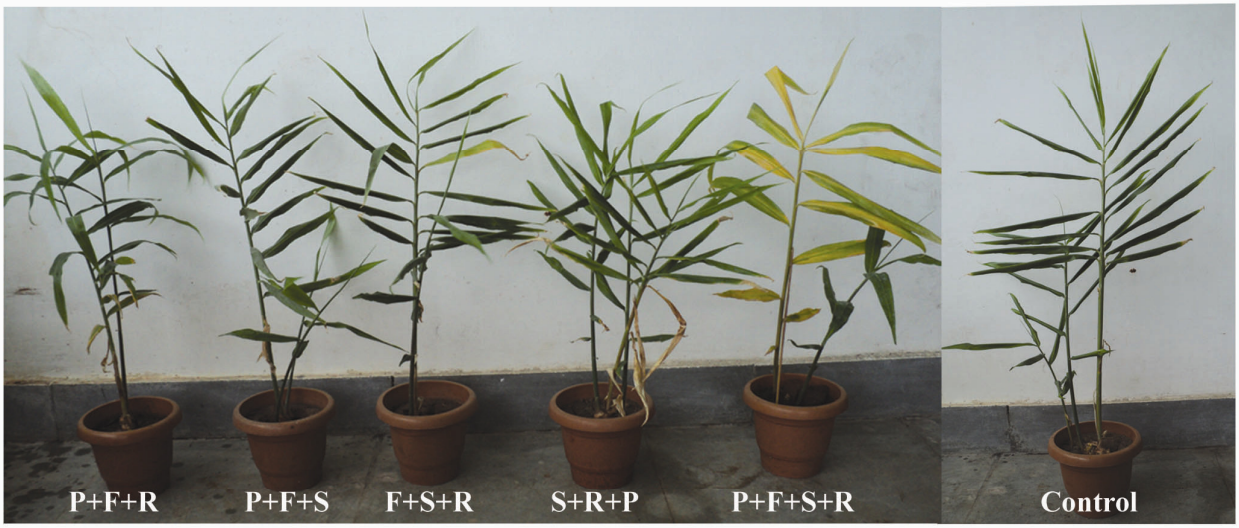


Plate 17. Interaction among different pathogens of rhizome rot of ginger at 135 DAP

case of *S. rolfsii* mancozeb was highly effective with cent per cent inhibition and COC was found to be least effective with only 13.70 per cent inhibition at @0.3 concentration.

Effect of date of planting on Rhizome rot incidence

Experiment was laid out with different dates of planting at Chikmarasa, Shimoga taluk during Kharif 2012 which is hot spot for rhizome rot of ginger. Sowing was done in different months *i.e.* First week of March, April, May, June and July in the year 2012. From the Table 24 it revealed that, per cent germination was highest in treatments which were planted in July (96.00) which were on par with June (94.25) and May (91.00). Planting in March significantly showed less per cent disease incidence (11.66) with higher yield (37.50 kg/plot) which is on par with April planting with the disease incidence (12.63) and yield (34.25 kg/plot). Maximum disease incidence (25.07 %) was recorded in July planted plot with less yield (14.46 kg/plot). (Figure 7)

Screening of ginger varieties against rhizome rot disease

Five ginger varieties which are commonly grown in malnad districts of Karnataka were screened against rhizome rot diseases as described in Material and Methods. Variety Varada has recorded highest germination (90.00) and number of tillers (18.33) and was on par with the Himachal and Rio-de-Janero. All the varieties were found susceptible to rhizome rot disease (Table 25).

The disease incidence ranged from 6.50 to 41.67 per cent. Among the different varieties evaluated, Himachal variety was very susceptible showing higher per cent disease incidence (41.67) even with higher disease incidence this variety was capable of giving maximum yield (19.67 kg/plot). Variety Humnabad Local was found to be resistant for

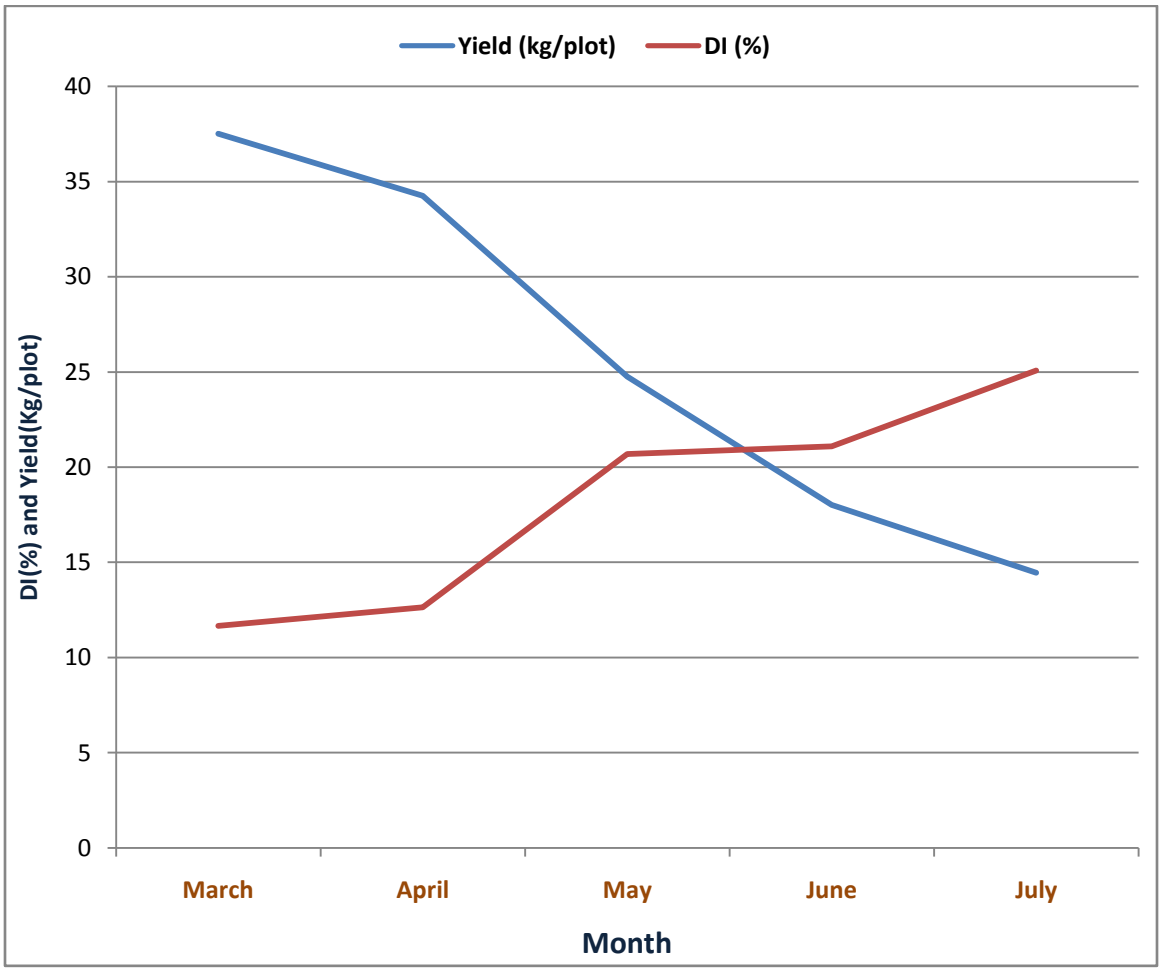


Fig. 7: Effect of date planting on the incidence of rhizome rot and yield of ginger

Table 24: Effect of date planting on the incidence of rhizome rot and yield of ginger

Treatment	Germination (%)	DI (%)	Yield (kg/4 m^2plot)
March	82.00	11.66	37.50
April	84.00	12.63	34.25
May	91.00	20.68	24.75
June	94.25	21.09	18.02
July	96.00	25.07	14.46
S.EM	1.64	1.25	1.91
CD at 5%	5.07	3.84	5.88

Experiment was conducted at Chikkamarasa village Shimoga taluk

Table 25: Screening of ginger varieties against rhizome rot complex

Variety	Germination (%)	Tillers	Disease started at (DAP)	DI % (180 DAP)	Yield (kg/4 m^2plot)
Himachal	86.67	10.33	58.00	41.67	19.67
Reo-de-genaro	85.00	12.00	61.00	33.17	16.00
Maran	80.67	15.00	53.00	20.50	14.33
Varada	90.00	18.33	60.00	27.17	17.00
Humnabad local	80.00	8.00	93.00	6.50	14.00
S.EM	2.90	0.52	4.43	2.25	1.02
CD at 5%	8.93	1.59	13.66	6.95	3.15

Experiment was conducted at Chikkamarasa village Shimoga taluk

the rhizome rot disease with only (06.50 %) could postpone the disease incidence up to 93 days after planting (Figure 8).

Integrated management of ginger rhizome rot disease under field conditions during Kharif 2012

Field experiments were conducted in the year *Kharif* 2012 on the integrated management of rhizome rot of ginger in the farmer's field located at Chikmarasa (Shimoga taluk) and at Nimbegundi (Shikaripura taluk) Shimoga district of Karnataka, where there were records of rhizome rot incidence. Treatments were allocated under Randomized Block Design as described in Material and Methods and observations were recorded on germination, number of tillers, per cent disease incidence along with monitoring of different pathogen population at monthly interval and yield data which are presented in the Table 26 to 28 and Plate 18.

Integrated management of ginger rhizome rot Experiment at Chikmarasa, Shimoga Taluk

Germination percentage and disease incidence at regular interval presented in the Table 26. There was significant increase in the per cent germination at all treatments when compared to control. Disease incidence started from 90 DAPS and gradually increases with crop growth period. Rapid development of disease was found between 180 to 210 DAP. All the treatments significantly reduced the disease incidence when compare to control. Treatment T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease) has recorded lowest disease incidence throughout the crop growth period which was followed by T6 (Rhizome treatment with *Trichoderma viride*+

Table 26: Effect of different treatments on rhizome rot incidence in ginger at different intervals of crop growth at Chikkmarasa

Treatments	Disease incidence of rhizome rot of ginger (%)							
	% germination	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
T1	94.44	0	0.00	2.30	2.37	8.52	8.74	8.91
T2	91.33	0	0.22	2.89	3.90	8.52	8.89	10.03
T3	96.44	0	0.44	1.04	2.96	7.41	7.41	9.08
T4	96.00	0	1.11	2.00	2.30	7.19	7.78	7.85
T5	85.78	0	1.33	1.56	3.41	7.19	8.00	8.00
T6	100.00	0	0.00	0.00	0.44	6.00	6.00	6.00
T7	92.22	0	0.00	0.44	0.96	3.56	4.41	4.56
T8	79.52	0	2.44	6.44	11.04	16.00	24.00	29.41
S.Em	3.16	-	0.48	0.59	0.74	0.29	0.46	0.69
CD at 5%	9.59	-	1.45	1.79	2.25	0.87	1.41	2.10

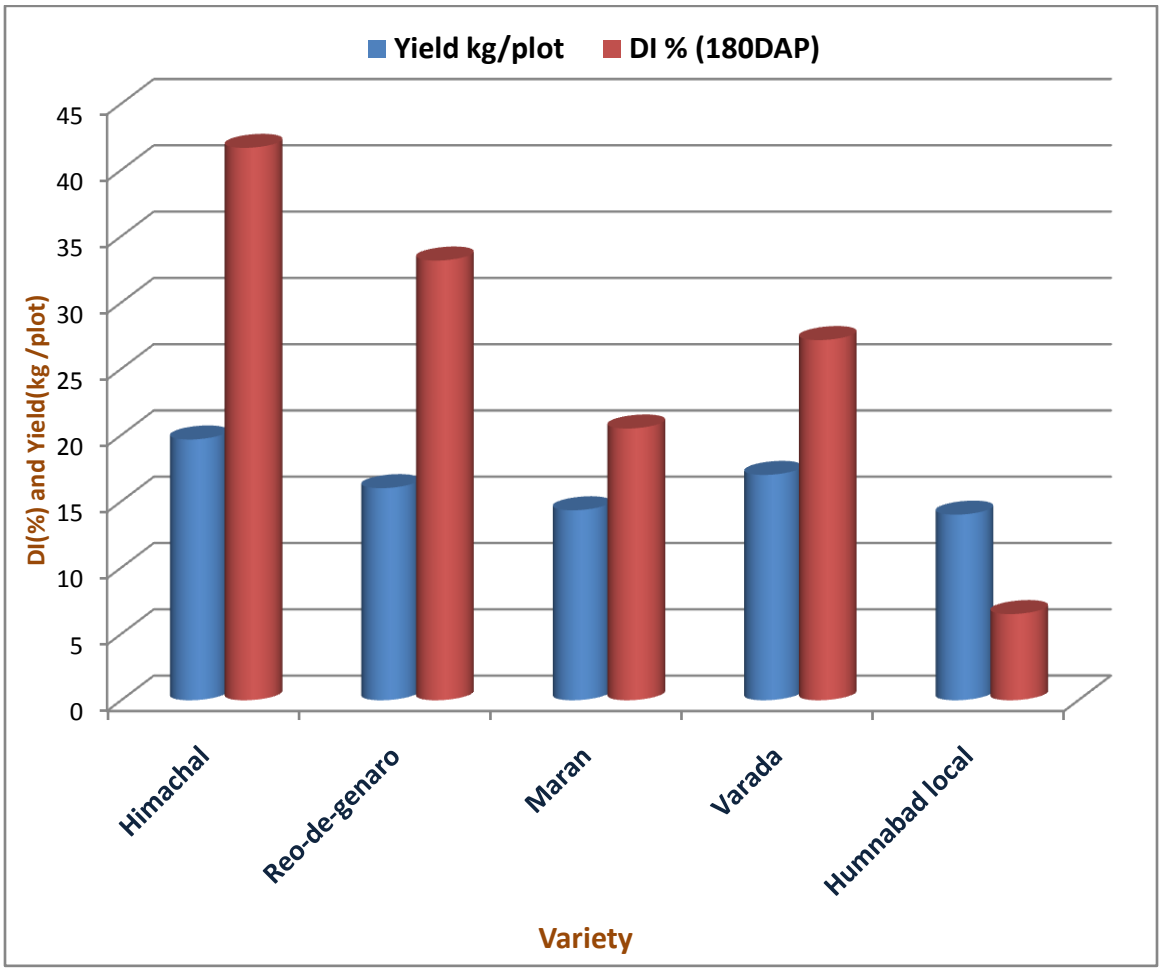


Fig. 8: Screening of ginger varieties against rhizome rot complex



General view of experimental plot at Chikkamarasa





Disease incidence in control plot

Plate 18. Integrated management of rhizome rot of ginger

Pseudomonas fluorescens @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) and T5 (Rhizomes dipped in 0.3% Copper Oxy Chloride +0.05% streptocycline for 30 min + One drench with same solution, immediately at the onset of the disease) (Figure 9).

All pathogens were monitored from the experimental field from the beginning of disease incidence (Table 27). At 90 DAP only *P. aphanidermatum* (2.0 x 10^2/g soil) was detected in T2 (Rhizomes dipped in 0.2% Mancozeb for 30 min + One drench with same solution immediately at the onset of the disease) whereas in control plot both *P. aphanidermatum* (0.30 x 10^2/g soil) and *F. oxysporum* (4.1 x 10^2/g soil) were recorded.

At 150 DAP all the four pathogens were detected in control but treatment T5 i.e. Rhizomes dipped in 0.3% Copper Oxy Chloride +0.05% streptocycline for 30 min + One drench with same solution, immediately at the onset of the disease, T6 (Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) and T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease) were capable of restricting the pathogen growth. Further stages of crop growth and at harvest, all most all pathogens were detected but significantly less population in treatments when compare to control.

Effect of different treatments on yield and yield contributing characters are presented in the Table 28. Highest number of tillers per hill (28.33) and maximum plant height (80cm) found in treatment T6

Table 27: Estimation of pathogen population at different intervals of crop growth period at Chikkamarasa

DAP	Pathogen	Treatments (x 10^2 cfu / g soil)							
		T1	T2	T3	T4	T5	T6	T7	T8
90 DAP	P	0.00	2x102	0.00	0.00	0.00	0.00	0.00	0.30
	F	0.00	0.00	1.10	0.00	0.00	0.00	0.00	4.10
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	R	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150 DAP	P	4.80	6.80	0.00	0.00	0.00	0.00	0.00	10.55
	F	3.60	7.80	4.50	6.80	0.00	0.00	2.50	9.40
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10
	R	0.00	0.00	6.50	0.00	0.00	0.00	0.00	15.76
210 DAP	P	5.60	4.50	5.10	6.10	0.00	0.00	0.00	14.21
	F	10.33	11.22	14.14	15.23	12.50	5.14	4.86	23.45
	S	0.00	4.10	0.50	3.40	0.00	0.00	0.00	0.00
	R	12.56	14.50	35.40	5.60	6.14	0.00	5.40	17.14
240 DAP	P	3.10	3.10	2.00	12.00	0.00	1.20	0.33	14.21
	F	14.10	11.22	14.14	15.23	12.50	5.14	4.86	23.45
	S	0.00	0.00	0.50	3.40	4.50	0.00	0.00	0.00
	R	54.10	14.30	32.10	12.50	5.10	0.00	5.40	17.14
At harvest	P	12.40	0.00	14.12	14.50	0.00	4.50	0.00	12.00
	F	6.10	14.36	5.10	15.20	2.55	4.60	9.10	17.15
	S	5.10	1.10	12.00	4.70	4.99	2.10	4.50	3.50
	R	14.85	6.33	3.50	21.50	5.40	0.00	1.30	27.41

P= *Pythium aphanidermatum*, F- *Fusarium oxysporum*, S= *Sclerotium rolfsii*, R= *Ralstonia solanacearum*

Table 28: Effect of different treatments on growth and yield in ginger

Treatments	No. of tillers per hill	Plant height (cm)	Per cent infection plot $^{-1}$	Yield/ plot (kg/20 m^2)	Yield/ha (tonnes)	B:C ratio
T1	14.00	61.76	9.18	40.67	20.33	12.99
T2	13.33	65.31	10.03	41.00	20.50	13.50
T3	13.67	71.50	9.08	41.83	20.92	13.52
T4	20.67	64.09	7.85	47.50	23.75	15.24
T5	22.67	68.61	8.00	48.50	24.25	15.03
T6	28.33	80.37	6.00	50.17	25.08	15.61
T7	23.67	75.35	4.56	48.00	24.00	14.29
T8	11.67	60.57	22.67	36.00	18.00	9.45
S. Em	1.45	3.22	1.13	0.86	0.43	-
CD at 5%	4.39	9.77	3.43	2.61	1.30	-

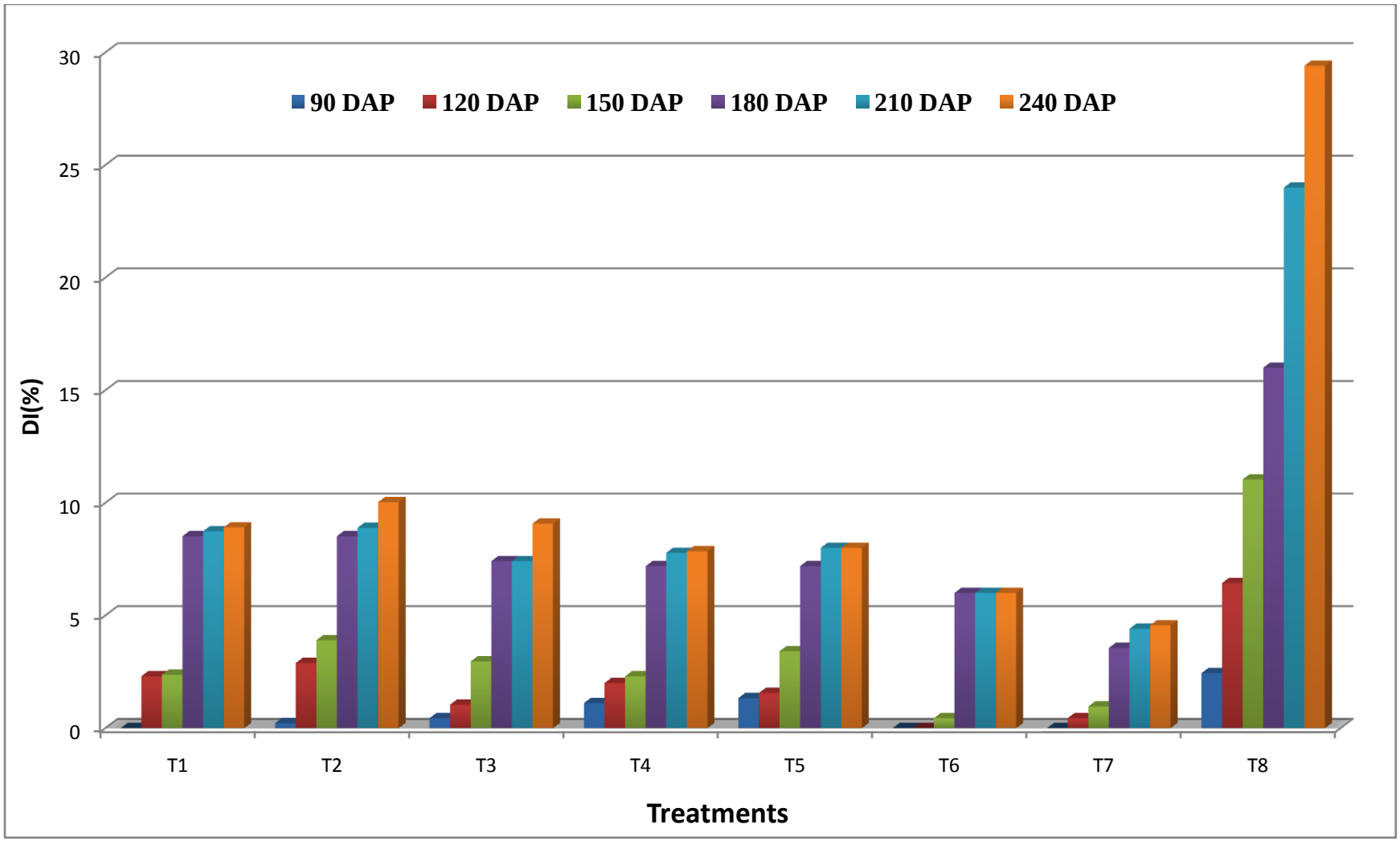


Fig. 9: Effect of different treatments on rhizome rot incidence in ginger at different intervals of crop growth at Chikkmarasa

(Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) whereas lowest was in control (11.67) and (60.57 cm) tillers and plant height, respectively.

There was a significant reduction in per cent infection and yield in all the treatments when compare to control. Lowest infection was found in T7 (4.56 %) which was on par with the T6 (Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) (6.00%). Maximum yield was also recorded by T6 (25.08 t/ha) which was on par with the T5 (24.25 t/ha) and T7 (24.00 t/ha). There was significant difference in the yield between control and treatments. Highest B: C ratio of 15.61 was recorded in T6 compare to control which recorded least B:C ratio of 9.45.

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Germination percentage and disease incidence at regular interval recorded and presented in the Table 29. Similar trend was observed as that of Chikmarasa experiment. There was significant increase in the per cent germination an all treatments when compared to control (71.94 %). Disease incidence started from 60 DAPS and gradually increases with crop growth period. Rapid developments of disease found between 150 to 180 DAP. All the treatments significantly reduced the disease incidence when compare to control. The treatment T6 (Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) has recorded lowest disease incidence throughout the crop growth period which was followed by T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil

Table 29: Effect of different treatments on rhizome rot incidence in ginger at different intervals at Nimbegundi

Treatments	% germination	Disease incidence of rhizome rot of ginger (%)						
		60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
T1	92.50	0.00	0.83	3.89	5.00	5.56	6.39	6.39
T2	96.11	0.83	2.78	5.28	5.28	7.50	8.33	8.33
T3	85.00	0.00	0.28	1.39	8.89	8.89	8.89	8.89
T4	80.28	0.56	0.56	1.11	6.67	6.67	6.94	8.61
T5	96.94	0.00	1.11	1.11	5.00	5.28	5.28	5.28
T6	96.94	0.00	0.00	2.50	3.06	3.33	3.61	3.61
T7	92.50	0.00	0.00	1.11	3.75	3.75	4.03	4.44
T8	71.94	1.11	2.22	12.22	16.67	30.28	30.83	30.83
SEm	2.59	0.68	0.68	0.79	0.86	0.93	0.67	1.08
CD at 5%	7.85	2.06	2.06	2.41	2.60	2.81	2.04	3.27

application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease) and T5 i.e. Rhizomes dipped in 0.3% Copper Oxy Chloride +0.05% streptocycline for 30 min + One drench with same solution, immediately at the onset of the disease (Figure 10).

All pathogens were monitored in the experimental field from the beginning of disease incidence data are presented in the Table 30. At 90 DAP only *P. aphanidermatum* (1.40 x 10^2/g soil) from T2, *F. oxysporum* (1.33 x 10^2/g soil) and *R. solanacearum* from T4 (1.20 x 10^2/g soil) were detected. Whereas in control plot, all these three pathogens i.e., *P. aphanidermatum* (0.30 x 10^2/g soil) and *F. oxysporum* (4.1 x 10^2/g soil) and *R. solanacearum* (6.56 x 10^2/g soil) were detected.

At 150 DAP all the four pathogens were detected in control but T6 and T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease) were capable of restricting the pathogen growth. Further stags of crop growth and at harvest all most all pathogens were detected but significantly less population compare to control.

Effect of different treatments on yield and yield contributing characters are presented in the Table 31. Highest number of tillers per hill (30.67) and maximum plant height (77.02cm) found in treatment T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset

Table 30: Estimation of pathogen population at different intervals of crop growth period at Nimbegundi

DAP	Pathogen	Treatments (x 10 ^{2} cfu /g soil)							
		T1	T2	T3	T4	T5	T6	T7	T8
90 DAP	P	0.00	1.40	0.00	0.00	0.33	0.00	0.00	0.30
	F	1.33	0.33	1.00	0.00	0.00	0.00	0.00	4.10
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	R	0.00	0.00	0.00	1.20	0.00	0.00	0.00	6.56
150 DAP	P	0.00	6.80	0.00	0.66	0.33	0.00	0.00	15.40
	F	6.50	17.50	4.50	19.55	7.80	0.00	2.50	32.15
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
	R	8.56	0.33	6.50	0.00	14.20	0.66	0.00	37.66
210 DAP	P	2.50	4.50	5.10	0.00	0.00	0.00	0.33	25.10
	F	18.66	0.33	14.14	15.23	12.50	5.68	2.11	30.51
	S	6.76	2.44	0.50	3.40	0.00	12.56	0.00	15.10
	R	17.55	13.55	35.40	2.22	6.14	15.60	6.48	13.35
240 DAP	P	0.00	3.10	6.33	6.00	0.00	12.00	0.33	28.66
	F	18.10	14.55	20.51	15.23	12.50	5.14	4.86	23.45
	S	0.00	0.00	3.55	3.40	4.50	0.00	0.00	14.24
	R	31.10	14.30	32.14	12.50	5.10	0.00	5.40	28.45
At harvest	P	0.00	0.00	0.00	14.50	0.00	14.52	0.00	25.10
	F	15.10	14.36	5.10	12.00	5.44	4.60	9.10	32.54
	S	19.56	12.00	12.00	4.70	4.99	2.10	4.50	30.00
	R	14.85	6.33	3.50	21.50	5.40	0.00	1.30	36.10

P= *Pythium aphanidermatum*, F- *Fusarium oxysporum*, S= *Sclerotium rolfsii*, R= *Ralstonia solanacearum*

Table 31: Effect of different treatments on yield and yield contributing characters of ginger at Nimbegundi

Treatments	No. of tillers per hill	Plant height (cm)	Per cent infection plot $^{-1}$	Yield/ plot (kgs/20 m2)	Yield/ ha (tonnes)	B:C ratio
T1	12.33	60.13	6.39	23.33	14.58	9.31
T2	14.00	57.13	10.28	23.50	14.69	9.68
T3	13.67	66.48	8.89	23.92	14.95	9.66
T4	20.67	52.15	9.72	26.75	16.72	10.73
T5	21.33	68.61	5.28	24.33	15.21	9.43
T6	28.67	64.00	4.72	27.00	16.88	10.51
T7	30.67	77.02	5.56	28.08	17.55	10.45
T8	12.67	45.33	30.83	21.00	13.13	6.89
S. Em	1.74	2.58	1.24	0.70	0.44	
CD at 5%	5.29	7.82	3.77	2.12	1.32	

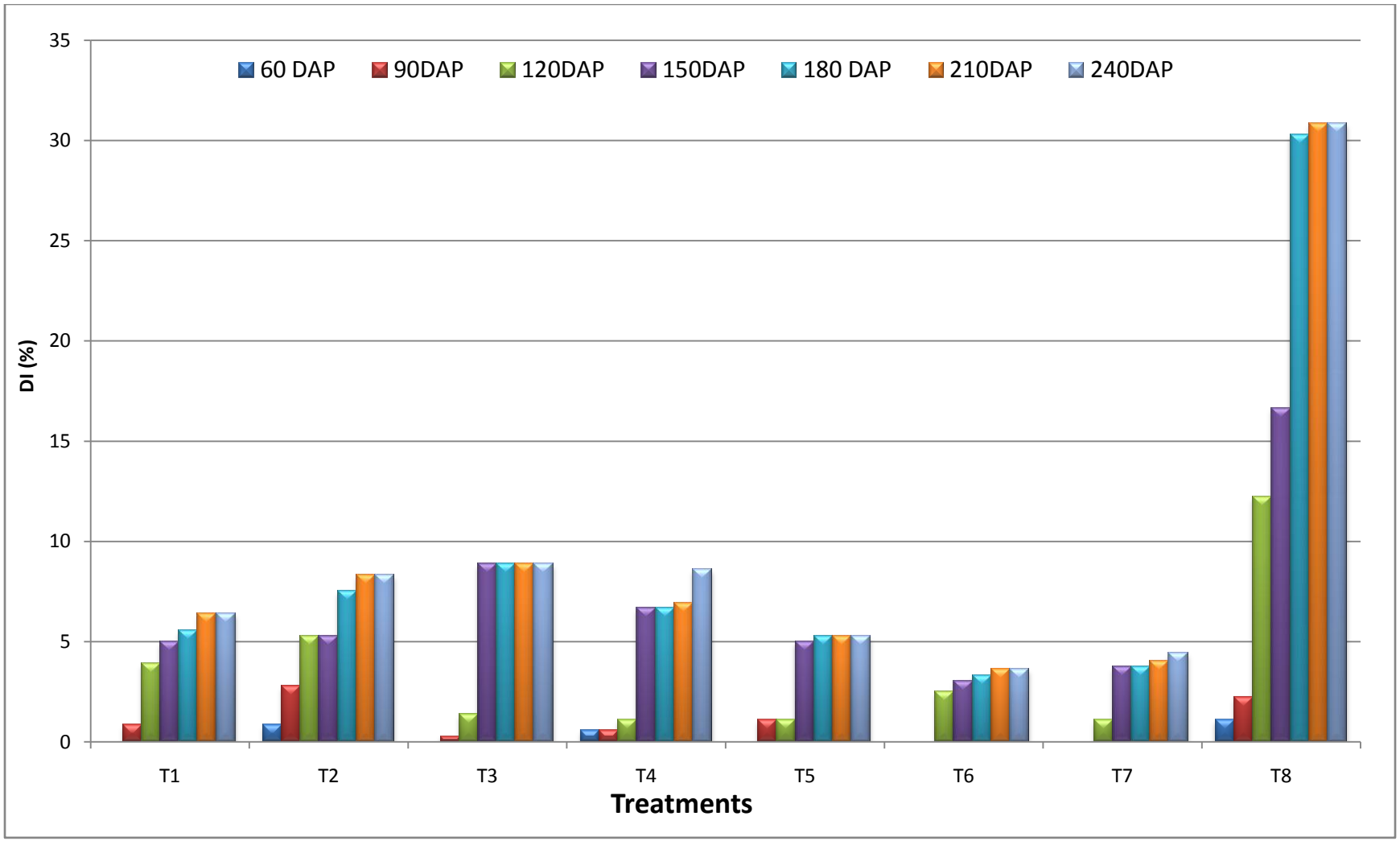


Fig. 10: Effect of different treatments on rhizome rot incidence in ginger at different intervals of crop growth at Nimbegundi

of the disease) where as lowest was in control (12.67) and (45.33 cm) tillers and plant height, respectively.

There was a significant reduction in per cent infection and yield in all the treatments when compare to control. Lowest infection of 4.72 per cent was found in T6 (Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha) which was on par with the T7 (Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens and Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease) which recorded 5.56 per cent followed by T6 (5.28%). Maximum yield was produced by T7 (17.55 t/ha) which was on par with the T6 (16.88 t/ha). There was significant difference in the yield between the control and treatments. However, highest B: C ratio of 10.51 was recorded in T6 compare to 6.89 in control.

Discussion

V. DISCUSSION

The results obtained on studies related to rhizome rot complex of ginger and its management with respect to survey, isolation of pathogens, interactions among the different pathogens and management of disease in the field conditions are discussed here under.

The major pathogens involved in causing rhizome rot complex were found to be *Pythium aphanidermatum* causing soft rot, *Fusarium* oxysporum causing yellows or wilt and *Ralstonia solanacearum* causing bacterial wilt. All these pathogens were known to form complexes with nematodes leading to synergistic effect on the severity of the disease. In field conditions accurate differentiation of the symptoms caused by combined infections could not be done. Foliar yellowing, stunted growth, wilting and drying of whole plant were the common symptoms observed irrespective of the pathogen involved. Similar symptoms were reported by Sharma (1994).

Pre emergence and post emergence damping off, extensive rotting of rhizomes and rotted tissues emitting foul smell and such plants came off with gentle pull. These symptoms were commonly found when ginger gets infected by *P. aphanidermatum*. Foliar yellowing which starts from lower leaf and spreads to upper parts of plant as disease progresses and slight discoloration of cortical tissue were observed in *Fusarium* infected plants. However, Small water soaked streaks in and around the collar region of plant as well as on the pseudostem, rhizomes of such plants when pressed gently exhibited oozing of bacteria were the specific symptoms observed when ginger infected by *R. solanacearum*. The similar observations on symptoms were given by Iyer (1987) and Sarma (1994).

Survey conducted during *Kharif* 2011-12 in major ginger growing areas of Karnataka revealed that, rhizome rot incidence was prevalent in all the locations surveyed with the range from 3.50 to 56.00 per cent. The maximum average disease incidence of 28.16 per cent was recorded in Uttara Kannada district, followed by Shimoga (25.89 %), Chikkamagalore (24.76%) Coorg (22.69%) and Hassan (15.20%). The disease incidence varied from locality to locality this could be due to cropping pattern, environmental conditions and build up of inoculum. The higher disease incidence could be attributed to heavy rains leading to water logging because of improper drainage which favoured rhizome rot disease. Average incidence in all the five malnad districts during 2011 was 24.68 per cent where as it was 20.08 per cent during 2012. This could be due to less rainfall in 2012 (Weather data given in the appendix). Similar results were reported from Kerala by Rajan and Agnihotri (1989) where losses were as high as 90 per cent during years of heavy rainfall.

Banavasi and Korlakotta (Uttara Kannada), Sevalal nagar, Hirekasvi, Rippenpet (Shimoga) and Makod (Chikkmangalore) villages were found to have more than average disease incidence and also the disease in endemic form. Higher incidence of rhizome rot in the same places was reported by Shalini (2006). Hence, these places can be considered as “hot spots” of ginger rhizome rot complex.

The survey and meteorological data revealed that, disease intensity depends on factors like location, cultural practices followed, use of infected rhizomes and meteorological factors like temperature, relative humidity and rainfall. In general, it was observed that, the disease progress under natural conditions was also in the months of July-August which coincides with heavy rains and cool weather. During survey, it was

observed that soils with poor drainage capacity were more prone to infection by pathogens.

McRae (1911) from Bangladesh reported that, the reduction in ginger yield was due to improper drainage and long mono cropping system adopted. The disease incidence was ranged from 10 to 15 per cent in low-lying fields and six per cent in upland areas. Disease appeared in epiphytotic forms to cause enormous loss in certain years. Moderate to severe incidence leading more than 50 and 80 per cent yield loss reported on an account of this disease due to heavy rains and monocropping system respectively (Butler,1918 and Joshi and Sharma, 1980).

In the present investigation it was observed that, disease starts at the onset of the monsoon. Maggots of rhizome fly were found in rhizomes of wilting plants and this would enhances/ predisposes the attack of other soil borne pathogens and saprophytes leading to aggravation of the disease. Root -knot nematode was also found but its distribution was very sparse. Association of rhizome fly with the rhizome rot was reported by Dohroo *et al.,* (1987) and nematodes by many workers (Dohroo *et al.,* 1987); (Sundararaju *et al.* 1980); (Kaur *et al.*, (1989).

Soil physicochemical parameters like pH, OC and N-content have got significant negative correlation with per cent disease incidence. R^2 was found 0.713 means that 71.30 per cent variation in the disease development was explained by all the six independent variables *i e.*, pH, EC, OC, N, P and K content in the soil. Similar results were obtained by Sharma *et al.,* (2010) where in they have obtained negative correlation with disease incidence(r^2=93.26).

Kim *et al.* (1997) reported that pH range of 6.0-7.0 was found to be optimum for the growth of the *Pythium myriotylum*, the causal agent of

rhizome rot of ginger. Consistent relationships between disease severity and soil physiochemical properties did not exist (Kim *et al.,* 1996). The reason may be lower pH may inhibit the germination of *F. oxysporum f. sp. zingiberi* conidia as reported by Lee *et al.* (1990).

In the present investigation it was found that, the succulent vegetative growth would make plant more prone to disease attack. Suppression of soil borne pathogens especially *Pythium*, *Fusarium* and *Sclerotium* by increased organic matter content was reported by many workers (Hadar and Mandelbaum, 1986; Chen *et al.*, 1988; Hardy Gesj and Sivasithamparan 1991; Diab *et al.,* 2003; Pane *et al.,* 2011; Cotxarrera *et al.*, 2002; Borrero *et al.* 2004; Borrero *et al.* 2009; Ntougias *et al.* 2008; Kavroulakis *et al.* 2010).

Suppression of pathogens is due to activity of beneficial microbes because of the increased water holding capacity of soils. This will finally improve the soil health (Pharand *et al.* 2002; Saadi *et al.*, 2010). There were evidence that the population of *R. solanacearum* race 3 declines in soils that have high organic matter content (Moffet *et al.,* 1983). The present investigation, therefore, indicated that pathogen population and their survibility would dependent on the soil physicochemical properties ultimately determined the severity of the disease of that particular soil or in that field.

In the present investigation, diseased samples revealed to produce *Pythium aphanidermatum, Fusarium oxysporum, Ralstonia solanacearum* and *Sclerotium rolfsii.* Hence pathogens involved in rhizome rot were *Pythium aphanidermatum*, *Fusarium oxysporum, Ralstonia solanacearum* and *Sclerotium rolfsii.*

P. aphanidermatum and *F. oxysporum* identified by morphological characters and cultural characteristics were found similar to description

given by Van der Plaats- Niterink (1981). The identities of these were further confirmed by Agharkar Research Institute, Pune, Maharastra.

Several *spp*. of *Pythium* have been reported as causal agents of soft rot in different parts of the world. Among them *Pythium aphanidermatum* (Edson) Fitzp. reported by many workers (Mitra and Subramaniam, 1928; Vaheduddin,1955; Sahare and Asthana, 1962; Dake and Edison, 1989; Sarma *et al.*, 1979; Shalini, 2006; Independent infection by *F. oxysporum* causing wet rot in Karnataka by Kumar (1977).

In the present investigation *Ralstonia solanacearum* was found to gram-negative, rod shaped, non-capsulated and non-spore forming, lophotrichously flagellated with two to four polar flagella. Several workers confirmed that the *R. solanacearum* is rod shaped lophotrichous flagellated (Khan, 1974; Ram Kishun, 1987 and Norman and Yuen, 1998).

In the present investigation *Sclerotium rolfsii* was found to be fast growing fungus started producing branched snow white coloured mycelia. The well developed mycelium started yielding tan coloured sclerotia at the periphery of the colony. The description of the fungus was similar to the description given for *S. rolfsii* Sacc. by Aycock (1966).

Pathogenicity tests for *P. aphanidermatum*, *F. solani*, *S. rolfsii* and *R. solanacearum* and were carried out on 45 days old ginger plants. The symptoms produced were similar to that described in symptomatology.

Enumeration of pathogen population from the diseased soil samples collected during survey revealed the association with either single or a combination of two, three, or four pathogens. Dake and Edison (1989) reported that ginger rhizome rot samples from Kerala was associated with either *P. aphanidermatum* or *F. solani* or *F. oxysporum* f

sp. *zingiberi* or *Pseudomonas solanacearum.* Disease may aggravate in the presence of nematodes and insects as noticed in the survey.

According to the present results, *R. solanacearum* was the most frequently associated, followed by *F. oxysporum, P. aphanidermatum* and *S. rolfsii.* Most of the farmers in the surveyed area have applied metalaxyl MZ for the control of rhizome rot this could be the reason for decline in the population of *Pythium* sp. Shalini (2006) reported that *R. solanacearum* has more commonly associated in the southern parts of Karnataka. Dominance of *R. solanacearum* may be due to some farmers procure the seed material from Kerala state and this bacterial wilt was a serious problem in that state. Further farmers did not used any antibiotics for the management.

In the present study, Potato dextrose agar, potato carrot agar, Sach's agar, Ashby's mannitol, oat meal agar and Sabouraud's agar were found best for *P. aphanidermatum* mycelial growth and Sabouraud's, potato dextrose and potato carrot agar were found best for oospores production. Maximum radial growth of *F. oxysporum* was observed in Tochina, Czapek's, Richards's and Glucose asparagine agar and were also favoroured in producing conidia. Whereas *S. rolfsii* was capable of growing on most of the media tested.

The nature of survival of *P. aphanidermatum* and *F. solani* in the seed rhizome was not clear. However, scales harbouring the oospores in seed rhizomes have been reported (Thomas, 1938; Mc Rae, 1911; and Butler, 1918). They considered the use of diseased rhizomes to be the principal factor in the dissemination of the pathogens. So, in the present investigation, the infected rhizome samples and culture discs were buried in sterilized and unsterilized soils revealed that, all the pathogens could able to survive for longer period in the sterilized soil than in the unsterilized soil. But *R. solanacearum* was alive up to 14 weeks in both

unsterilized and sterilized soils. *P. aphanidermatum* can survive up to 30 weeks, *F. oxysporum* can survive up to 34 weeks, *S. rolfsii* could survive up to 40 weeks and *R. solanacearum* can survive up to 22 weeks in the infected rhizomes. Oospores were the primary survival structures of *P. aphanidermatum*, Chlamydospores in *F. oxysporum and Sclerotial* bodies in *S. rolfsii* they are resistant to desiccation and could survive in the soil for longer period in the absence of suitable hosts or organic substrates that support saprobic growth.Similar findings were reported by Peethambaran and Singh (1977), Lin *et al*. (1992), Stanghellini and Nigh (1972). Peethambaran and Singh, (1977) and recovered the *P. aphanidermatum* after 11 months from soil. In another study, culture-produced oospores or oospores in cucumber leaf tissue had a dormant period of 50 days when incubated in dry soil or 100 days in distilled water (Lin *et al.*, 1992). According to Stanghellini and Nigh (1972) *P. aphanidermatum* survived in the form of oospores in oat roots that were buried in fallow field soil for 16 months. De Vay *et al*. (1982) also reported, the survival of oospores of *P. aphanidermatum* for five months in naturally infested field soil.

Fusarium solani being a soil dweller and survives in the form of chlamydospores in the field, year after year (Kulkarni and Hegde, 2002). Sharma and Jain (1978) reported that, the infected but apparently normal ginger rhizomes serve as the primary source of inoculum and chlamydospores serve as the perennating propagules.

Liddell and Burgess (1985) demonstrated that *F. moniliforme* microconidia could survive up to 900 days under various humidity and temperature conditions in the laboratory. *F. moniliforme* conidia and hyphae survived two Kansas winters in sorghum stalks without any loss of viability or pathogenicity (Manzo and Claflin, 1984). Nyvall and Kommedahl (1970) studied the survival of *F. moniliforme* for eight months

in maize stalk residue in Iowa field. They observed longer survival duration for residue buried at 30 cm than for surface residue. So the present study indicated that, the infected rhizomes should not be used for sowing and also taking suitable rhizome treatment methods is mandatory.

Studies related to survival of *R. solanacearum* was very sparse. Survival of *R. solanacearum* in plant-free potting medium for 120 days and for 150 to 180 days in potting medium with infected edible ginger was reported by Mathews *et al.*, (2008).

In the present investigation, in ginger the inoculum density of pathogens influenced the development of rhizome rot. Disease severity was progressed as there was increase in inoculum concentrations. Similar findings were reported by Landa *et al.* (2001) in chickpea, who expressed that, increase in inoculum density of *Fusarium oxysporum* f. sp. *ciceris* increased the disease severity.

Interaction among the pathogens causing rhizome rot of ginger was studied at different stages of crop growth by inoculating pathogens individually and in combinations. The results revealed that, *P. aphanidermatum*, *F. oxysporum, R. solanacearum* and *S. rolfsii* pathogenic potentiality.

R. solanacearum was capable of inducing the symptoms at the earliest in all the stages of crop growth, it could be due to ability of faster multiplication rate than the fungi and also wound formed during the inoculation would facilitate its entry faster than the fungi. Similar results were obtained by Shalini (2006).

Individually *P. aphanidermatum* was more potential pathogen in early stages of ginger growth, reason might be the succulent nature of

plants wherein plant was not strong enough to resist the attack by pathogen. It was very clear from the results that, *P. aphanidermatum* potential has reduced to cause disease at 105 and 135 DAP. The *P. aphanidermatum* could not be detected in rotted rhizomes after at 105 and 135 DAP failed to establish even with other pathogens.

F. oxysporum alone could had taken 25 days to produce symptoms and *S. rolfsii* alone has taken 20 days after inoculation in most of the stages of ginger growth. In the present investigation, it was inferred that, *R. solanacearum* alone inoculated plants showed early symptoms and caused maximum disease incidence. These results are in accordance with the findings of Lum (1973), who conducted a pathogenicity study with *R. solanacearum* on ginger and proved that, it caused early symptom and maximum disease. Rajan *et al.* (2002) reported that among the individual inoculation of *R. solanacearum, P.aphanidermatum* and *F. solani, R. solanacearum* caused the maximum disease incidence.

With the combined inoculations of pathogens at almost all stages (15, 45, 75, 105 and 135 DAP) there was increase in the disease incidence compare to individual inoculations and this shows that there was a synergistic effect among the pathogens of rhizome rot. In only one combination *i e.,* S+R there was lower rhizome rot incidence was recorded because of antagonistic effect between these two pathogens. In some combinations, when pathogens were detected later from those samples, *P. aphanidermatum* and *R. solanacearum* were recorded in the early stages of crop growth and *R. solanacearum* and *F. oxysporum* were recorded in later stages of crop growth. This indicated that, two pathogens were dominant not allowing others to cause infection. Disease complex syndrome between *Pythium* spp. and *Fusarium* spp. is also known with other pathosystems (Hendrix and Campbell, 1973).

Chauhan and Patel, (1990) reported that independent infection of ginger as well as interaction between *Pythium* spp. and *F. solani* would lead synergistic effect. Both the organisms were pathogenic in independent inoculations. But combined infection resulted in rapid drying of the shoot followed by rhizome rot.

Association of *Pythium* spp. and *Fusarium* spp. especially *F. solani* and *F. equiseti* have been demonstrated by Bhardwaj *et al*. (1988). In artificial inoculation tests, it has been demonstrated that maximum rotting occurred only when *P. aphanidermatum* was inoculated first followed by *F. solani*. Since environmental conditions required for *Pythium* and *Fusarium* were different, it was possible that a succession of the two pathogens occur in the same field. This possibility was particularly interesting since agro climatic conditions were not uniform throughout the crop season. Periodic isolation of pathogens from the same field was necessary to test this hypothesis. Dake and Edison (1989) stated that, *F. oxysporum* f. sp. *zingiberi* could form complex with *Pythium* spp. The same workers conducted survey in Kerala reported that, there was association among *Pythium* spp., *Fusarium* spp. or *R. solanacearum.* In this present study, it was found that, none of the samples yielded more than one pathogen on isolation.

Nematode pre infection would aggravate the disease which predispose the crop for secondary infection. This was in conformity with the findings of Mani and Sethi (1987) who reported that the nematodes provide a congenial atmosphere either by facilitating the entry of fungi, into roots through the injury or modifying the substrate or by producing stimulants in the form of secretions which help the multiplication of fungi. Sumer Jan and Khan (2002) reported that high incidence in the presence of nematode might be due to the physiological changes in the host induced by the nematode infection and resulting in accumulation of

carbohydrates and amino acids. Such environment would be favourable to fungal growth (Kleineke-Borchers and Wyss, 1981).

Many reports on interaction of fungal pathogens and nematodes in rhizome rot complex of ginger are available. Combined inoculations of ginger with *M. incognita* and *P. myriotylum* resulted in significant reduction in weight of aerial shoot, root and rhizome in a pot culture test (Lanjewar and Shukla, 1985). *Pythium myriotylum* also caused significant growth reduction but *M. incognita* alone did not. An instance of synergistic effect of *P. aphanidermatum* and *M. javanica* was observed in Madhya Pradesh (Vadhera *et al.*, 1992).

There was a significant inhibition of mycelial growth on the media poisoned with all combi products (SAFF, Ridomil gold and Curzate) and systemic fungicides (Hexaconazole, Carbendazim, Metalaxyl and Triademefon) non-systemic (Emisan, COC and Mancozeb) fungicides at different concentrations. But some non-systemic fungicides like Thiram and Captan are less effective. These chemicals could be effectively utilized in rhizome treatment for management of disease. These findings are in accordance with results of Shalini (2006).

Thakore *et al.* (1988) evaluated six non-systemic and four systemic fungicides against rhizome rot with respective fungicides before planting. Of these, Mancozeb, Captafol, Ziride, Captan and Metalaxyl decreased rhizome rot incidence besides increased germination and yield. Seed dip in Emisan 6, Blitox and mercuric chloride effectively controlled rhizome rot caused by *P. pleroticum* and their effectiveness was at par with Dithane, M- 45 (Sharma and Dohroo, 1982).

However, from the present study it revealed that, rhizome treatment with fungicides helps in elimination of *P. aphanidermatum* and *F. solani* since both the pathogens were rhizome-borne. These fungicides

could be recommended to farmers for rhizome treatment which is a potential primary source of inoculum for further spread.

Experiment on date of planting revealed that, planting in March and April significantly recorded less per cent disease incidence of 11.66 and 12.63, respectively with higher yields of 37.50 kg/plot and 34.25 kg/plot, respectively. The reason would be when crop sown early it becomes hardy by the time peak rainy season and less vulnerable to infection during critical period (July- August). In Calicut (Kerala) planting during May or early June resulted in less disease incidence (*Anon.*, 1984). Since the crop season varies at different places and the ideal time of planting also vary accordingly (Sarma, 1994).

In the present investigation, five ginger varieties were screened for resistance to rhizome rot in field where ginger was the last crop grown. The results revealed that, none of ginger varieties screened for rhizome rot showed resistant reaction. However,among the varieties tested Humnabad local has recorded less disease incidence followed by Maran. These two varieties could be considered as less susceptible compare to other varieties. None of the tested verities found resistant. These findings are in agreement with Indrasenan and Paily (1973), who reported the variety Maran was more resistant to soft rot of ginger caused by *P. aphanidermatum.* Moderate resistance was reported in two varieties *viz.* Nadia and Naraspatam (Balagopal *et al.*, 1975). Nair (1965) reported that, the resistance of Maran variety and greater susceptibility of Rio-de-Janero.

Nybe and Nair (1979) also reported that, the variety Maran expressed field tolerance against *P. aphanidermatum*. Sarma *et al.(*1979) demonstrated lack of resistance or tolerance in 33 accessions of ginger including indigenous and exotic collections for rhizome rot. Setty *et al.* (1995) also reported that, none of the 18 cultivars tested were resistant

to rhizome rot disease. This indicates that, there are no resistance sources for rhizome rot of ginger in the country. The use of fungicides has become an inevitable method in the management, rhizome treatment along with soil application of fungicide might gives maximum protection against rhizome-borne disease.

Individual management strategies may be sufficient for managing this complex disease situation, an attempt was made to integrate cultural biological and chemical management strategies to evolving efficient combination of these strategies at two different field situations (Chikmarasa of Shimoga taluk and Nimbegundi of shikaripur taluk) in Shimoga district.

At Chikkamarasa, Rhizomes dipped in 0.2% Curzate M8 + streptocycline 0.05% for 30 min + Soil application of neem cake @5q/ha + Soil application of *Pseudomonas fluorescens* and *Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease (T7) and rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha (T6) were found effective in reducing per cent disease incidence and population density of pathogens. Along with increasing germination percentage, number of tillers per hill, plant height and yield.

At Nimbegundi also same treatments (T6 and T7) which were effective at Chikmarasa were found superior and also treatment Rhizomes dipped in 0.3% Copper Oxy Chloride +0.05% streptocycline for 30 min + One drench with same solution, immediately at the onset of the disease was found on par with those two effective treatments. The soil application as well as rhizome treatment of *Trichoderma* and *Pseudomonas* will lead to sufficient inoculum build up of bioagents to

fight against the pathogens in soil and rhizome. This will also create protective zone around the establishing seedling in the early stages of crop growth. Integration of bioagents with curzate will have synergistic effect besides, presence of neem cake further supported microbial activity and organic substrate for crop growth.

Addition of organic matter favourably improves crop yield mainly by enhancing soil fertility rather than through provision of nutrients to the plants. Considerable improvements in soil structure, water retention capacity and aeration in different types of soils have been observed following the addition of green manures, farm yard manures and other organic matter. Another additional advantage of using organic matter is the activation of many beneficial microbes antagonistic to soil borne pathogens, leading to disease suppression.

The disease incidence and yield at Chikkamarasa are higher than at Nimbegundi, because, Planting was done at chikkamarasa on 18th march 2012 and harvested on 14th April 2013 so crop has got almost one year time the field but in case of Nimbegundi planting was done on 24th june 2012 and harvesting done in 20th January 2013 so crop was there in the field for only seven months. Some farmers leave the crop in field till they get good market prize and this will also lead to good maturity of the crop there by higher yield.

Many evaluation trials with organic amendments have been conducted in India and some of them were recommended to farmers. Results of some of the experiments were as follows: neem oilcake @ 2mt/ha gave reduction of rhizome rot and increased yield by 1.78mt/ha (Sadanandan and Iyer, 1986). Thakore, (1987) reported that, neem oilcake as well as other oilcakes has also been shown to reduce ginger rhizome rot caused by *P. aphanidermatum* and *F. solani.*

Jayasekhar *et al.,* (2000) reported that Metalaxyl MZ @ 1% at 45 and 90DAP recorded the lowest disease incidence (4.23%) and Cost:benefit ratio was highest (1:2.85) with *T. harzanium* + neem cake application followed by 0.1% Metalaxyl (1:2.71).

Rhizomes dipped in 0.6% metalaxyl MZ for 30 min + Soil application of tender Eupatorium plants @ 10 t/ha + Soil application of *Trichoderma harzianum* @ 10 Kgs mixed with 25t FYM /ha + One drench with copper oxy chloride @ 0.3%, immediately after the onset of the disease was found to be efficient in reducing the disease with higher B:C ratio and yield (10150kg/ha) when compare to the control (Shalini, 2006).

Ziaur Rahman Bhuiyan *et al.*, (2013) reported that highest reduction of disease incidence (95.66%) over untreated control in treatment with poultry waste + Ridomil gold MZ 72 at 180DAP followed by poultry waste + Alamanda leaf extract at 240 DAP. Ajit Kumar singh, (2011) reported that Ridomil MZ 72% WP (metalaxyl 8% + mancozeb 64% (1.25 g /litre) found 81.6% of plant survival and maximum yield of 10.2 tonnes /ha, followed by the treatment with *T. harzianum* 72.05% plant survival and 7.6 tonnes /ha of yield.

From the present investigation, basal application of Neem cake @5t/ha and rhizome treatment with *Trichoderma harzianum* and *Pseudomonas florescens* along with the application of FYM enriched with these two bioagents at the base of the rhizome planting and drenching of Curzate @ 0.2% or COC @ 0.3%+Streptocycline @ 0.05% at the onset of disease can be recommended as integrated management strategy for the control of Rhizome rot complex of ginger.

FUTURE LINE OF WORK

- Suitable crop rotation and agronomic practices to regulate the soil moisture levels need to be standardized.
- Studies on molecular aspects of *Ralstonia solanacearum* to identify the race and biovar infecting ginger because the work done in this area is very limited, which is the need hour as this pathogen is called as species complex.
- Domestic quarantine at least between the states should be strengthened to avoid the spread of the inoculum through the seed material.
- Effective integrated disease management schedule for the disease and epidemiological studies to be emphasised.
- Development of disease free planting material through single eye bud technique.

Summary

VI. SUMMARY

The present investigations were carried during 2011-12 and 2012-13. at Plant Pathology laboratory of organic farming research centre (OFRC) ZARS, Shimoga, while field experiments were conducted at farmer's field in Shimoga district, Karnataka which included survey and surveillance to know the disease scenario and to identify 'endemic areas' or 'hot spots' for rhizome rot of ginger in the malnad districts, Isolation and identification of causal agent/agents, evaluation of cultivars for rhizome rot resistance and natural/cultural practices against the diseases, integrated management of diseases by integrating with effective management components and the results obtained thereon are summarized hereunder.

Foliar yellowing, stunted growth, wilting and drying of whole plant were the common symptoms observed irrespective of the pathogen involved. *P. aphanidermatum* causes Pre- emergence and post-emergence damping off, extensive rotting of rhizomes and rotted tissues emit foul smell, such plants came off with gentle pull. Slight discoloration of cortical tissue was observed in *Fusarium* spp. Small water soaked streaks in and around the collar region of plant as well as on the pseudostem. Rhizomes of infected plants when pressed gently exhibited oozing of bacterial exudates infected by *R. solanacearum*. Dry rotting was observed in case of *S. rolfsii*.

Rhizome rot incidence of ginger was noticed in all the locations surveyed with the range from 3.5 per cent at N.R. pura to 56.00 per cent at Anavatti. The maximum average disease incidence of 28.16 per cent was recorded in Uttara Kannada district, followed by Shimoga (25.89%), Chikkamagalore (24.76%) Coorg (22.69%) and least in Hassan (15.20%).

In Uttara Kannada district Banavasi and Korlakotta, in Shimoga sevalal nagar, Hirekasvi, Rippanpet and Makod villages in Chikkmagalore district were found to be endemic to rhizome rot complex.

Grey leaf spot, Rhizome fly infection, root knot nematode association were some of the other major constraints identified.

Soil physicochemical parameters like pH, OC and N-content had significant negative correlation with per cent rhizome rot incidence. Disease incidence= 77.072-6.743(pH) - 1.116(EC) - 5.693(OC) -0.033(N) + 0.033(P) - 0.005 (K) is disease prediction equation for ginger rhizome rot complex obtained by Multiple regression analysis, where soil physicochemical parameters (pH, EC, OC, N, P and K-content) were independent variables and Disease incidence was dependent variable.

Analysis of disease samples collected from different locations indicated the involvement of pathogens like *Pythium aphanidermatum*, *Fusarium oxysporum, Ralstonia solanacearum* and *Sclerotium rolfsii.* The individual pathogen could cause rhizome rot or combination of pathogens could cause disease leading to rhizome rot complex. *Ralstonia solanacearum* was the most predominant pathogen in malnad districts followed by *F. oxysporum, P. aphanidermatum* and *S. rolfsii.*

Ralstonia solanacearum isolated from rhizome rot diseased sample was found to be a gram-negative, rod shaped, non-capsulated and non-spore forming bacteria.

Potato dextrose agar, potato carrot agar, Sach's agar, Ashby's mannitol, oat meal agar and Sabouraud's agar were found to be ideal media for culturing of *P. aphanidermatum* as these supported maximum growth. Maximum sporulation was on Sabouraud's, potato dextrose and potato carrot agar. In case of *F. oxysporum* maximum radial growth was

observed in Tochina, Czapek's, Richards's and Glucose asparagine agar and were also favorable in producing conidia. Where as *S. rolfsii* was found growing on most of the media tested.

All fungal pathogens survived for longer period in the sterilized soil than in the unsterilized soil. But *R. solanacearum* was alive up to 14 weeks in both unsterilized and sterilized soils. Whereas in infected rhizomes *P. aphanidermatum* survived up to 30 weeks, *F. oxysporum* survived up to 34 weeks, *S. rolfsii* could survive up to 40 weeks and *R. solanacearum* survive up to 22 weeks. Survival ability was more in rhizome than the soil.

Concentration of 5 x 10^4 cfu/ml for the fungal pathogens and 5 x 10^6 for *R. solanacearum* were found to be optimum for pot culture inoculation studies.

Interaction among the pathogens causing rhizome rot of ginger was studied at different stages of crop growth by inoculating pathogens individually and in combinations. *R. solanacearum* was capable of inducing the symptoms at the earliest in all the stages of crop growth but *F. oxysporum* took longer time. Individually *P. aphanidermatum* was more potential pathogen at early stages of crop growth but reduced at 105 and 135 DAP. *F. oxysporum* alone inoculated plants exhibited symptoms after almost 25 days and when *S. rolfsii* alone was inoculated, symptoms were seen on 20th days after of inoculation in all the stages of ginger growth.

When pathogens were inoculated in different combinations, in almost all stages, there was increase in the disease incidence when compare to individual inoculations. In only one combination that is S+R there was lower rhizome rot incidence this could be due to antagonistic effect between these two pathogens.

Carbendazim + Mancozeb, Metalaxyl + Mancozeb, Cymaxanil + Mancozeb, Hexaconazole, Carbendazim, Metalaxyl, Triademefon, Emisan, COC and Mancozeb were found effective in reducing mycelial growth of *P.aphanidermatum, F. oxysporum* and *S. rolfsii* significantly over the control under *in-vitro* condition.

Sowing in March significantly showed less disease incidence (11.66 %) with higher yield (37.50 kg/plot) which was on par with April planting with disease incidence of 12.63 per cent and yield (34.25 kg/plot). Maximum disease incidence (25.07 %) was recorded in July planted plot with fewer yields (14.46 kg/plot).

Among the different varieties tested under field conditions Humnabad local proved moderately resistant and Maran was less susceptible compare to others.

Rhizomes dipped in 0.2% Curzate M8 + Streptocycline 0.05% for 30 min + Soil application of neem cake @ 5q/ha + Soil application of *Pseudomonas fluorescens* and *Trichoderma viride* @ 10 Kg mixed with 25t FYM /ha + One drench with 0.2% Curzate M8 immediately at the onset of the disease and Rhizome treatment with *Trichoderma viride*+ *Pseudomonas fluorescens* @ 10 g/Kg + Soil application of *Trichoderma viride* + *Pseudomonas fluorescens* @ 10 Kg mixed with 25t FYM /ha were found effective in reducing per cent disease incidence and population density of pathogens along with increasing germination percentage, number of tillers per hill, plant height, yield and B:C ratio.

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Appendix

APPENDIX

Weather data of Shimoga District -2011-12

Month	Rainfall (mm)	Temperature ^{0} C		Relative Humidity (%)
		Maximum	Minimum	
April-2011	98.60	39.07	20.36	66.33
May-2011	105.60	38.56	19.83	68.50
June-2011	186.00	38.44	19.54	68.40
July-2011	278.20	35.54	18.77	65.87
Aug-2011	328.80	33.73	19.82	67.92
Sept-2011	271.80	33.28	20.22	68.95
Oct-2011	251.80	33.58	19.85	72.87
Nov-2011	138.40	31.24	9.58	71.45
Dec-2011	-	29.58	18.88	72.85
Jan-2012	-	30.81	16.09	72.77
Feb-2012	-	33.54	14.50	79.30
Mar-2012	1.40	34.35	17.17	71.35

Weather data of Shimoga District -2012-13

Month	Rainfall (mm)	Temperature ^{0} C		Relative Humidity (%)	
		Maximum	Minimum	At 08.30 hours	At 17.30 hours
April-2012	135.6	38.12	21.23	91.90	43.73
May-2012	22.4	37.83	22.57	91.84	44.45
June-2012	74.4	33.21	21.65	92.03	55.00
July-2012	176.2	30.90	21.20	92.00	72.48
Aug-2012	246.4	31.11	20.22	91.77	68.52
Sept-2012	78.0	30.74	21.58	88.35	66.81
Oct-2012	109.6	33.36	20.49	91.87	60.19
Nov-2012	135.0	32.18	18.33	88.45	65.60
Dec-2012	0.0	34.15	15.39	91.00	56.03
Jan-2013	0.0	36.27	15.50	90.90	46.71
Feb-2013	6.2	36.98	25.25	91.79	83.06
Mar-2013	0.0	39.01	21.57	92.06	38.87

Weather data of Chikkamagalore District 2011

Month	Actual RF mm	No. of rainy days	Temperature ^{O}C		Relative Humidity (%)	
			Min	Max	Min	Max
Jan 2011	Nil	Nil	14.69	26.80	67.45	77.20
Feb2011	32.20	2	13.00	28.66	54.71	67.25
Mar2011	6.20	2	17.24	31.87	59.61	77.29
Aprl2011	219.20	10	18.65	31.71	81.30	89.70
May2011	123.20	8	18.58	31.58	79.64	89.35
June 2011	918.40	24	18.13	27.83	81.60	89.83
July2011	814.40	24	16.80	25.50	84.77	91.00
Aug2011	619.60	28	17.11	26.37	82.03	89.54
Sept2011	542.10	20	18.26	26.58	79.53	88.60
Oct 2011	343.90	11	17.90	26.16	89.00	91.58
Nov2011	121.20	8	17.36	26.60	76.03	85.96
Dec2011	Nil	Nil	14.98	26.74	75.29	85.83

Weather data of Chikkamagalore District 2012

Month	Actual RF mm	No. of rainy days	Temperature ^{o}C		Relative Humidity (%)	
			Min	Max	Min	Max
Jan 2012	Nil	-	26.75	14.56	75.74	64.90
Feb2012	Nil	-	27.00	15.46	74.72	59.58
Mar2012	Nil	-	31.69	19.09	81.54	42.83
Aprl2012	216.9	9	31.51	18.31	87.26	79.43
May2012	66.20	5	31.41	18.43	86.67	74.12
June 2012	275.10	15	27.73	17.78	85.86	75.20
July2012	573.30	26	26.40	17.00	84.54	72.38
Aug2012	782.00	20	26.19	17.48	88.80	79.74
Sept2012	649.20	20	26.58	21.21	87.60	77.90
Oct 2012	380.80	11	26.16	18.00	91.16	84.32
Nov2012	444.40	17	26.60	17.35	85.96	75.60
Dec2012	Nil	-	26.64	14.80	85.16	74.45

Weather data of Uttara Kannada District (Sirsi) -2012

Month	Rainfall (mm)	Temperature ^{0} C		Relative Humidity (%)	
		Maximum	Minimum	Morning	Evening
Jan 2012	0.0	30.5	12.9	81.8	57.8
Feb 2012	0.0	33.1	13.9	83.7	28.1
March 2012	0.0	24.5	18.3	87	38.0
April 2012	74.2	34.0	21.2	93.2	70.3
May 2012	34.8	32.2	21.8	89.1	68.7
June 2012	241.3	28.7	21.3	90.7	75.6
July 2012	560.9	26.4	21.4	93.3	84.4
August 2012	766	26.9	21.0	93.8	82.5
Sept 2012	246.8	28.0	20.7	94.1	80.9
Oct 2012	37.8	30.0	19.3	91.3	77.9
Nov 2012	14.1	29.9	17.0	86.0	59.7
Dec 2012	3.0	30.9	15.5	83.5	52.3
Average	1978.9	29.6	18.7	89.0	64.7

Weather data of Coorg District -2011-12

Month	Temperature ^{0} C		Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum		
April 2011	31.33	18.19	66.44	178.50
May 2011	31.67	19.75	70.77	117.30
June 2011	25.69	19.62	84.23	603.70
July 2011	25.05	19.16	85.46	339.09
Aug 2011	25.21	19.26	85.46	386.10
Sept 2011	25.74	18.26	86.57	270.50
Oct 2011	29.38	18.11	77.37	211.80
Nov 2011	27.53	16.15	75.89	43.20
Dec 2011	33.86	12.79	67.65	-
Jan 2012	30.01	11.33	63.91	-
Feb 2012	31.3	12.15	58.20	-
Mar 2012	34.17	16.38	60.45	-

Weather data of Hassan District 2011-12

Month	Rainfall (mm)	Temperature ^{0} C		Relative Humidity (%)
		Maximum	Minimum	
April	126.3	32.24	18.58	79
May	242.3	30.89	18.32	66.77
June	86.4	25.89	18.46	81.8
July	106.8	25.52	17.54	24.29
August	80.6	25.88	16.70	84.19
September	52.1	26.80	15.76	79.36
October	220.2	28.64	16.01	78.03
November	104.1	27.12	13.30	69.83
December	0	27.83	12.64	55.22
January	0	29.05	12.26	36.25
February	0	31.72	13.71	29.6
March	0	33.8	17.20	39.9
Mean	**84.9**	**28.78**	**15.87**	**60.35**