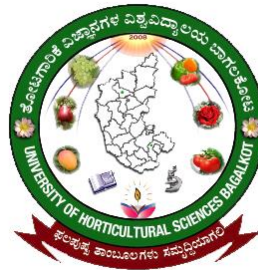


**STUDIES ON ROOT-KNOT NEMATODE
(*Meloidogyne incognita*) OF CUCUMBER AND ITS
MANAGEMENT UNDER POLYHOUSE
CONDITION**

JAWED HABIBI



**DEPARTMENT OF PLANT PATHOLOGY
COLLEGE OF HORTICULTURE, BENGALURU
UNIVERSITY OF HORTICULTURAL SCIENCES
BAGALKOT, KARNATAKA, INDIA**

NOVEMBER, 2020

**STUDIES ON ROOT-KNOT NEMATODE
(*Meloidogyne incognita*) OF CUCUMBER AND ITS
MANAGEMENT UNDER POLYHOUSE
CONDITION**

*Thesis submitted to the
UNIVERSITY OF HORTICULTURAL SCIENCES, BAGALKOT
In partial fulfillment of the requirements for the
Degree of*

**MASTER OF SCIENCE (Horticulture)
in
PLANT PATHOLOGY**

By

JAWED HABIBI

UHS18PGM1114

**DEPARTMENT OF PLANT PATHOLOGY
COLLEGE OF HORTICULTURE, BENGALURU
UNIVERSITY OF HORTICULTURAL SCIENCES
BAGALKOT, KARNATAKA, INDIA**

NOVEMBER, 2020

UNIVERSITY OF HORTICULTURAL SCIENCES, BAGALKOT
COLLEGE OF HORTICULTURE, BENGALURU
DEPARTMENT OF PLANT PATHOLOGY

CERTIFICATE

This is to certify that the thesis entitled "STUDIES ON ROOT-KNOT NEMATODE (*Meloidogyne incognita*) OF CUCUMBER AND ITS MANAGEMENT UNDER POLYHOUSE CONDITION" submitted by Mr. JAWED HABIBI, ID. No. UHS18PGM1114 for the award of the degree of MASTER OF SCIENCE (Horticulture) in PLANT PATHOLOGY to the University of Horticultural Sciences, Bagalkot, is a record of *bona-fide* research work done by him during the period of his study in this University under my guidance and supervision. The data of this thesis has not previously formed the basis for the award of any degree, diploma, associate-ship, fellowship or other similar titles.

Place: Bengaluru

Date: November, 2020


(V. DEVAPPA)
Major Advisor

Approved by:

Chairman :


(V. DEVAPPA)

Co-chairman :

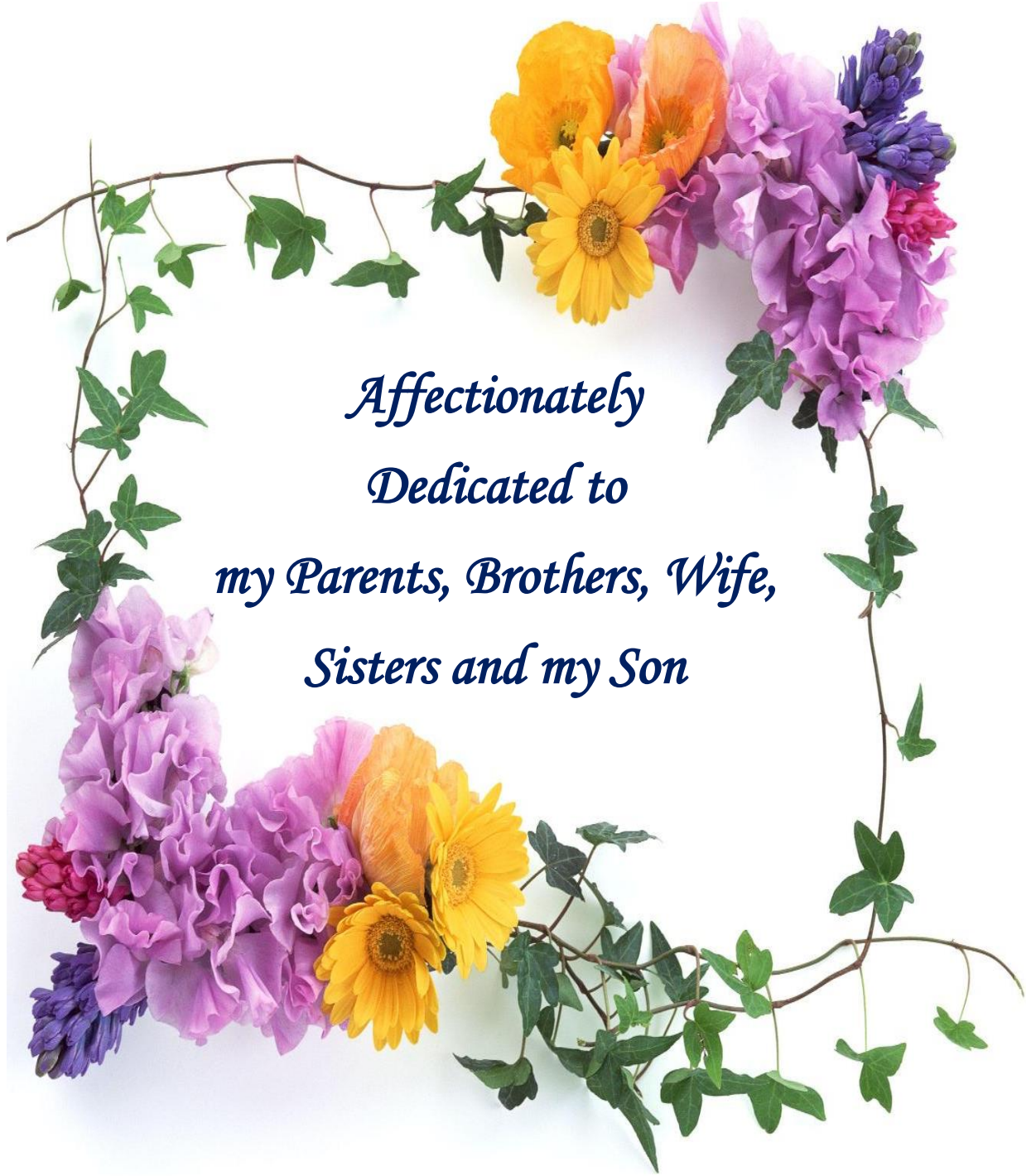

(M. NAGESH)

Members :


(M. V. DHANANJAYA)


(R. L. RAGHUNATHA REDDY)


(C. G. SANGEETHA)



*Affectionately
Dedicated to
my Parents, Brothers, Wife,
Sisters and my Son*

ACKNOWLEDGMENT

“IN THE NAME OF ALLAH THE MOST GRACIOUS THE EVER MERCIFUL”

“Gratitude is a memory of the heart”, no scientific endeavour is a result of individuals effect. Therefore it is a matter of pleasure at this endeavour to recall all the faces and spirits in the form of teacher, friends and juniors, near and dear ones. Words cannot express the love and gratitude that is in my heart, but this is my humble attempt...

*I cannot, but consider myself lucky to have worked under guidance of **Dr. V. Devappa**, Professor and Head, Department of Plant Pathology the Chairman of Advisory Committee. I thank him for excellent guidance and encouragement in completion of this thesis. It is my privilege to record my deep sense of gratitude for the valuable guidance, constant inspiration, kind help constructive criticism, unflinching interest and meticulous planning right from suggesting the problem till the completion of this thesis.*

*I wish to express my sincere gratitude to **Dr. Nagesh, M.** Head I/C, Division of Genomic Resources, ICAR-NBAIR, Bengaluru-65 and Co-chairman of advisory committee for the valuable assistance, suggestions, constant encouragement, support and above all the kind of understanding throughout the course of this research work.*

*I am very much grateful to all other members of my advisory committee, **Dr. Dhananjaya, M. V.** Principal Scientist, Division of Vegetable Science, IIHR, Bengaluru-87. **Dr. R. L. Raghunatha Reddy**, Assistant Professor, Soil Science & Agriculture Chemistry, COH, RHREC, Bengaluru-65 and **Dr. Sangeetha, C. G**, Assistant Professor, Department of Plant Pathology, College of Horticulture, Bengaluru-65, for their constant supervision, valuable guidance and all the facilities extended during the course of this investigation.*

*It is my pleasure to thank my teachers **Dr. B. Anjaneya Reddy**, Assistant Professor, Department of Plant Pathology, College of Horticulture, Bengaluru and **Dr. K. S. Shankarappa**, Assistant Professor, Department of Plant Pathology, College of Horticulture, Bengaluru, for their help and advice during my degree programme.*

*My first thanks go to my family members especially my father, **Mr. Mohammad Reza Habibi** and my lovely **Mother**, who brought me to this world and have been besides me, helping me psychologically, emotionally, morally and materially to overcome all the obstacles I faced during my life. Thanks to my brothers, **Engineer Wahid Habibi, Mr. Habibullah Habibi, Engineer Rohollah Habibi, Mr. Ramin Habibi**, my Lovely wife **Mrs. Lida Mohammadi**, my angels two sisters, my son **Mr. Shahim**. I will always remain grateful towards them for what they have been doing.*

*It is my pleasure to thank my UG teacher **Dr. Abdul wasi amiri**, and friends **Mr. Mohammad Bashir Mahmoodi, Mr. Ehsanullah Seraji, Mr. Fetrat Ahmad Noory, Mr. Mohammad Nasim Ayobi, Mr. Naqebullah Mandozai, Mr. Shah Samand Samandary, Mr. Mohammadullah Nikzad, Mr. Najibullah Anwerzai, Mr. Baz Mohammad Waseem** my classmates and our department senior friends for their help and advice during my degree programme.*

*I find no words to express many heartfelt thanks to my beloved friend **Mrs. N. Jhansirani** and my Senior **Mr. Goutham Suresh** whom my two years of masters degree would be in complete without their timely support and helps. I thank them very much and love them always.*

*I am very grateful to **Ministry of Agriculture, Irrigation and Livestock of Afghanistan**, for providing me the opportunity to pursue my master's degree in **India**.*

*I am very thankful to **ICAR, New Delhi** for their financial support during entire period of my study and very grateful to the Indian government and University of Horticultural Sciences (UHS), Bagalkot, for providing the opportunity to pursue my master's degree and cherish two years of stay in Department of Plant Pathology, and thanks to all teaching and non-teaching staff of University of Horticultural Sciences, Bagalkot, for their kind co-operation.*

Last but not the least; I thank all those who have helped me either directly or indirectly during my course of study.

*I love and am proud of my motherland, my **Afghanistan**, may it witness peace.*

Bengaluru

November, 2020

(Jawed Habibi)

STUDIES ON ROOT-KNOT NEMATODE (*Meloidogyne incognita*) OF CUCUMBER AND ITS MANAGEMENT UNDER POLYHOUSE CONDITION

ABSTRACT

Root knot-nematode (RKN) is the most important and widely distributed nematode in cucumber grown in polyhouses and is serious pest of vegetable crops and major limiting factor for varieties / hybrids of cucumber in many parts of the Karnataka, India. Survey for root-knot nematode incidence in cucumber grown areas under polyhouse conditions in 11 villages of Bengaluru was undertaken. The results from survey revealed that, severe infestation of *M. incognita* was recorded in Hadonahalli village of Doddaballapur taluk with nematode population of 583 / 250 g soil and 117 / 5 g root respectively followed by Gummanahalli of Chikkaballapur with nematode population of 381 / 250 g soil and 93 / 5 g root respectively. All the 19 screened cucumber varieties / hybrids were highly susceptible and none of them were found highly resistant, resistant or immune. Highly susceptible hybrid (Pallavi) was selected for the management of root-knot nematode under polyhouse condition. The trial revealed that, combination of nematicide along with bio agents, showed maximum growth parameters viz., plant height, number of leaves, fresh and dry shoot weight, fresh and dry root weight and yield per plants. The plants which received *Trichoderma harzianum* + *P. chlamydosporia* + *Pseudomonas fluorecens* + Fluopyram recorded maximum reduction of nematode population, number of galls per root system and egg masses per root system. Followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram treated plants. While, highest nematode population in soil and root with more number of galls were recorded in inoculated control.

JAWED HABIBI
(Student)

Dr. V. DEVAPPA
(Chairperson)

**ಪಾಲಿಹೌಸ್‌ನಲ್ಲಿ ಬೆಳೆದ ಸೌತೆಯಲ್ಲಿ ಜಂತುಹುಳುವಿನಿಂದ ಬರುವ ಗಂಟುಬೇರು ರೋಗ ಹಾಗೂ
ಅದರ ನಿರ್ವಹಣೆ**

ಸಾರಾಂಶ

ಗಂಟುಬೇರು ರೋಗವು ಸೌತೆಜಾತಿಗೆ ಸೇರಿದ ಎಲ್ಲಾ ಬೆಳೆಗಳಲ್ಲಿ ಕಂಡುಬರುವ ಪ್ರಮುಖ ರೋಗವಾಗಿದ್ದು, ಇದರಿಂದ ಹೆಚ್ಚಿನ ಇಳುವರಿಯು ಹಾನಿಯಾಗುತ್ತದೆ. ಈ ರೋಗದ ತೀವ್ರತೆಯನ್ನು ತಿಳಿಯಲು ಬೆಂಗಳೂರಿನ ಸುತ್ತಲಿನ ಸುಮಾರು 11 ಹಳ್ಳಿಗಳಲ್ಲಿ ಸಮೀಕ್ಷೆಯನ್ನು ಸೌತೆಕಾಯಿ ಬೆಳೆಯುವ ಪಾಲಿಹೌಸ್‌ಗಳಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಸಮೀಕ್ಷೆಯಿಂದ ಗಂಟುಬೇರು ರೋಗವು ದೊಡ್ಡಬಳ್ಳಾಪುರ ತಾಲೋಕಿನ ಹಾಡೋನಹಳ್ಳಿಯಲ್ಲಿ ಅತಿ ಹೆಚ್ಚಿನ ಜಂತುಹುಳುವಿನ ಸಂಖ್ಯೆ 583/250 ಗ್ರಾಂ ಮಣ್ಣಿನಲ್ಲಿ ಹಾಗೂ 117/5 ಗ್ರಾಂ ಬೇರಿನಲ್ಲಿ ಇರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ ಹಾಗೆಯೇ ಅದರ ನಂತರದ ಸ್ಥಾನದಲ್ಲಿ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಗುಮ್ಮನಹಳ್ಳಿಯಲ್ಲಿರುವುದು ರುಜುವಾತಾಗಿರುತ್ತದೆ. ಮುಂದುವರೆದು ಮಾರುಕಟ್ಟೆಯಲ್ಲಿ ಸಿಗುವಂತಹ 19 ಸೌತೆತಳಿ/ಸಂಕರನಾ ತಳಿಗಳನ್ನು ಜಂತುಹುಳುವಿಗೆ ತಡೆದುಕೊಳ್ಳುವಂತೆ ಇದೇಯೇ ಎಂಬುದನ್ನು ತಿಳಿಯಲು ಪರಿಕ್ಷಿಸಲಾಯಿತು. ಅದರ ಪರಿಶೋಧನೆಯ ಮೇಲೆ ತಿಳಿಸಿದ 19 ತಳಿಗಳಲ್ಲಿ ಯಾವುದೇ ತಳಿ ಜಂತುಹುಳುವಿಗೆ ನಿರೋಧಕತೆಯನ್ನು ಹೊಂದಿಲ್ಲವೆಂಬುದು ಸಾಬೀತಾಗಿದೆ. ತದನಂತರ ರೋಗದ ನಿರ್ವಹಣೆಗಾಗಿ ಮಾರುಕಟ್ಟೆಯಲ್ಲಿ ದೊರಕುವ ಜಂತುಹುಳು ನಾಶಕ ಹಾಗೂ ಜೈವಿಕ ನಾಶಕಗಳನ್ನು ಉಪಯೋಗಿಸಿದ್ದು, ಟ್ರೈಕೊಡರ್ಮಾ ಹಾರ್ಬಿಯಾನಮ್ + ಪಾಚಿನಿಯಾ ಕ್ಲಮೀಡಸ್ಪೋರಿಯ + ಪ್ಲೂಪರಮ್‌ನ್ನು ಉಪಯೋಗಿಸಿದಲ್ಲಿ ಹೆಚ್ಚಿನ ಗಿಡದ ಬೆಳವಣಿಗೆ ಹಾಗೂ ಅತಿಕಡಿಮೆ ಜಂತುಹುಳುವಿನ ಸಂಖ್ಯೆಯಿರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ.

(ಜಾವೇದ್ ಹಬೀಬಿ)
ವಿದ್ಯಾರ್ಥಿ

(ವಿ. ದೇವಪ್ಪ)
(ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು)

CONTENTS

CHAPTER	PARTICULARS	PAGE No.
	CERTIFICATE	iii
	ACKNOWLEDGEMENT	v-vi
	ABSTRACT	vii-iii
	LIST OF TABLES	xi
	LIST OF PLATES	xii
	LIST OF FIGURES	xiii
	LIST OF APPENDICES	xiv
1	INTRODUCTION	1-4
2	REVIEW OF LITERATURE	5-19
2.1	Survey for root-knot nematode species associated with cucumber in polyhouses in Bengaluru rural district.	5
2.2	Screening of cucumber cultivars for root-knot nematode under pot condition	11
2.3	Management of root-knot nematode (<i>Meloidogyne incognita</i>) under polyhouse condition	14
3	MATERIAL AND METHODS	20-33
3.1	Survey for root-knot nematode species associated with cucumber in polyhouses in Bengaluru rural district.	20
3.2	Screening of cucumber cultivars for root-knot nematode under pot condition	24
3.3	Management of root-knot nematode (<i>Meloidogyne incognita</i>) under polyhouse condition	26
4	EXPERIMENTAL RESULTS	34-70
4.1	Survey for root-knot nematode species associated with cucumber in polyhouses in Bengaluru rural district.	34

CHAPTER	PARTICULARS	PAGE No.
4.2	Screening of cucumber cultivars for root-knot nematode under pot condition	39
4.3	Management of root-knot nematode (<i>Meloidogyne incognita</i>) under polyhouse condition	50
5	DISCUSSION	71-78
5.1	Survey for root-knot nematode species associated with cucumber in polyhouses in Bengaluru rural district.	71
5.2	Screening of cucumber cultivars for root-knot nematode under pot condition	72
5.3	Management of root-knot nematode (<i>Meloidogyne incognita</i>) under polyhouse condition	73
6	SUMMARY	79-81
7	REFERENCES	82-95
8	APPENDIXES	96-98

LIST OF TABLES

Table No.	TITLE	Page No.
1	Status of root-knot nematode incidence in cucumber grown in polyhouses of different villages of cucumber grown areas	35
2	Population of root-knot nematode spp. in soil associated with root zone of cucumber in polyhouses in Bengaluru rural and chickkaballapur district	40
3	Population of root-knot nematode spp. associated in roots of cucumber in polyhouses in Bengaluru rural and Chickkaballapur.	41
4	Root-knot nematode population in soil and Root Knot Index (RKI) of crops in polyhouses surveyed in different village of Bengaluru rural districts	42
5	Screening of root-knot nematode (<i>Meloidogyne incognita</i>) on growth of cucumber cultivars under polyhouse condition	43
6	Effect of <i>Meloidogyne incognita</i> on multiplication of root-knot nematode on cucumber cultivars under polyhouse condition	44
7	Effect of different treatments on growth of cucumber plants infested by root-knot nematode (<i>Meloidogyne incognita</i>)	52
8	Effect of different treatments on fresh and dry shoot and root weight of cucumber plants infested by <i>Meloidogyne incognita</i>	53
9	Effect of different treatments on soil and root population of root-knot nematode (<i>Meloidogyne incognita</i>) under polyhouse condition	61
10	Effect of different treatments on nematode population of <i>Meloidogyne incognita</i> under polyhouse condition	62

LIST OF PLATES

Plate No.	Title	Page No.
1	View of root-knot nematode infested cucumber polyhouse at Hadonahalli village, Doddaballapura, Bengaluru rural district	36
2	Healthy and root-knot nematode infested cucumber roots	37
3	Morphological nature of <i>Meloidogyne incognita</i> . (A) Egg mass (B) Nematode eggs under 40X microscope resolution (C) Second stage juvenile (D) Female nematode	38
4	General view of screening of cucumber varieties in pots culture inoculated 2500 J ₂ of root-knot nematode (<i>Meloidogyne incognita</i>) / pot (A) 25 days after infestation (B) 75 days after inoculation.	46
5	Root growth and galling in different varieties of cucumber screened against root-knot nematode (<i>M. incognita</i>) under polyhouse condition	47
6	Effect of root-knot nematode (<i>Meloidogyne incognita</i>) on susceptible cucumber variety	48
7	Combined (A) Cobb's sieving method (B) Baermann's funnel method for extraction of root-knot nematode, <i>Meloidogyne incognita</i> from soil samples	49
8	General view of the cucumber root-knot nematode management under polyhouse condition (plate A) 10 days after transplanting (Plate B) 75 days after transplanting	58
9	View of nematode extraction of 5 g root samples from infested root-knot nematode in cucumber plants roots	65
10	Effect of different treatments management methods on root-knot nematode <i>M. incognita</i> under polyhouse condition	66
11	Effect of different treatments at reduction of galls on cucumber root systems of T ₁₁ and comparison with T ₁₃ (Untreated control)	69
12	Effect of different treatments at reduction of galls on cucumber root systems of T ₁₂ and comparison with T ₁₃ (Untreated control)	70

LIST OF FIGURES

Figure No.	Title	Page No.
1	No. of galls/root system, No. of egg masses/root system and nematode population / 250 g of soil on growth of cucumber cultivars under polyhouse condition	45
2	Effect of different treatments on plant growth of cucumber plants infested by root-knot nematode <i>Meloidogyne incognita</i>	54
3	Effect of different treatments on yield of cucumber plants infested by root-knot nematode <i>Meloidogyne incognita</i>	55
4	Effect of different treatments on fresh and dry shoot weight of cucumber plants infested by root-knot nematode <i>Meloidogyne incognita</i>	56
5	Effect of treatments on root growth of cucumber plants infested by root-knot nematode <i>Meloidogyne incognita</i>	57
6	Effect of different management methods on reduction of <i>M. incognita</i> in soil and root of cucumber plants under polyhouse condition	63
7	Effect of different management methods on reduction of galls numbers and egg masses of <i>Meloidogyne incognita</i> on cucumber plants under polyhouse condition	64

LIST OF APPENDICES

Appendix	Title	Page No.
I	Monthly meteorological data during the experimental period at the experimental site from January 2019 – October 2019	96
II	Available nutrient, Physical and physico-chemical properties of soil of the pots experimetns	97
III	List of abbreviations	98



Introduction

I. INTRODUCTION

Cucumber (*Cucumis sativus* L.) belongs to family cucurbitaceae or gourd family. Cucumber is grown worldwide, it is a warm season vegetable grown under tropical and subtropical conditions. It is said to be the native of northern India and “Kamal Kakdi” is the common name of this crop in Hindi (Pursglove, 1969).

Cucumber is one of the important vegetable and studied as the fourth extensively cultivated crop in the world after tomato, cole crops and onion. It has passed across countries and continents, spreading through China, Europe and Americas. The native-Americans began cultivating them along with other gourds like pumpkins and squash. In India, during 2016-2017 the predictable area under this crop is around 78,000 ha with total production of about 1,142,000 metric tons. In Karnataka, cucumber cultivated in an area of around 866,000 ha with total production of 146.02 MT/ha and the ranking position is at three behind Haryana and Madhya Pradesh (National Horticulture Board, 2017). The percentage share to the total production in Karnataka is around 10.58%.

The fruits contain low-calorie food material and it provides approximately 15 calories per 100 g of fresh fruit. It is a good reservoir of potassium and plays an important role in electrolyte balance. Cucumbers contain unique antioxidants in moderate ratio such as β -carotene and α -carotene, vitamin-C, vitamin-K, vitamin-A, zeaxanthin, and lutein. The fruits are considered as delicious cuisine in many traditions and have been used in treatment of various diseases (Lutfa *et al.*, 2019).

Its versatility as a food and medicine is well-known in India. The seeds of cucumber are a useful entity in *Ayurvedic* preparations and the pulp is an important raw material in cosmetic industry. It is also identified as edible fruits because of its high nutrients, low calories, delicacy, crispy texture and good fiber content that is pre-requisite for a healthy digestive system. Hence, the cultivation of cucumber in a locality influences the health of the inhabitants positively. The fresh cucumbers are the store house of various nutrients required for various metabolic functions in human body and the

estimates prove that it contains niacin, vitamin-C, iron, calcium, thiamine, phosphorus and fibers (Floraceli, 2008).

Cucumber is affected by many biotic agents' viz., fungal, bacterial, virus and nematodes among those fungal diseases such as downy mildew, powdery mildew, fusarium wilt, anthracnose, belly rot, gummy stem blight, scab and cercospora leaf spot, cause more economic losses. Important bacterial and viral diseases are bacterial wilt, angular leafspot, and watermelon mosaic virus (WMV), cucumber mosaic virus (CMV), zucchini yellow mosaic virus (ZYMV) and papaya ring spot virus (PRSV).

Among the various pathogens attacking different crops, plant parasitic nematodes are causing serious yield losses. Most of plant parasitic nematodes (PPN) that attack the roots of plants are Root-Knot Nematode (RKN). The most economically important genus which obligates plant roots is the genus *Meloidogyne* distributed worldwide. It infect more than 2000 to 3000 species including almost all cultivated plants; including vegetables, fruit trees, oil crops, fiber crops, grains crops and leguminous crops. Worldwide, more than 100 species have been reported (Karssen and Moens, 2006). The most well-known species for genus *Meloidogyne* include *Meloidogyne incognita*, *M. incognita* (Kofoid & White) Chitwood, *M. javanica* (Treub,) Chitwood, *M. arenaria* (Neal), Chitwood and *M. hapla* Chitwood were of outstanding economic importance In tropical and sub-tropical regions recorded at least 80 to 90% of all damage caused by root-knot nematodes (Castagnone-Sereno, 2002; Sikora and Fernández, 1990).

The root-knot nematode is the most destructive pest amidst the top five pathogens of the crop (Hussey and Janssen, 2002). It is estimated to account 5 per cent of crop loss globally (Lahm *et al.*, 2017). Due to nematode infestation, crop health, yield and fruit quality are greatly affected. Beyond these, four species viz., *Meloidogyne incognita*, *M. javanica*, *M. arenaria* and *M. hapla* affect a number of crops and cause huge economic loss.

In India, root-knot nematode was first reported by Barber (1901) on plantation crop (tea roots) from Devala territory of Kerala. Root-knot nematode in tomato was

identified by Arya (1957) from Jodhpur, Rajasthan. Under the open field cultivation, production of cucumber is mainly restricted. However, biotic and abiotic stresses are the main factors responsible for lower yield and poor quality under open field cultivation, particularly, during rainy season crop. Upon root-knot nematode infection, carbohydrate and protein composition in infected plants were changed and free amino acids were increased in root galls.

The root-knot infected plants exhibited the symptoms such as poor growth, yellowing and drooping of leaves, immature fruits, root galls, reduced root system, finally yield of the plant declined. Root-knot nematode obtains nutrients from host by piercing the stylet into host roots. After penetration, it establishes feeding site. The oesophageal secretions of nematode increase the production of plant growth regulators, by this plant cell size increase and stimulates rapid division of forming specialized cells. This combined group of specialized cells is known as giant cell. Where the nematode remains permanently attached. Being obligate sedentary endoparasites with an inherent capacity to interact with other fungal and bacterial pathogens to cause complex diseases, these are the most difficult pests to manage (Fourie and McDonald, 2000).

Cucurbitaceous crops are often cultivated in rotation with Solanaceae in double-cropping systems. Many of the cucurbits are susceptible to root-knot nematodes. Farmers are selecting inadequate rotation in lure of earning higher incomes. But, growing of susceptible crop continuously, helps for the accumulation of root-knot nematode population and under high infestations, crops are badly affected. Since, root-knot nematode causes severe yield losses, efforts have been started on the management of this root-knot nematode through host resistance, bio-agents and chemicals. Nevertheless, information related to the occurrence and distribution of root-knot nematode on cucumber, availability of tolerant or resistant cultivars and an effective, management of root-knot nematode in cucumber are lacking. Keeping the shortage of research in view, a study was undertaken with the following objectives.

1. Survey for root-knot nematode species associated with cucumber in polyhouses in Bengaluru rural district.
2. Screening of cucumber cultivars for root-knot nematode under pot condition.
3. Management of root-knot nematode (*Meloidogyne incognita*) under polyhouse condition.



Review of Literature

II. REVIEW OF LITERATURE

Most of the vegetables are liable to one or the other type of nematodes. Cucumber is also susceptible to nematode pests which suffer significant loss and found in the rhizosphere of the plant and produce typical symptoms on roots viz., galls, necrosis, lesions, stubbiness, dwarfness and bunchy root system. The above ground parts of the plant shows symptoms such as stunting, yellowing of foliage, sickly appearance and even symptoms of nutrient deficiencies due to the damage of roots. The detailed review of survey, screening of varieties against root-knot nematode and management on cucumber is presented here under.

2.1 Survey for root-knot nematode species associated with cucumber in polyhouses in Bangalore rural district

Almohit *et al.* (2020) conducted a survey of greenhouse grown vegetable crops in Riyadh region, central of Saudi Arabia to know the status of plant parasitic nematode associated with vegetable crops. The results revealed that total of 18 plant parasitic nematodes extracted from 349 infected root, rhizosphere and soil samples of tomato (*Solanum lycopersicum* (140 samples); cucumber (*Cucumis sativus* (128)); Aubergine (*Solanum melongena* (25); sweet pepper (*Capsicum annuum* (26), Green beans (*Phaseolus vulgaris* (22) and squash (*Cucurbita pepo* (8). The genera of plant parasitic nematodes isolated with frequency were *Meloidogyne* (45.8%), *Aphelenchus* (16.6%), *Tylenchorhynchus* (12.9%), *Aphelenchoides* (12%), *Ditylenchus* (10.3%), *Pratylenchus* (3.7%), *Tylenchus* (2.3%), *Subanguina*, *Trichodorus*, *Tylencholaimus* (1.7% each), *Hemicriconemoides* (0.9%), *Helicotylenchus*, *Longidorus*, *Merlinius* (0.6% each), *Paratrichodorus*, *Paratylenchus* sp., *Telotylenchus* and *Zygotylenchus* (0.3% each).

Dhillon and Kaur (2018) surveyed 29 polyhouses in different districts of Punjab to assess the spreading of root-knot nematode. Among the 29 polyhouses surveyed, in 18 polyhouses nematode infection was observed. The frequency of distribution of nematode was 54%. Total 118 soil and rhizosphere samples were collected. They reported that the root gall index more than 3.

Chandel *et al.* (2017) surveyed polyhouse grown vegetable crops in Himachal Pradesh to know the status of root-knot nematode (*Meloidogyne* spp.) From the survey reports, they revealed that nearly 83.10 per cent of polyhouses were affected with root-knot nematode. The disease severity was highest in cucumber crop followed by carnation, tomato and sweet pepper.

Singh (2017) conducted a study to assess the root-knot nematode infestation in open field and polyhouses in Punjab. They surveyed 45 polyhouses from five districts *viz.*, Ludhiana, Sri Muktsar Sahib, Patiala, Ferozepur and Bathinda. The frequency of occurrence of infestation in surveyed polyhouses was 68.68 %. Highest disease incidence was observed in Ludhiana (62.72 %) followed by Ferozepur (50 %), Patiala (39.13%), Bathinda (32 %) and Sri Muktsar Sahib (30%).

Tariq-Khan *et al.* (2017) studied the incidence of root-knot nematode in vegetable crops in Neelum, Muzaffarabad and Hattian Bala districts of Pakistan during 2012, 2013 and 2014. Among the districts surveyed, higher incidence was reported from Muzaffarabad (64%) followed by Hattian Bala (30%) and Neelum (24%). They also reported the gall index range in surveyed vegetable crops. In okra gall index range from 3-9, in tomato 2-10, in cucumber 3-9 and in egg plant 3-9.

Patil *et al.* (2017) surveyed polyhouses in different districts of Haryana during 2015-16 to investigate the incidence of major plant parasitic nematodes on different vegetable crops *viz.*, cucumber (*Cucumis sativus*), tomato (*Lycopersicon esculentum*), chilli (*Capsicum annum*) and bell peppers (*Capsicum frutescens*). From the infected soil samples, nine plant parasitic nematodes *viz.*, *Meloidogyne incognita*, *Pratylenchus* spp. *Rotylenchulus* spp. *Hoplolaimus* spp. *Helicotylenchus* spp. *Tylenchorhynchus* spp. *Ditylenchus* spp. were isolated. Though different nematodes extracted, highest distribution of *M. incognita* was observed under protected conditions. The population density ranged between 30-10000J₂/200cc soil and the frequency of distribution of *M. incognita* was noted at 63.15%.

Suresh *et al.* (2017) conducted survey in 20 districts of Tamil Nadu during (2015-2016) for prevalence of root-knot nematode in different cropping ecosystems. They reported that, from the soil and rhizosphere samples, seven plant parasitic nematodes *viz.*, *Meloidogyne incognita*, *M. javanica*, *M. arenaria*, *M. hapla*, *M. graminicola*, *M. enterolobii* and *M. naasi* were detected. Among the different species, distribution of *M. incognita* was found to be maximum.

Kumar and Khan (2015) surveyed mango orchards in four districts of Uttar Pradesh to know the distribution of plant parasitic nematodes associated with mango orchards. The nematodes they isolated *viz.*, *Meloidogyne incognita*, *Rotylenchulus reniformis*, *Tylenchorhynchus sp.*, *Helicotylenchus dihystera*, *Hoplolaimus indicus*, *Pratylenchus sp.*, *Tylenchus sp.* and *Hemicriconemoides mangiferae*. They reported that highest distribution of *H. indicus* was maximum followed by *H. mangiferae* in Lucknow, Unnao and Faizabad districts. Whereas, *M. incognita* was recorded only in Faizabad district and *Tylenchus sp.*, in all districts surveyed except Barabanki.

Manju and Subramanian (2015) surveyed gerbera fields located in different districts of Tamil Nadu to assess the distribution of plant parasitic nematodes associated with gerbera. From the root and rhizosphere soils, they isolated nematodes *viz.*, *Tylenchorhynchus spp.*, *Rotylenchulus reniformis*, *Pratylenchus coffeae*, *Helicotylenchus multicinctus* and *Meloidogyne incognita*. They stated that among the plant parasitic nematodes isolated, the *M. incognita* distribution was maximum in gerbera fields.

Singh *et al.* (2015) surveyed different vegetable grown under polyhouses to know the distribution of plant parasitic nematodes associated with vegetable crops (French bean, cucurbits, tomato, crucifers and potato). The results revealed that *Meloidogyne Spp.*, were majorly associated with vegetable crops grown in polyhouse.

Gautam *et al.* (2014) conducted survey in different vegetable crops in the central plain region of Chattisgarh to record the incidence of root-knot nematode disease. They collected roots and rhizosphere soil samples from 44 fields denoting five districts of Chattisgarh. They reported that disease incidence ranged from 30 to 80% in five districts.

Among the 44 samples, 24 farmland samples showed the root-knot nematode incidence. They isolated different species of plant parasitic nematodes viz., *Meloidogyne incognita* (63.33%), followed by *Meloidogyne arenaria* (20%) and *Meloidogyne javanica* (16.67%). The population density of nematodes in 200 cc soil, ranged from 766 and 9076 nematodes.

Bem *et al.* (2014) surveyed tomato fields based on symptoms exhibited by tomato plants such as yellowing of leaves, wilting and stunted growth to assess the incidence of root-knot nematode in tomato fields. From the results they noted that the disease incidence ranged between 20-80% and gall index ranged from 1.0 - 4.0. The root-knot nematodes they isolated were *M. incognita* and *M. javanica*.

Kayani *et al.* (2013) surveyed 378 randomly selected cucumber fields in 126 villages of the four districts across the Pothohar zone of the Pakistan to evaluate the root-knot nematode infestation during mid and late season. They stated that overall disease incidence was found to be 15.66%. Among the four districts, highest infestation was observed in Rawalpindi district (21.86%), followed by 13.89% in Attock, while minimum infestation 10.97% was recorded in Jhelum district.

Anwar *et al.* (2013) surveyed vegetable crops including cucumber (*Cucumis sativus*) cultivated under plastic tunnels during 2010-11 to assess the distribution and population density of plant-parasitic nematodes. Total nine species of plant-parasitic nematodes viz., *Meloidogyne javanica*, *Aphelenchus avenae*, *Hoplolaimus columbus*, *M. incognita*, *Helicotylenchus dihystra*, *Pratylenchus penetrans*, *Radopholus similis*, *Tylenchorhynchus claytoni* and *Xiphinema* spp. detected from infected rhizosphere soil samples. They also reported stunted and poorly growing, restricted root systems with reduced number of feeder roots; root galling and brown lesions were exhibited by infected plants.

Mohammad *et al.* (2013) conducted a survey in randomly selected 378 cucumber fields in 126 villages of the four districts across the Pathohar zone of the country during mid to late season to evaluate the root-knot nematode infestation. The results revealed

that, there is variation in root-knot nematode severity and incidence and the mean disease incidence in surveyed areas were recorded as 15.66%.

Ismail *et al.* (2012) conducted a survey in open-field and plastic tunnel planted cucumber crop to know the incidence of root-knot nematode. They collected 200 soil and rhizosphere disease samples and isolated nematodes. The isolated nematodes were identified as *M. incognita* and *M. javanica*. The disease incidence arrayed from 20 to 50%. They stated that in open field, the egg mass (3.85 %) and gall index (7.14 %) was higher compared to tunnel grown cucumber plants.

Singh *et al.* (2012) surveyed okra fields in some localities of Jammu and Samba district of Jammu and Kashmir to know the status of major plant parasitic nematodes. They reported that, the plant parasitic nematode *Meloidogyne* spp. were higher in surveyed areas of Jammu and Samba district of Jammu and Kashmir.

Srivastava *et al.* (2012) conducted survey of okra growing fields in Allahabad, Uttar Pradesh to record the occurrence of root knot nematode. They surveyed 32 different farming fields and collected 227 root and soil samples to isolate and identify the root-knot nematodes. The disease incidence was reported as 55.9% in surveyed fields. Among the different areas surveyed, Beraunji, Basahra, Mansoorabad and Urua villages where okra is grown majorly affected by root-knot nematodes.

Kayani *et al.* (2012) conducted survey in Rawalpindi district of Pakistan to know the status of root-knot nematode incidence in cucumber crop. In surveyed fields, higher distribution of *M. incognita* (74.17%) was recorded followed by *M. javanica* (21.69%), *M. hapla* (1.81%) and *M. arenaria* (2.33%). Among the districts surveyed, highest incidence was recorded from Tehsil Taxila (31.11%) followed by Merree (26.11%). In Tehsil Kahuta, the population density of *M. incognita* was more in Tehsil Kahuta (90%) followed by Taxila (88.33%) while lowest was observed in Tehsil Gujjar Khan (47.5%).

Safdar *et al.* (2012) conducted survey in vegetable growing areas of Pakistan in 2007 and 2009 to assess the population of associated plant-parasitic nematodes. They collected 325 soils and root samples from 19 vegetable crops. They stated that the most

abundant plant parasitic nematode was *Meloidogyne incognita*. The frequency of infestation recorded was (90%).

Anamika *et al.* (2011) surveyed different field and vegetable crops *viz.*, rice, tomato, okra, cowpea, onion, pumpkin, brinjal and bitter gourd to investigate the damage intensity of root-knot disease. From survey revealed that, *Meloidogyne* species were more abundant species in infected fields. The infected root system showed heavy galling root decay or reduced root system.

Chandra and Khan (2011) collected different plant parasitic nematodes from okra-based cropping systems in West Bengal state. They were identified *Rotylenchulus reniformis*, *Criconeoides onoensis*, *Meloidogyne incognita*, *R. reniformis*, *Hoplolaimus indicus* and *Tylenchorhynchus mashhoodi* nematode species were more abundant. They found that, okra, tomato, cowpea and brinjal sustained nematode multiplication whereas, cabbage, rice and mustard in the sequence had a suppressive effect on *M. incognita*.

Esfahani (2009) surveyed tomato fields in Aligarh in India to investigate the threat of root-knot nematode. They reported that in all the fields surveyed were infected by root-knot nematode. Highest incidence was recorded from Idgah (90%) area.

Patel *et al.* (2008) conducted survey in different field's *viz.*, garlic, onion, cotton, coconut, brinjal, castor and flowering plants in Diu, an Union territory and in Gujarat to identify the status of nematodes infestation. They isolated five different plant parasitic nematodes (*Helicotylenchus* spp., *Tylenchorhynchus* spp., *Meloidogyne* spp., *Rotylenchulus reniformis* and *Pratylenchus* spp.) from soil and rhizosphere samples gathered from the above host species. Among these, highest population of *Helicotylenchus* spp. (40.91) was recorded followed by *Tylenchorhynchus* spp. (36.36) in Junagahd districts of Gujarat. Whereas, in Diu, highest population of *Meloidogyne* spp. were noted (70.0) followed by *Pratylenchus* spp.

Kumar *et al.* (2008) collected 30 populations of root-knot nematodes (*Meloidogyne* spp.) from different pockets of Haryana distinguished on the basis of morphological characters (perineal pattern) of females of root-knot nematodes

(*Meloidogyne* spp.). They belonged to three species *i.e.* *Meloidogyne incognita*, *M. arenaria* and *M. javanica* species and races were further confirmed by electrophoresis techniques by using enzyme phenotypes esterase, glutamate oxalo acetate transaminase (GOT), superoxide dismutase (SOD) and malate dehydrogenase (MDH). *Meloidogyne* species, were easily be differentiated by banding patterns of esterases and superoxide dismutase (SOD).

Nagesh *et al.* (2005) evaluated the yield loss due to root-knot nematode, *Meloidogyne incognita* in gherkin [cucumber] in Kolar and Bagepalli, Karnataka, India. The results revealed that, in both areas, the nematode incidence was higher, ranging from 25- 50 %. The disease severity ranged between 3.2 to 4.5 on a 0-5 scale.

Khan *et al.* (2000) conducted survey of vegetable crops (cucumber, okra, tomato, pepper, cabbage and cauliflower) grown in 20 plain and 10 hilly districts of Uttar Pradesh to assess the occurrence of root-knot nematodes. They stated that *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla* nematode species were majorly associated with vegetable crops grown in that area. Among the different vegetable crops, highest distribution of nematodes was found in cucumber, okra and tomato. Whereas, less distribution was found in cabbage and cauliflower.

2.2 Screening of cucumber varieties for root-knot nematode under pot condition

Bhati and Baheti (2020) conducted survey in different locations of Rajasthan to determine the distribution of root-knot nematode in polyhouse conditions. They visited total 40 polyhouses and collected the rhizosphere and soil samples. The results revealed that nearly, 40 to 142 galls/5 g roots and 26 to 135 egg masses/5 g root of cucumber were found. Whereas, 545 to 1460 J₂ per 100 cc soil were recorded.

Thangamani *et al.* (2018) screened different cucurbitaceous species against root-knot nematode to assess them to use as rootstocks in grafting. The plants were inoculated 2 J₂·g⁻¹ (J₂ = second with stage juvenile) of soil in pot culture at the 1 to 2 true leaf stage. After 45 days, uprooted the plants and recorded the root-knot Index (RKI). Among the cucurbit species evaluated *Cucurbita moschata*, *Cucumis callosus*, *Cucumis metuliferus*

and *Citrullus colocynthis* exhibited highly resistance with RKI-2. Whereas, *Cucurbita ficifolia*, *Cucurbita maxima*, *Cucumis melo* sub spp. *agrestis* were found to be moderately resistant with RKI-3.

Pandey *et al.* (2018) screened 15 cucumber cultivars against the root-knot nematode, *Meloidogyne incognita* (race-2). They stated that among the 15 cultivars, one was found to be resistant, two were moderately resistant and 12 were susceptible or highly susceptible to the nematode.

Li and Chen (2017) conducted a study on root-knot nematode (*Meloidogyne* spp.) incidence in vegetables crops grown continuously in greenhouses. They stated that, especially, cucumbers (*Cucumis sativus*) affected more because of root-knot nematodes, and only some wild species having resistant activity against root-knot nematode.

Li and Chen (2016) screened seven rootstocks and 21 germplasms of cucumber against *Meloidogyne incognita*. They used Cluster analysis and Principal Component Analysis (PCA) for evaluation. From the results obtained, they stated that all 21 cucumber germplasms exhibited vulnerability or high susceptibility to *M. incognita* and root stock showed moderate resistance. Based on the cluster analysis, the seven rootstocks and 21 germplasms divided in three groups: moderately resistant, susceptible, and highly susceptible to *M. incognita*. Among the germplasms evaluated, Jinyou No.1 cultivar exhibited highest resistance and among the 21 cucumber germplasms, Huangzhen No.1 cultivar exhibited highest resistance against *M. incognita*.

Liu *et al.* (2015) screened wild *Cucumis* species, *Cucumis pustulatus*, as a possible rootstock for cucumber, melon, and watermelon scions. Total fifty-three accessions from 16 species were evaluated. The results revealed that among the 53 accessions, 5 accessions identified as highly resistance to southern root-knot nematode.

Hwang *et al.* (2014) developed different screening methods for resistance of cucumber to root-knot nematode. 45 commercial cucumber cultivars were screened. Out of 45, one rootstock cultivar, Union exhibited resistance to the root-knot nematode. But there was no significant difference with other cultivars.

Mukhtar *et al.* (2013) conducted a study with root-knot nematode (*Meloidogyne* spp.), one of the most destructive pathogens of vegetables. The cultivars resistant to root-knot nematodes have comparatively better crop yield than susceptible varieties and can be employed as a component of integrated nematode management. In their study, 15 cultivars of cucumber (*Cucumis sativus*) were tested for their response to *Meloidogyne incognita* by inoculating with 3000 second stage juveniles of the nematode. All cultivars showed different reactions in reducing the growth parameters compared with control. Similarly, all cultivars responded differently to the percentage of galls, egg masses and reproductive factor.

Gu and Zhang (2006) screened rootstock cultivars of self-rooted cucumber plants and bur cucumber (*Sicyos angulatus*) black seed pumpkin, cucumber (*Sicyos angulatus*) and white seed pumpkin-grafted cucumber cultivars. The results revealed that pumpkin-grafted cucumber were identified as resistant to root-knot nematode and also improves the growth parameter like plant height and fruit flavour.

Praveen and Gowda (2004) screened gherkin cultivars and cucumber varieties against *M. incognita*. Among gherkin cultivars screened Stemora and PS 64487 cultivars showed resistance and noted less number of galls (34 and 57 respectively) and egg masses (13 and 28) respectively. Among the cucumber varieties screened, Poinsette found to be possess immunity against *M. incognita* and N. C-42 and NC-43 resistance to *M. arenaria* and *M. javanica*.

Walters *et al.* (1993) evaluated germplasm of Cucumber (*Cucumis sativus* L.) and horned cucumber (*C. metuliferus* Naud.) against root-knot nematode. Among the germplasm of horned cucumber, 24 cultigens (breeding lines, plant introduction accessions and cultivars) were found to be resistant to all root-knot nematodes *M. incognita* (Kofoid and White) Chitwood race 3, *M. arenaria* (Neal) Chitwood race 2, and *M. hapla* Chitwood. Whereas, among the cucumber cultigens, 884 cucumber cultigens were resistant to *M. hapla* and few to *M. incognita* race 3 and 50 out of 884 were moderately resistant to *M. arenaria* race 2 and *M. incognita* race 3. The cultigens LJ

90430 and 'Mincu' were the only cultigens that were moderately resistant to *M. arenaria* race 2.

2.3 Management of root-knot nematode (*Meloidogyne incognita*) under polyhouse condition

Madhushri *et al.* (2020) evaluated four nematicides and five oil cakes against *M. incognita* and they also evaluated their effect on plant growth parameters like fresh shoot weight, dry shoot weight, fresh root weight, dry root weight, shoot length, root length. Among the nematicides Phorate (0.01 g/ml) was found effective followed by carbosulfan (11.22). Among the oil cakes, neem cake significantly reduced the egg mass and juveniles of RKN followed by pongamia cake. Among the treatments, neem cake and Phorate applied plants prior and after inoculation of *M. incognita* showed higher fresh shoot weight, dry shoot weight, fresh root weight, dry root weight, shoot length, root length and less number of galls.

Pocurull *et al.* (2020) proved the induction of plant defense mechanisms by some *Trichoderma* spp. against *Meloidogyne* spp. in tomato, by conducting pot experiment. The results revealed that two strains *i.e.*, *Trichoderma asperellum* (T34) and *Trichoderma harzianum* (T22) induce systemic resistance in tomato and cucumber against an avirulent *Meloidogyne incognita* population and the T34 strain with tomato carried the Mi-1.2 resistance gene against an avirulent *M. incognita* population in sterilized soil. The two strains T34 and T22 reduced egg masses (54% and 48%) respectively.

Azeem *et al.* (2020) tested the efficacy of biological control agent, *Trichoderma harzianum* and an antagonistic plant, *Azadirachta indica* against *Meloidogyne incognita* in tomato. The results revealed that both the agents were inhibit number of galls, egg masses and reproductive factor. They reported that there is no significant difference between *T. harzianum* and *A. indica* in controlling the population of root-knot nematode. At the same time it also enhances the plant growth parameters.

Ghahremani *et al.* (2019) tested the bio efficacy of egg parasite *Pochonia chlamydosporia* and fungal plant interaction studies and resistance mechanism developed

through fungal egg parasite against root-knot nematode and cyst nematode they stated that, application of fungal egg parasite *Pochonia chlamydosporia* induce systemic resistance in plants against root-knot nematode and that resistance is dependent on plant species.

Silva *et al.* (2019) evaluated some non fumigant nematicides (Fluensulfone, Fluopyram and Fluazaindolizine) against *Meloidogyne incognita* in tomato under greenhouse conditions. The results revealed that all the nematicides reduced the egg mass and population density of root-knot nematode and it increases the fresh root, shoot weight and fruit yield of tomato.

Hajihassani *et al.* (2019) tested the efficacy of four non-fumigant nematicides, Oxamyl, Fluopyram, Fluensulfone, and Fluazaindolizine against root-knot nematode in cucumber. The results revealed that, Fluopyram, Fluensulfone, and Fluazaindolizine nematicides effectively reduced the root gall index and population density of root-knot nematode compared with control.

Dahlin *et al.* (2019) tested the efficacy of nematicide Velum (active ingredient Fluopyram) and *Purpureocillium lilacinum* strain 251 against *M. incognita* in tomato. They used commercial product of *Purpureocillium lilacinum* strain 251 formulated as wettable granulate (BioAct WG) along with nematicide. The results revealed that combined application increased the plant growth parameters and reduced the nematode population throughout the growing season.

Zewain and Ali (2019) field trail was conducted in Iraq to evaluate the organic formulations namely; Tervigo 20SC by two doses 8 L/ha and 10 L/ha, nematicide Nematron, and bio control agent *Paecilomyces lilacinus* and compared with nematidide Oncal 5% G as positive control against *Meloidogyne* spp. on cucumber plants. The results revealed that all the treatments significantly manage the root galling and population of nematode. Among all the treatments tested, *Paecilomyces lilacinus* showed maximum effect in reducing gall index and nematode population by 88.92%, 44.72 respectively.

Whereas, Tervigo at 8 l/ha showed minimum effect by 61.67%, 37.89 respectively compared with control.

Yadav *et al.* (2018) conducted pot experiments under greenhouse conditions for management of the root-knot nematode, *Meloidogyne incognita* in tomato. They tested different dosages of neem leaves @ 5, 10, 20 and 30 g / kg soil along with chemical as positive check and untreated control. The results revealed that, doses neem leaves 30 g / kg soil were effective in suppressing the nematode population and improves the plant growth parameters.

Basyony and Abo-Zaid (2018) isolated 14 *Bacillus subtilis* isolates from different locations of Egypt to test their efficacy against *Meloidogyne incognita* under laboratory conditions. Among the 14 isolates B10 and B8 at a concentration of 50% showed lowest percentage of hatched eggs reaching 44.7 and 46.3%, respectively. The culture broth of B10 isolate showed 99.7% juvenile mortality, which was the highest mortality compared with other isolates. They tested their efficacy towards reduction of root galling and egg masses capacity of *M. incognita* in tomato under greenhouse conditions. The results revealed that, both the concentrations of 10 ml / pot, 2×10^9 CFU / ml in a soil infested with *M. incognita*, recorded least number of galls (9.3) and egg masses (6.7) respectively. The bio formulation of B10 isolate @ 0.1 g / pot effectively reduced the number of galls and egg masses of root-knot nematode.

Ali and Zewain (2018) conducted a study to determine the efficiency of some bio control agents *Paecilomyces lilacinus*, *Trichoderma harzianum*, pomegranate peel powder, pesticide Tervigo 20SC and nematicide Vydate10 / L against root-knot nematode *Meloidogyne* spp. under greenhouse conditions. Among the treatments tested, Tervigo effectively reduced the root galls and nematode population by 61.37% and 80.48% respectively. Whereas, *T. harzianum* had less effective compared with control.

Fayzia *et al.* (2018) evaluated some bio control agents and botanicals *viz.*, *Arthrobotrys oligospora*, *Paecilomyces lilacinus*, *Glomus fasciculatum*, *Eucalyptus globules*, *Tagetes erecta*, *Allium sativum* and nematicide Fenamiphos (10%G). They

stated that all the treatments effectively reduce the nematode population in soil and root samples compared with untreated check.

Mukhtar (2018) evaluated bio control agents *Trichoderma harzianum* and *T. viride* against *Meloidogyne incognita* on tomato. They reported that both bio control agents significantly reduced the egg mass, number of galls and population density of *M. incognita* in a dose dependent manner. The maximum results were obtained from two doses 8×10^3 and 1×10^4 CFU / g of soil. *T. harzianum* gave best results than *T. viride*.

Jaydeep *et al.* (2017) evaluated different botanicals *viz.*, Neem, Aak, Castor leaves and Neem seed kernel powder @ 20 and 30 g / kg soil along with untreated check against root-knot nematode, *Meloidogyne incognita* under pot conditions. They observed that all the botanicals significantly reduced the population of nematode.

Patil *et al.* (2017) evaluated different bio control agents *viz.*, *Pseudomonas fluorescens*, *Purpureocillium lilacinum* (*Paecilomyces lilacinus*) and *Trichoderma viride* @ 0.3 and 0.5 g/kg soil and liquid formulation of bio agents, (*T. viride* + *P. fluorescens* + *P. lilacinus*) @ 0.5 and 1 ml/ kg soil against *Meloidogyne incognita* and wilt complex disease caused by *Fusarium oxysporum f. sp. cucumerinum*+ *Meloidogyne incognita*. The treatments they followed as individual application of nematode, fungus and inoculation of both simultaneously. Bavistin @ 2 g / l water and carbofuran @ 0.1 mg / kg soil were used as positive control and untreated check as negative control. The results revealed that all bio control agent effectively controlled the population of nematode and fungus in soil while less effective results were recorded from Bavistin treated plants.

A study was carried out to test the effect of bio control agents namely *Trichoderma viride*, *Pasteuria penetrans*, *Glomus fasciculatum* and FYM along with Carbofuran 3G @ 9 g / m² as chemical check for the control of root-knot nematode (*Meloidogyne incognita*) in brinjal susceptible local variety (JC1). The results revealed that, among treatments tested, Carbofuran 3G @ 9 g / m² gave best results in controlling the no. of egg masses (17.20), no. of galls (11.60) and nematode population (150.60 / 250cc soil) followed by *T. viride* (Jena *et al.*, 2017).

Sellitto *et al.* (2016) tested the efficacy of the commercial bio fungicide (POCHAR) developed from *P. chlamydosporia* against root-knot nematode and its growth promotion capacity in tomato fields. They stated that POCHAR effectively control the nematode population after application and it also improves the growth parameters of tomato.

Huang *et al.* (2016) evaluated the capacity of bio control agents *viz.*, *Syncephalastrum racemosum*, *Paecilomyces lilacinus* and *Bacillus cereus* against *M. incognita* in pot and greenhouse grown cucumber. The nematicide Fosthiazate was used as positive control. The results revealed all the bio control agents have ovicidal and larvicidal action. Under *in-vitro* conditions, all the bio agents significantly reduced the egg mass and juveniles at concentration of 2%. Maximum ovicidal and larvicidal activity was observed at 50%, which caused 96.7% mortality rate. In pot experiments and greenhouse conditions, *S. racemosum* combined with *P. lilacinus* significantly reduced the root galls and improves the plant growth.

Burelle (2015) conducted an experiment to test the efficacy of marketable formulations of the bio control agent *Pasteuria penetrans* against *M. incognita* on tomato and cucumber under Microplot and greenhouse conditions. The result revealed that *Pasteuria penetrans* application reduced the rot galling, population of nematodes in soil and root samples.

Parihar *et al.* (2015) conducted a pot experiment to assess the efficacy of *Pochonia chlamydosporia*, oil cakes of neem, mustard and cotton and nematicide (Carbofuran) for control of root-knot nematode in brinjal under glasshouse conditions. The results revealed that Neem cake was more effective than other oil cakes in controlling *M. javanica* and combination of neem cake + *P. chlamydosporia* treatment were found to be effective in controlling root-knot nematode followed by mustard cake + *P. chlamydosporia* and cotton cake + *P. chlamydosporia*.

Huang *et al.* (2014) tested the efficacy of *Syncephalastrum racemosum* fungus and the nematicide, Avermectin, alone or in combination against root-knot nematode in

cucumber grown under pot conditions and field trials. They observed that application of *Syncephalastrum racemosum* alone and combined with Avermectin both significantly reduced the nematode population, disease severity under pot and field level and it also enhances the growth and yield in cucumber.

Mascarin *et al.* (2012) tested the bio control agent *Trichoderma harzianum* strain ESALQ-1306 for its potential in controlling root-knot nematode *Meloidogyne incognita* race-4 under *in-vitro* and greenhouse conditions. The results revealed that, under *in-vitro* conditions 64% of conidial attachment of fungus on eggs and second-stage juveniles (J₂) and under greenhouse conditions 50% nematode reduction was observed after three sequential applications of *T. harzianum*.

Hashem *et al.* (2011) tested the nematicidal capacity of bio agents' viz., *P. fluorescens*, *P. lilacinus*, *Pichia guilliermondii* and *Calothrix parietina* alone or combined application against root-knot nematode, *Meloidogyne incognita* under *in-vitro* conditions. Among the tested bio agents, *P. fluorescens* and *P. lilacinus* caused 45% and 30% juvenile mortality rate after 48 hrs of exposures, respectively. Under greenhouse conditions, all the treatments significantly reduced the disease severity except *C. parietina*.

Chanppa *et al.*, (2008) reported that the cell concentration of 4 strains of *P. fluorescens* have been found inhibitory to eggs hatchability and larval motility of *M. incognita*.

Mansoor (2006) tested the efficacy of neem leaves, seed powder, oil cake and two nematicides viz., carbofuran and Phorate alone and in combination against root-knot nematode *M. incognita*. He revealed that among the different treatments, oil cake combined with Carbofuran significantly controlled the population of nematode and also improved the growth parameters of cucumber.



Material and Methods

III. MATERIAL AND METHODS

The root-knot nematode, *Meloidogyne incognita* has been observed frequently in cucumber grown under protected conditions and causes more economic damage to the crop. The experiments were directed to know the occurrence of root-knot nematode (*M. incognita*) on cucumber, screening of commercially available cucumber varieties / hybrids and the efficacy of treatments viz., *Trichoderma harzianum*, *Pochonia chlamydosporia*, *Pseudomonas fluorescens* and Fluopyram 400 SC and their combination in the management of root-knot nematode on cucumber was carried out at field of Plant Pathology Department, College of Horticulture (COH), UHS campus, Bengaluru. The material and methods adopted in the research work are clearly explained in this chapter.

3.1 Survey for root-knot nematode species associated with cucumber in polyhouse in Bengaluru rural and Chikkabalapur district

A roving survey was carried out in main cucumber growing areas mainly under polyhouse conditions in Bengaluru rural and Chikkabalapur district to study the incidence of different *Meloidogyne* spp. nearly ten locations were surveyed. The plants infected with root-knot nematode exhibited the symptoms such as stunted, patchy growth, yellowing of leaves, poor yield, heavy root galling, weak plants and small immature fruits, root deterioration and reduced root system and unthrifty growth. During the survey, root and rhizosphere soil samples were collected and brought to the laboratory for further studies.

3.1.1 Collection of soil and root samples:

To notice the occurrence and incidence of root-knot nematode, *Meloidogyne* spp., survey was conducted in different cucumber, tomato and chilli growing areas. Infested rhizosphere soil of about 250 g and root samples of standing cucumber crop were collected arbitrarily from 5 to 10 locations. Then information about condition of crop, locality, soil condition, disease incidence, type of cultivars and package of practices followed etc., were collected. Samples filled in polythene cover with good mark and

labeling were carried to the laboratory and stored in refrigerator at about 10° C. The samples were processed within a week

3.1.2 Occurrence per cent

The frequency of occurrence per cent of the root-knot nematode infection in each locality was calculated by the following formula (Esfahani, 2009).

$$\text{Occurrence (\%)} = \frac{\text{Number of samples containing } J_2 / \text{infective juvenile}}{\text{Number of samples collected}} \times 100$$

3.1.3 Estimation of nematode population in soil samples

Soil sample of 250g was processed using combined Cob's sieving and Baermann's funnel method". The procedure followed is mentioned below (Ayoub, 1977).

- 1) Initially, 250 g of soil was taken into 1000 ml beaker then required quantity of water was added to prepare soil solution.
- 2) The soil sample was stirred carefully and allowed to settle down heavier particles.
- 3) For extraction of nematodes, a set of sieves of 100, 250, 325 and 400 mesh sizes were used respectively.
- 4) Then the residues were collected from 325 and 400 mesh sieves and poured on to a tissue paper, spread on a steel mesh and sited on Baermann's funnel.
- 5) The water level was maintained carefully to keep the tissue paper wet and kept in undisturbed condition for 48 hours.
- 6) After 48 hours, the volume of suspension was made to 200 ml; out of that 10 ml was pipetted out and used for counting of root-knot nematodes. Nematode population found in this suspension was estimated for 250 g soil.

3.1.4 Estimation of nematode population in root samples

The nematode population in 5 g of root was predicted by root incubation method (Ayoub 1977). The below given procedure was followed for estimation.

3.1.4.1 Procedure

1. Roots were washed thoroughly.
2. Then cut into small bits of 2 cm and split longitudinally.
3. Then the root bits were placed over tissue paper spread on a wire gauge and kept in a Petri plate.
4. The water level was maintained in Petri plate and kept in undisturbed condition for 48 hours.
5. Later, the suspension was collected and observed for nematodes using stereo-binocular microscope.

3.1.5 Maintenance and multiplication of pure cultures

3.1.5.1 Soil sterilization

1. Red sandy loam soil, free from stones and lumps was collected, sieved and mixed thoroughly with FYM in 3:1 proportion.
2. Cleaned soil mixture was added with four per cent formaldehyde (1lit in each 23 cm soil thick layer / 1m²) for sterilization.
3. Then the soil bed was covered with polythene sheet.
4. After 7 days, the polythene sheet was removed and the soil was spread to facilitate escape of toxic fumes, if any.
5. Then sterilized soil was tested to confirm that no living nematodes exist in it.

3.1.6 Source and identification of root-knot nematode (*Meloidogyne incognita*) associated with cucumber

Inoculum of root-knot nematode (*Meloidogyne incognita*) was collected from the nematode infected cucumber plants from farmer's field in Bengaluru rural district. Root-knot nematode egg masses were extracted from the roots of the infested cucumber plants. For the extraction, roots showing galls were collected and washed with water to remove the adhering soil particles and the bulging egg mass in the galls were picked with the

needle under microscope. The collected egg masses were placed in petri dishes containing distilled water for hatching. After 24-48 hrs, eggs hatched into juveniles and the freshly hatched juveniles were inoculated into one-month old tomato plants which were planted in 5 kg cement pots filled with sterilized soil at one juvenile per gram of soil (5000 juveniles / pot). After 30 days of inoculation, eggs were extracted from the tomato roots with above mentioned procedure and used for the screening studies. Meanwhile, the female nematodes collected from the tomato roots were handled for perineal pattern to confirm the species of root-knot nematode (*Meloidogyne incognita*) associated with the plant.

3.1.7 Identification of root-knot nematode species

- 1) The infected roots were washed.
- 2) The females were separated out from mature galls of infested root under stereo-binocular microscope and transferred to Petri dish containing water. Then posterior portion of the female was cut with perennial sharp blade (Taylor and Netscher, 1974) and the body contents were cleaned.
- 3) The cleaned posterior portion was further clipped and moved to drop of glycerin on a clean microscopic slide.
- 4) A cover slip was placed on it, sealed with nail polish and observed under stereo-binocular microscope. The species confirmation was done based on the perennial pattern as described by Chitwood (1949).

3.1.8 Taxonomic position of nematode

Phylum	: Nematoda
Class	: Phasmidia(Secernentia)
Order	: Tylenchida
Sub order	: Tylenchina
Sub family	: Heteroderoidea
Family	: Heteroderidae
Genus	: <i>Meloidogyne</i>
Species	: <i>incognita</i>

3.1.9 Morphological characters of *Meloidogyne incognita*

The lifecycle of *M. incognita* comprises nearly 25-28 days. The body shape of root-knot nematode varied in males, females and larval stages. The body of male and larvae is elongated whereas female body is spheroid, and acute with distinct neck. The stylet also varied in males and females. In females, the stylet is slender with strong basal knobs. Male stylet is strong with rounded knob. Esophagus contains large median bulb followed by short isthmus. Excretory pore is present between posterior stylet knobs opposite to median bulb. Vulva and anus are surrounded by fine lines like human finger prints and present exactly opposite to neck. Spicules are present at terminal portion of the males. Second stage juveniles (J₂) measures 415-484 µm in length, 22-27 µm in thickness, tail less pointed and rectum not detailed. Females have swollen measuring 445-765 µm long and 275-520 µm in diameter, spheroid and perennial pattern with whorl of striate around tail tip and male measures 1000-2000 µm long and 100-200 µm diameter, lateral field with 6-8 lateral incisures. Parasitism and habitat are endoparasitic on numerous plants. All stages are found inside the roots and in soil around the roots.

3.2.1 Screening of cucumber varieties for root-knot nematode (*Meloidogyne incognita*)

To know the level of resistance or susceptibility of cucumber varieties / hybrids to the root-knot nematode, pot experiment was conducted in the polyhouse (26.7±3⁰ C temperature, 73.5 % ± 11 % relative humidity and 0.917 kPa) at Department of Plant Pathology, in COH, Bengaluru. The cement pots (30 cm diameter) were filled with a mixture of sterilized sandy loam soil to screen the available cucumber varieties / hybrids for their reaction to *Meloidogyne incognita*. A total of nineteen cultivars viz., Sunstar Rz, Kingstar Rz, Deltastar Rz, Green long, Falconstar Rz, Captainstar Rz, Green cucumber, Sitha ashoka, NS-404, DWR long, Legend, Nalini, Swadish, Sunny85, Shalini, Snow White, Pallavi, Kohnoor and Swarna ageti, were screened against *Meloidogyne incognita*. The varieties were purchased from different shops and seed companies of Bengaluru and Chikkaballapur district and were sown in trays filled with coco peat and watered regularly. After 10 days, seedlings were transplanted to the pots filled with sterilized soil.

3.2.2 Experimental procedure

The experiment stock culture of the root-knot nematode, *Meloidogyne incognita* for the study was originally obtained from a single egg mass progeny in tomato plant. The nematode population was sub-cultured periodically by inoculating with infective J₂ in sterile water to the root zone in pots (4-5 kg capacity) containing infested soil. For screening, autoclaved soil was inoculated with root-knot nematode @ 2500 J₂ / 4-5 kg soil.

3.2.3 Inoculation of root-knot nematodes for screening propose

In case of screening different varieties / hybrids of cucumber, cement pots having 30 cm diameter were used in the experiment. The pots were washed with normal water and disinfected with 4 per cent formaldehyde. After complete evaporation of formaldehyde, pots were used for screening studies. Sterilized soil filled in cement pots and each variety was replicated 3 times in transplanted pots. The pots were watered regularly to maintain constant moisture in pots. Then 10 days after transplanting small glass tube (2 cm long 0.5 cm bore) was inserted into the soil near the root zone of each of seedlings. Two weeks after, nematodes were counted in seedlings under a stereoscopic microscope and released freshly hatched 2nd stage juveniles (J₂) of *Meloidogyne incognita* around the sown seeds @ 2,500 J₂ / 4-5 Kg of the soil into the holes per seedling in 10 ml sterile water. The severity of the disease was recorded at 90 days after sowing. The observations *viz.*, plant height (cm), number of leaves / plant; number of galls / root system, number of egg masses / root system, and nematode population / 5 g root system and nematode population / 250 g of soil were taken.

The numbers of galls produced on each plant roots were observed under stereo microscope. The root system was fixed in 4 % formalin and stored in plastic container with proper labels, for observation of egg-masses in the root system of plant. The root system of each plant was cut and five grams was stained with lacto-phenol acid fuchsine. The egg masses present in them were counted through a stereoscopic microscope.

Based on the root-knot index for *M. incognita*, varieties were categorized as per 1-5 gall index as given below. The varieties / hybrids were categorized into resistant, tolerant and susceptible (Anon., 1993).

Number of galls	Gall Index	Reaction
0	1	HR (Highly Resistant)
1-10	2	R (Resistant)
11-30	3	MR (Moderately Resistant)
31-100	4	S (Susceptible)
101 and above	5	HS (Highly Susceptible)

3.3.1 Management of root-knot nematode (*Meloidogyne incognita*) under polyhouse condition

Evaluation of bio-control agents viz., *Trichoderma harzianum*, *Pochonia chlamydosporia*, *Pseudomonas fluorescens* and their combination with chemical Velume prime (Fluopyram 400 SC) against root-knot nematode were studied in this objective. The efficacy of the treatments was tested on highly susceptible cucumber cultivar. The experiment was conducted in polyhouse at Department of Plant Pathology, College of Horticulture, Bengaluru. The treatment combinations used in the study are given below.

3.3.2 Treatment Details

Sl. No.	Treatment	Concentration / dosage
T ₁	<i>Trichoderma harzianum</i>	10g / pot (1x10 ⁹ CFU / g of talc powder)
T ₂	<i>Pochonia chlamydosporia</i>	10g / pot (1x10 ⁹ CFU / g of talc powder)
T ₃	<i>Pseudomonas fluorescens</i>	10g / pot (1x10 ⁹ CFU / g of talc powder)
T ₄	Fluopyram 400 SC	0.13 ml / l water
T ₅	T ₁ +T ₂	
T ₆	T ₁ +T ₃	
T ₇	T ₁ +T ₄	
T ₈	T ₂ +T ₃	

T ₉	T ₂ +T ₄	
T ₁₀	T ₁ +T ₂ +T ₃	
T ₁₁	T ₁ +T ₂ +T ₄	
T ₁₂	T ₁ +T ₂ +T ₃ +T ₄	
T ₁₃	Inoculated control	

3.3.3 Experimental details

Crop : Cucumber
 Variety : Pallavi Hybrid
 Number of treatments : 13
 Replications : 3
 Design : CRD
 Location : COH, Bengaluru
 Duration : Three months
 Soil : Red sandy loam

3.3.4 Sterilization of soil

The soil and pots were sterilized by using 4% formaldehyde. The soil was kept closed for 7 days and after complete evaporation of formaldehyde, filled to sterilized pots. At the same time cement pots were washed with water and disinfected with 4 per cent formaldehyde. After complete evaporation of formaldehyde, pots were used for management studies.

3.3.5 Transplanting of seedlings

The 15 days old cucumber seedlings were transplanted to cement pots filled with sterilized soil and FYM at 3:1 ratio. The selected susceptible variety / hybrid was replicated three times to minimize statistical error. All normal packages of practices like fertilizers and micro nutrients were applied to the pots and moisture was maintained in the pots by regular watering.

3.3.6. Inoculation of root-knot nematode (*Meloidogyne incognita*)

At 10 days after transplanting, small glass tube (2 cm long 0.5 cm bore) was inserted into the soil near the root zone of each of seedlings, then released the nematodes (freshly hatched 2nd stage juveniles (J₂) of *Meloidogyne incognita*) around the plant @ 1,500 J₂ / 4-5 kg of the soil.

3.3.7 Application of treatments

Before transplanting of cucumber seedlings, except chemical Velum Prime 400 SC (Fluopyram), all bio agents namely, *Trichoderma harzianum*, *Pochonia chlamydosporia*, *Pseudomonas fluorescens* and their combination were mixed well into cement pots then Velum prime (Fluopyram 400 SC) at the concentration of 0.13 ml / L of water was drenched twice After 15 and 48 days of cucumber seedling transplanted in each respective pot.

3.3.8 Treatments background

1. *Trichoderma harzianum*

Fungus belongs to Division: Ascomycota; Class: Sordariomycetes; Order: Hypocreales; Family: Hypocreaceae and Genus: *Trichoderma*: Species: *Harzianum*. Besides being a potential antifungal bio control agent, it has also been used as an effective tool in the management of nematode and showed high variable degree of parasitism and its mode of action (Sharon *et al.*, 2009). Eapen and Venugopal (1995) reported that *Trichoderma* isolates have antagonistic potential against wide variety of fungi and nematodes and the culture filtrate of *Trichoderma* spp., also has potential nematicidal properties (IISR, 1995). The number of root-knot nematode, *Meloidogyne incognita* eggs hatched was significantly reduced after incubation along with pure PRA1 (Trypsin like protease) preparation of *T. harzianum* CECT 2413 (Suarez *et al.*, 2004).

2. *Pochonia chlamydosporia*

Fungus belongs to Division: Ascomycota; Sub division: Pezizomycotina; Class: Sordariomycetes; Order: Hypocreales; Family: Clavicipitaceae; Genus: *Pochonia*;

Species: *chlamydo-sporea*, was first reported in 1974 by Wilcox and Tribe in UK, as a parasite of nematode eggs and later it subsequently became one of the most studied potential bio-control agent of nematodes. It has worldwide distribution in nematode suppressive soil and able to colonize the roots of host plant, its growth habit may result in benefit to host plant defense against soil-borne pathogens (Lopez- Llorca. *et al.*, 2002). Generally the fungus is a facultative parasite of nematode and hyperparasite of other fungi (Lumsden *et al.*, 1982; Zare *et al.*, 2001).

3. *Pseudomonas fluorescens*

It is a gram negative bacterium belonging to the Family: Pseudomonadaceae; generally an aerobic rods and cocci shape. It is one among the efficient biological antagonist against various pathogens. And its phosphate solublizing bacteria widely used in nematode management. It not only suppresses the pathogenesis of nematode but also promotes the plant growth by solubilizing the minerals present in the soil (Siddiqui and Shaukat, 2004). Culture filtrates of *P. fluorescens* strain CHAO showed significant mortality of 46% of *M. incognita* juveniles over control under *in-vitro* (Siddiqui *et al.*, 2003).

4. Velum Prime (Fluopyram 400 SC)

Velum Prime (fluopyram 400 SC) by chemical structure and formation (N - {2 - [3 - chloro - 5 - (trifluoromethyl) - 2 - pyridyl] ethyl} - α , α , α - trifluoro - o - toluamide), a pyridylethylamide compound, active ingredient. Earlier it had been used in many horticulture and arable crops for protection against a range of ascomycetes and deuteromycetes. Later explored its potential as nematicide and was observed to be very effective against nematodes (Faske and Hurd 2015). By applying fluopyram, nematodes get paralysed, remain immobile and stretch out like needle in soil and finally die. Also it effects on early stage of nematode development and eggs are hatched late which interrupt next generation of nematodes growth. (The Bayer Scientific magazine., 2017).

3.3.9 Treatments imposition or details

T₁. *Trichoderma harzianum*

Ten gram / pot of bio-control agent comprising an average of 1×10^9 CFU / g of talc powder mixed with 5 kg of soil into each of three pots and mixed well.

T₂. *Pochonia chlamydosporia*

Ten gram / pot of bio-control agent comprising an average of 1×10^9 CFU / g of talc powder was mixed with 5 kg of soil into each of three pots and mixed well.

T₃. *Pseudomonas fluorescens*

Ten gram / pot of bio-control agent comprising an average of 1×10^9 CFU / g of talc powder mixed with 5 kg of soil into each of three pots and mixed well.

T₄. Velum prime (Fluopyram 400 SC)

The chemical Velum prime (Fluopyram 400 SC) was applied twice at different time intervals for all **T₄**, **T₇**, **T₉**, **T₁₁** and **T₁₂** at 0.13 ml Fluopyram / L of water applied after 15 days of transplanting and second 48 days of transplanting.

T₅. Combination of T₁ + T₂ (*Trichoderma harzianum* + *Pochonia chlamydosporia*).

T₆. Combination of T₁ + T₃ (*Trichoderma harzianum* + *Pseudomonas fluorescens*).

T₇. Combination of T₁ + T₄ (*Trichoderma harzianum* + (Fluopyram 400 SC). Initially the T₁ mixed well in soil before cucumber transplanting and then Fluopyram 0.13 ml / L of water was drenched twice after 15 and 48 days of transplant.

T₈. Combination of T₂ + T₃ (*Pochonia chlamydosporia* + *Pseudomonas fluorescens*).

T₉. Combination of T₂ + T₄ (*Pochonia chlamydosporia* + Fluopyram. First T₂ was mixed well in soil and then Fluopyram 0.13 ml / L of water was drenched twice after 15 and 48 days of transplanting.

T10. Combination of T₁ + T₂ + T₃ (*Trichoderma harzianum* + *Pochonia chlamydosporia* + *Pseudomonas fluorescens*).

T11. Combination of T₁ + T₂ + T₄ (*Trichoderma harzianum* + *Pochonia chlamydosporia* + Velum prime (Fluopyram 400 SC)). First bio-controls agents were mixed well with soil and then Fluopyram 400 SC 0.13 ml / L of water was drenched twice after 15 and 48 days transplant.

T12. Combination of T₁ + T₂ + T₃ + T₄ (*Trichoderma harzianum* + *Pochonia chlamydosporia* + *Pseudomonas fluorescens* + Fluopyram 400 SC. First bio-control agents were mixed well with soil and then Fluopyram 0.13 ml / L of water was drenched twice after 15 and 48 days of transplant.

T13. Untreated control.

Termination of the experiment

The experiment was terminated by uprooting the plants from pots after 95 days transplanting and observations were recorded.

3.3.9 Observations recorded

1. Growth parameters of the host:

Plant height (cm): Recorded from tip to base of the plant after 90 days.

Number of leaves: Counted after 90 days.

Root length (cm): Recorded from base of the stem to the tip of the roots in centimeter.

Root weight (g): After harvesting the crop, fresh and dry root weight was recorded from the uprooted plants. For taking dry root weight, roots were cut into small pieces and kept in microwave oven at 60° C until constant weight reached, then the dry root weight recorded.

Fruit yield (Kg): Recorded in kg / pot.

2. Nematode parameters

Nematode Population in soil: The nematode population in soil was estimated after uprooting of plants followed by combining “Cobb’s sieving and Baermann’s funnel method” (Ayoub, 1977) below given procedure.

Procedure

1. Two hundred and fifty grams of soil was taken in a beaker and required amount of water was added to it to prepare soil solution.
2. The solution was stirred thoroughly and allowed to settle the heavier particles.
3. Then the soil solution was passed through a set of sieves of 100, 250, 325 and 400 mesh sizes respectively.
4. Residues leftover in 325 and 400 mesh sieves were collected and poured on tissue paper on a wire gauge placed on a Baermann’s funnel.
5. The tissue paper was kept wet by maintaining water level continuously and kept for 48 hours in undisturbed condition.
6. After 48 hrs., the suspension was poured into beaker and the volume was made to 200 ml. The suspension was stirred and 10 ml of aliquot was taken and transferred to a counting dish and nematodes were counted by seeing under stereo binocular microscope, the nematode counts from this were converted to 250 g of soil by multiplying with a common factor 25.

Nematode Population in the root: The nematode population in the root was estimated by root incubation method (Ayoub, 1977).

Number of galls per root system: After uprooting the plant, the number of galls per root system were recorded.

Number of egg masses per root system: The infected roots were treated with 0.25 per cent trypan blue for 3 minutes. Then number of egg masses were recorded.

3.3.10 Statistical analysis

In the present study, Completely Randomized Design (CRD) was applied for analysing the data. The value of F at 5% level of probability was calculated (Fisher and Yates, 1968) for the appropriate degrees of freedom (d.f.). The analysis of variance was used to study the differences among treatments in the experiments. The treatment difference was obtained and compared with critical difference (CD). If it was less than C.D. then there was no significant difference in among treatments.



Results

IV. EXPERIMENTAL RESULTS

To evaluate significance result of the experiments under the topic “studies on root-knot nematode, *Meloidogyne incognita* on cucumber and its management under the polyhouse condition” was carried out at College of Horticulture, Bengaluru. Initially, a survey was undertaken on different species of root-knot nematodes that caused galls in the root system rhizosphere of cucumber in the Bengaluru rural and chikkaballapur districts. Nineteen different commercially available cucumber varieties / hybrids were purchased from seed shops and seed companies located in Bengaluru and screened against root-knot nematode. From the screening study, highly susceptible cucumber variety / hybrids was collected and utilized for the management studies. For management of *M. incognita*, three bio-agents and a nematicide were used and by using different treatments, efficacy of their specific and combined effect on root-knot nematode under polyhouse conditions were tested. The results got from these studies presented here.

4.1 Survey for root-knot nematode (*Meloidogyne* spp.) associated with cucumber in polyhouse in Bengaluru rural and Chikkabalapur districts

To study the occurrence of major root-knot nematode species associated with cucumber, a survey was conducted during September to November 2019 in 11 different locations in polyhouses which were growing cucumber and tomato in different areas of Bengaluru rural district like Hadonahalli, Bachhahalli, Shivalingapura, Naraganahalli, and Chikkabalapur district viz., Gummanahalli, Chadalapura, Bandahalli, Vijayapura, Doddathamangala, Kasvanahalli and GKVK. During the survey, 4-5 places in each polyhouse were selected. Then roots and soil samples of the infected plants were collected (Table 1).

4.1.1 Symptoms

Root-knot nematode (RKN) infected cucumber plants exhibited symptoms like stunted, patchy growth and yellowing of leaves, heavy root galling, poor yield, weak plants and small slow growing fruits, root decay, reduced root system and unthrifty growth (Plate 1 and 2). The plants which exhibited symptoms were selected from

polyhouses and then infected rhizosphere soil samples and roots were collected and filled in polythene bags then labeled, tied and carried to the laboratory. The samples were stored in refrigerator at about 10 C°. The samples were processed within a week after identification of perennial pattern and morphological nature of *Meloidogyne incognita* (Plate 3).

Table 1: Status of root-knot nematode incidence in cucumber grown in polyhouses of different villages of cucumber grown areas

Districts	Taluk	Villages	No. of polyhouses visited	No. of samples collected	No. of samples infested
Bengaluru rural	Bengaluru rural	GKVK	1	5	4
		Kasvanahalli	1	5	1
	Doddaballapur	Hadonahalli	1	5	5
		Bachahalli	2	5	5
		Naraganahalli	1	4	4
		Shivalingapura	2	4	4
Chikkaballapur	Chikkaballapur	Gummanahalli	1	5	4
		Chadalapura	2	5	5
		Bandahalli	2	5	4
	Devanahalli	Vijayapura	1	4	4
		Doddathamangala	1	4	3

During the survey, polyhouse grown cucumber and tomato plants were examined. Nematode infestation was observed in all surveyed polyhouses and population of root-knot was recorded (Table 1). The table 1 indicates the presence of root-knot nematode infection and per cent infestation varied with locations and polyhouses.

The results showed that root-knot nematode, *M. incognita* was the predominant (27-583 nematodes / 250 g soil) followed by *M. javanica* 43 / 250 g soil, and *M. arenaria* 5 / 250 g soil respectively.



Plate 1: View of root-knot nematode infested cucumber polyhouse at Hadonahalli village, Doddaballapura, Bengaluru rural district



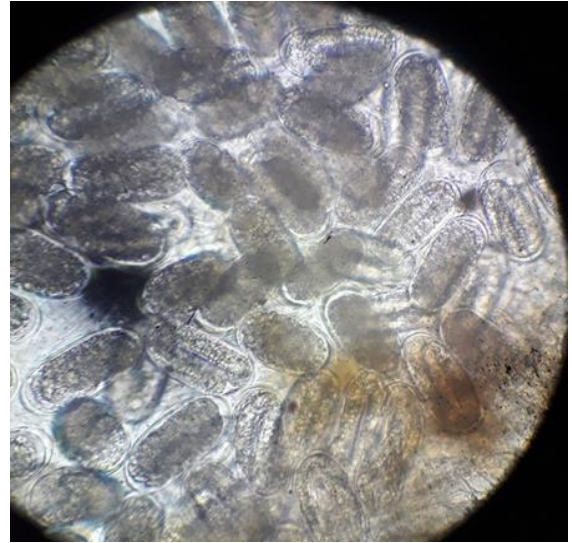
A

B

Plate 2: Root-knot nematode infested cucumber roots (A). Healthy cucumber root (B)



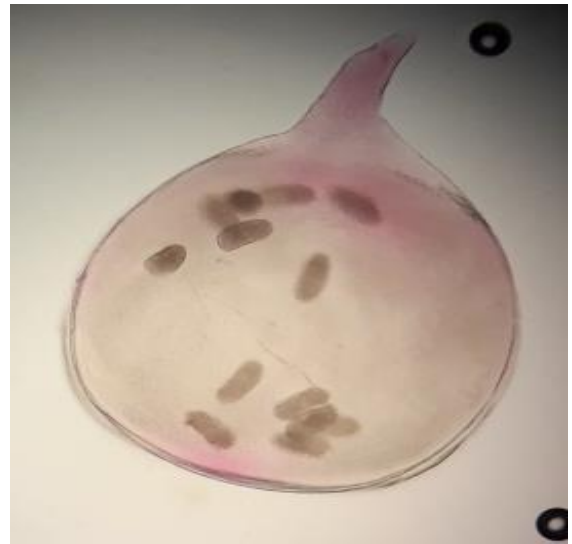
A



B



C



D

Plate 3: Morphological nature of *Meloidogyne incognita*. (A) Egg mass (B) Nematode eggs under 40X microscope resolution (C) Second stage juvenile (D) Female nematode

The highest population of *M. incognita* 583 / 250 g soil was recorded in Hadonahalli followed by Shivalingapura 392 nematodes / 250 g soil villages of Doddaballapur taluk, followed by Gummanahalli of Chikkaballapur taluk 381 nematode / 250 g soil and Vijayapura of Devanahalli taluk 238 / 250 g soil. Whereas least population 27 / 250 g soil of *M. incognita* was recorded in Kasvanahalli of Bengaluru.rural taluk (Table 2).

The root samples collected from cucumber growing polyhouses were also examined for nematode population. The maximum population of *M. incognita* was recorded in root samples collected from Hadonahalli village of Doddaballapur taluk (117 / 5 g root) followed by Gummanahalli of Chikkaballapur taluk (93 / 5 g root), Vijayapura of Devanahalli taluk (78 / 5 g root) and GKVK of Bengaluru taluk (75 / 5 g root). The least population (19 / 5 g root) was noted in Kasvanahalli of Bengaluru (Table 3).

4.2 Screening of cucumber varieties / hybrids for root-knot nematode (*Meloidogyne incognita*)

Nineteen different commercially available cucumber varieties / hybrids viz., SunStar Rz, Kingstar Rz, Deltastar Rz, Falconstar Rz, Captainstar Rz, DWR Long, Green Long, Shalini, Nalini, NS-404, Sitha Ashoka, Legend Cucumber, Green Cucumber, Swadish Cucumber, Snow White, Sunny-85, Pallavi, Kohinoor and Swarna Agiti of cucumber were screened against root- knot nematode (*M. incognita*) and their reaction on each varieties / hybrid were recorded (Plate 4). The experiment was directed in cement pots. The recorded screening data is evaluated and presented in Table 5 and 6, and Plate 4, 5, 6, 7 and Fig. 1. The results showed that all the varieties / hybrids screened against root-knot nematode. Pallavi hybrid recorded with maximum number of galls 420.6 per plant and 517.3 nematodes / 250 g of soil with root-knot index of 5.0 (Plate 6), followed by Sunstar Rz 412 galls and 493 nematodes / 250 g of soil with root-knot index of 5.0 indicating highly susceptible reaction to *M. incognita*. Whereas, Green long recorded least number of galls (121) per plant and 88 nematodes / 250 g of soil with 5 RKI. From the results it is revealed that, all the tested 19 varieties / hybrids were highly susceptible to *M.incognita*. (Plate 5).

Table 2: Population of root-knot nematode spp. in soil associated with root zone of cucumber in polyhouses in Bengaluru rural and chickkaballapur

District	Taluk	Location	Number of nematodes / 250 g of soil				
			<i>Meloidogyne incognita</i>	<i>Meloidogyne javanica</i>	<i>Meloidogyne arenaria</i>	<i>Meloidogyne hapla</i>	Total
Bengaluru rural	Bengaluru rural	GKVK	289	21	0	0	310
		Kasvanahalli	27	0	0	0	27
	Doddaballapur	Hadonahalli	583	43	5	0	631
		Bachhahalli	412	21	4	0	437
		Naraganahalli	107	0	0	0	107
		Shivalinga pura	392	35	0	0	427
Chikkaballapur	Chikkaballapur	Gummanahalli	381	18	2	0	401
		Chadalapura	180	7	0	0	187
		Bandahalli	133	3	0	0	136
	Devanahalli	Vijayapura	238	13	0	0	251
		Doddathamangala	167	0	0	0	167
Total			2,909	161.00	11.00	0	3081

Table 3: Population of root-knot nematode spp. associated in roots of cucumber in polyhouses in Bengaluru rural and Chickaballapur

District	Taluk	Place	Number of nematodes / 5 g of root sample				
			<i>Meloidogyne incognita</i>	<i>Meloidogyne javanica</i>	<i>Meloidogyne arenaria</i>	<i>Meloidogyne hapla</i>	Total
Bengaluru rural	Bengaluru rural	GKVK	75	0	0	0	75
		Kasvanahalli	19	3	0	0	22
	Doddaballapur	Hadonahalli	117	9	0	0	126
		Bachhahalli	109	10	0	0	119
		Naraganahalli	21	0	0	0	21
		Shivalinga pura	101	8	0	0	109
Chikkaballapur	Chikkaballapur	Gummanahalli	93	3	0	0	96
		Chadalapura	57	2	0	0	59
		Bandahalli	29	0	0	0	29
	Devanahalli	Vijayapura	78	0	0	0	78
		Doddathamangala	46	0	0	0	46
	Total			745	35	0	0

Table 4: Root-knot nematode population in soil and Root Knot Index (RKI) of crops in polyhouses surveyed in different village of Bengaluru rural districts

Sl. No.	Location	Village	No. of Polyhouses visited	Previous crops grown	Crop observed during survey	RKI
1	Bengaluru rural	GKVK	1	Cucumber / okra	Cucumber	5
		Kasvanahalli	1	Chili / Cucumber	Cucumber	3
2	Doddaballapur taluk	Hadonahalli	1	Cucumber / Chili	Cucumber	5
		Bachhahalli	2	Cucumber / tomato	Cucumber	5
		Naraganahalli	1	Cucumber / bringal	Cucumber	5
		Shivalinga pura	2	Cucumber / maize	Cucumber	5
3	Chikkaballapur district	Gummanahalli	1	Cucumber / okra	Cucumber	5
		Chadalapura	2	Capsicum / cucumber	Tomato	5
		Bandahalli	2	Bell Paper / cucumber	Cucumber	5
4	Devanahalli taluk	Vijayapura	1	Cucumber / brinjal	Cucumber	5
		Doddathamangala	1	Cucumber / tomato	Cucumber	5

Table 5: Screening of root-knot nematode (*Meloidogyne incognita*) on growth of cucumber cultivars under polyhouse condition

Sl. No.	Varieties / hybrids	Plant height (cm)	No. of leaves/plant
1	Falconsatr (Mini cucumber)	139.67	33.00
2	Sitha Ashoka	127.33	21.67
3	NS-404	224.33	28.67
4	Kingstar (Mini cucumber)	195.67	33.67
5	Deltastar (Mini cucumber)	202.67	36.33
6	DWR- Long	240.00	62.00
7	Legend	164.00	25.67
8	Green Cucumber	211.33	31.33
9	Sunstar (Mini cucumber)	84.00	17.00
10	Nalini	164.67	23.67
11	Swadish	150.33	27.33
12	Green Long	239.33	31.33
13	Sunny-85	157.67	22.33
14	Shalini	158.00	35.33
15	Snow White	149.33	29.67
16	Captanstar (Mini cucumber)	157.33	33.00
17	Pallavi	144.00	30.67
18	Kohinoor	201.67	25.33
19	Swarna Ageti	213.67	30.67
	S. Em ±	23.15	3.41
	CD at 5%	66.53	9.79

Table 6: Effect of *Meloidogyne incognita* on multiplication of root-knot nematode on cucumber cultivars under polyhouse condition

Sl. No.	Varieties/hybrids	Number of galls/plant	Number of egg masses/root system	Nematode population / 250 g of soil	Root-knot index (RKI)	Disease reaction
1	Falconsatr mini cucumber	274.67	17.00	235.67	5	*HS
2	Sitha Ashoka	132.67	9.00	176.67	5	*HS
3	NS-404	166.00	10.00	121.33	5	*HS
4	Kingstar mini cucumber	220.33	14.00	148.67	5	*HS
5	Deltastar mini cucumber	171.33	10.33	150.33	5	*HS
6	DWR- Long	276.00	11.00	214.33	5	*HS
7	Legend	149.33	9.00	116.67	5	*HS
8	Green Cucumber	146.33	9.00	104.33	5	*HS
9	Sunstar mini cucumber	412.00	30.67	493.00	5	*HS
10	Nalini	227.00	14.00	154.33	5	*HS
11	Swadish	168.00	12.67	140.67	5	*HS
12	Green long	121.00	9.00	88.00	5	*HS
13	Sunny-85	390.00	24.67	337.33	5	*HS
14	Shalini	334.00	21.00	205.00	5	*HS
15	Snow white	218.00	10.67	143.00	5	*HS
16	Captanstar	398.33	18.67	353.00	5	*HS
17	Pallavi	420.67	44.67	517.33	5	*HS
18	Kohinoor	385.33	15.00	342.67	5	*HS
19	Swarna Ageti	294.00	13.00	231.67	5	*HS
	S. Em ±	35.19	2.62	35.26		*HS
	C.D. at 5%	101.15	7.52	101.33		*HS

INP: 2500 J₂/ 5 kg of soil

* HS= Highly susceptible

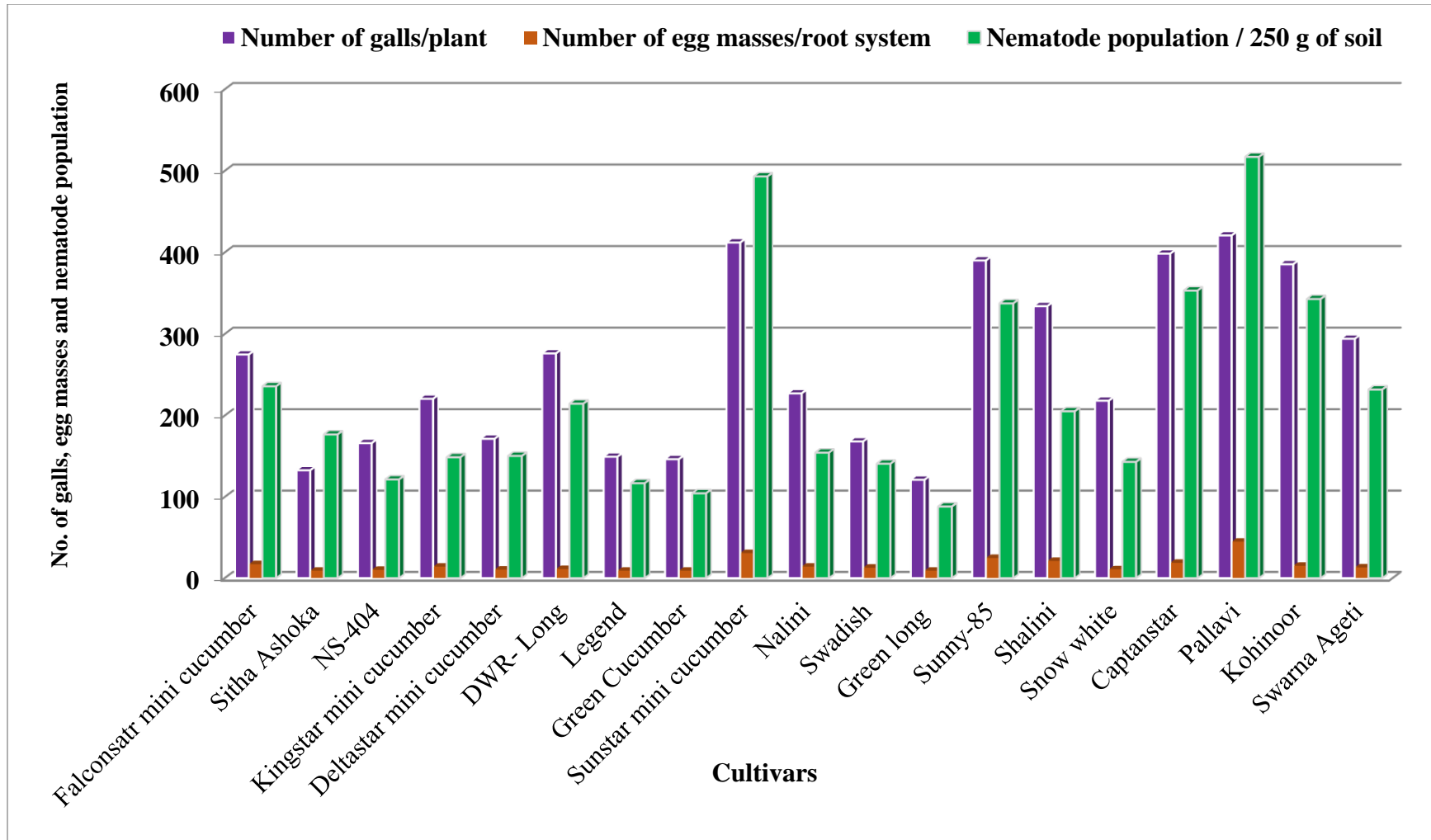


Fig. 1: No. of galls / root system, No. of egg masses / root system and nematode population / 250 g. of soil on growth of cucumber cultivars under polyhouse condition



A



B

Plate 4: General view of screening of cucumber varieties in pots culture inoculated 2500 J₂ of root-knot nematode (*Meloidogyne incognita*) / pot (A) 25 days after infestation (B) 75 days after inoculation

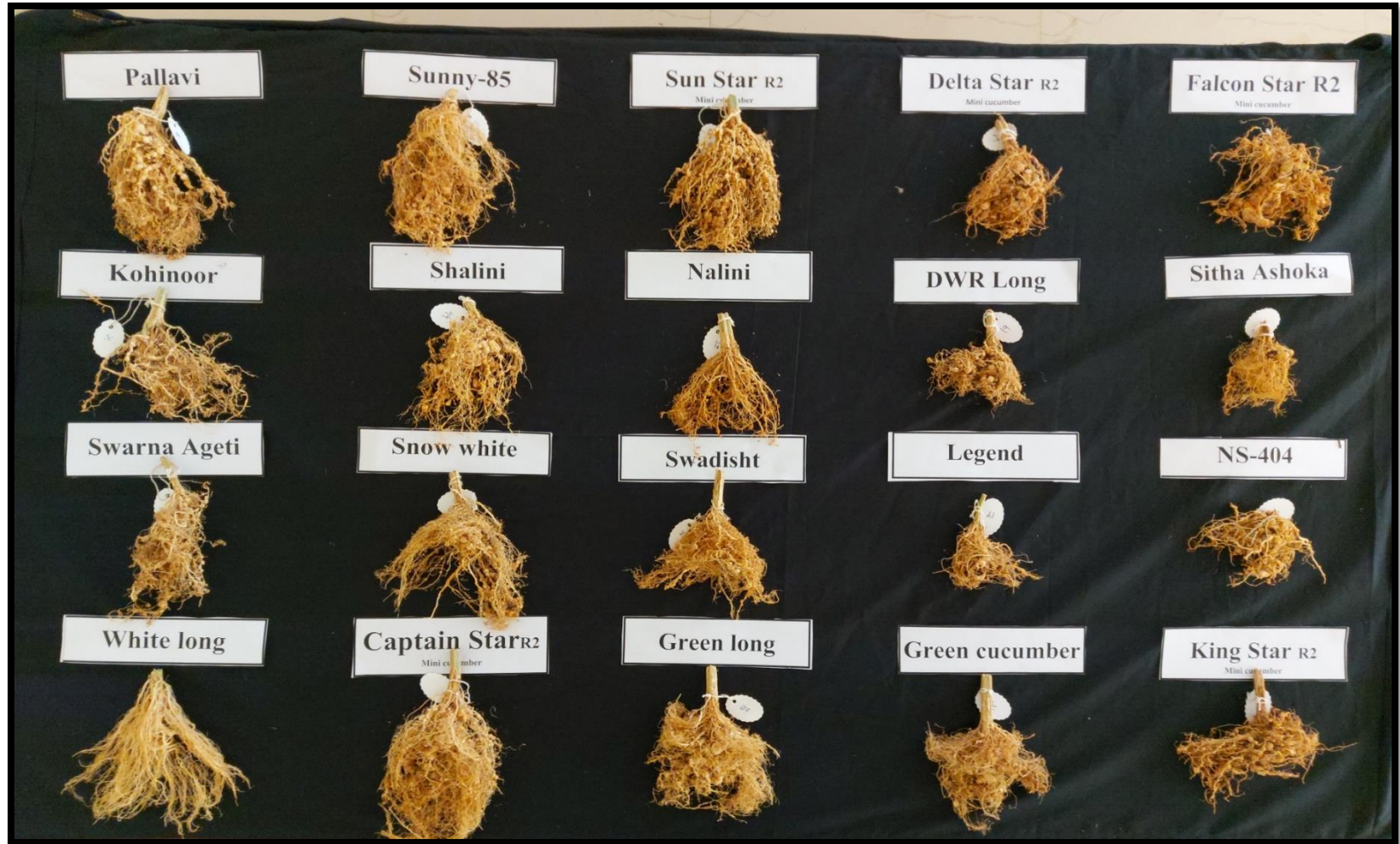


Plate 5: Root growth and galling in different varieties of cucumber screened against root-knot nematode (*M. incognita*) under polyhouse condition

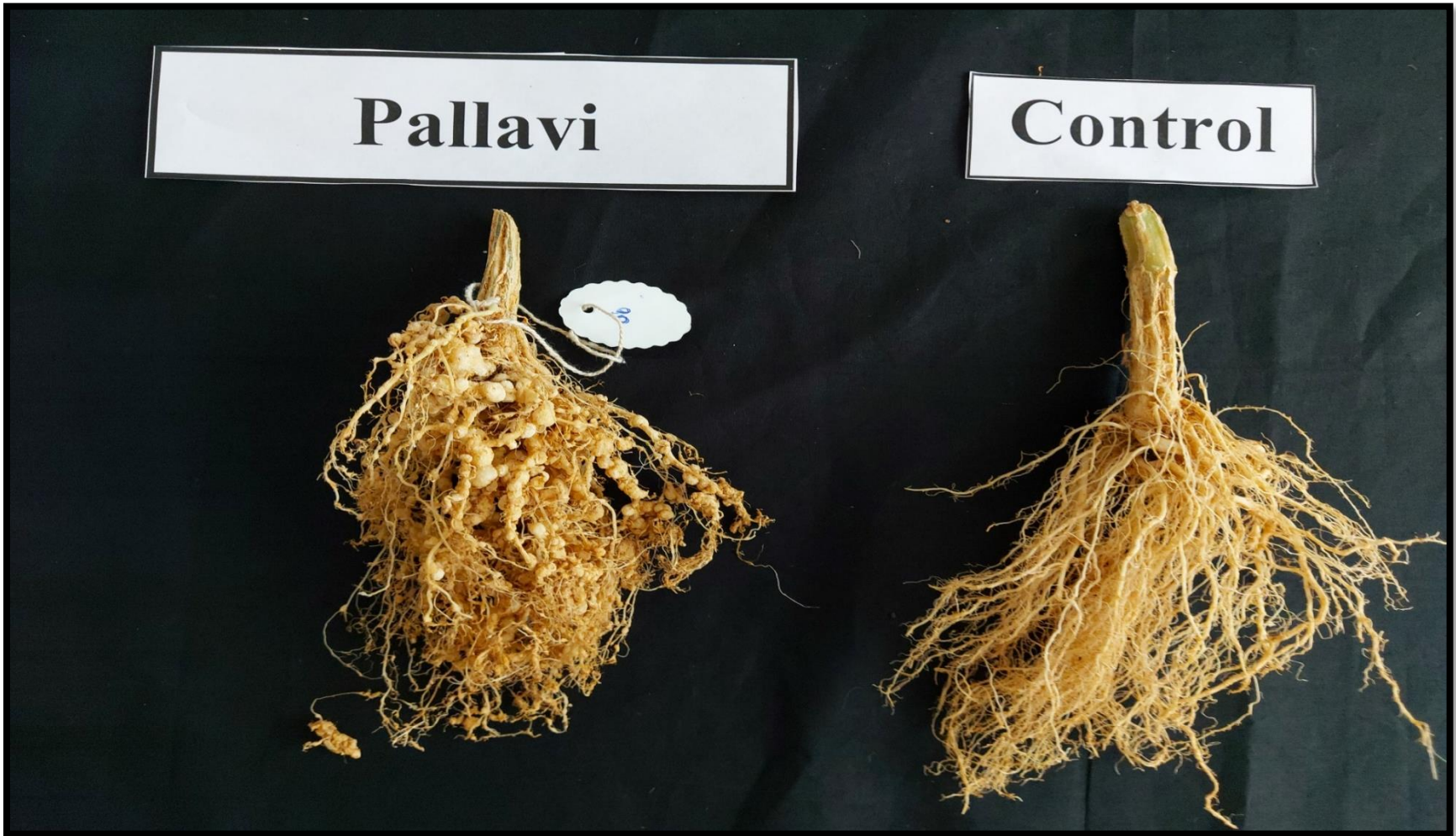


Plate 6: Effect of root-knot nematode (*Meloidogyne incognita*) on susceptible cucumber variety



A



B

Plate 7: Combined (A) Cobb's sieving method (B) Baermann's funnel method for extraction of root-knot nematode, *Meloidogyne incognita* from soil samples

4.3 Management of root-knot nematode (*Meloidogyne incognita*) in cucumber under polyhouse condition

To achieve the objective of management of root-knot nematode (*M. incognita*) in cucumber a pot experiment was conducted in the polyhouse condition at Department of Plant Pathology, College of Horticulture Bengaluru, GKVK campus Bengaluru. The efficacy of different bio agents viz., *Trichoderma harzianum*, *Pochonia chlamydospora* and *Pseudomonas fluorescens* and nematicide Velum prime (Fluopyram 400 SC) were tested against root-knot nematode (*M. incognita*) in single and in combination treatments. Inoculated control was maintained as check. The variety Pallavi was selected for this experiment as it was highly susceptible for *M. incognita* infestation compared to other varieties; it was selected for further management studies. (Plate 3)

A pot experiment was laid out by using completely randomized design (CRD) with three replications. Total of thirteen treatments were made by single and combination of bio agent and nematicide along with check (untreated control).

Cucumber seedlings (Pallavi variety) were raised in pro tray filled with coco peat. Sterilized soil filled in cement pots and cucumber variety was replicated three times and transplanted in pots. Before transplanting the cucumber seedlings, bio agents viz., *Trichoderma harzianum*, *Pochonia chlamydosporia*, *Pseudomonas fluorescens*, and the chemical Velum prime (Fluopyram 400 SC) and their combinations were applied. Freshly hatched 2nd stage juveniles (J₂) of *Meloidogyne incognita* were inoculated @1500 J₂ / 10 ml sterile water to 4-5 kg of the soil inside each pot two weeks after transplanting of seedlings. The observations related to plant growth parameters viz., plant height, fresh shoot weight, number of leaves, dry shoot weight, and dry root weight, fresh root weight and yield per plant, nematode population in soil and root system, number of galls and egg masses were recorded after 90 days of inoculation (Plate 8).

4.3.1 Plant growth parameters

The efficacy of various treatments on various plant growth parameters *viz.*, number of leaves, plant height, dry shoot weight, fresh shoot weight, and dry root weight, fresh root weight and yield per plant of *M. incognita* infected plants are presented in Tables 7 and 8 and Figure 2 and 5.

4.3.1.1 Plant height

The results showed that all the treatments exhibited significantly higher plant height compared to control. The maximum plant height (297.00cm) was recorded in *P. chlamydosporia* + Fluopyram (T₉) treated plants. The next best results were recorded (287.3cm and 280.6cm) in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) and *T. harzianum* + *P. chlamydosporia* + *P. fluorescens* (T₁₀) treated plants respectively. Combination of bio-agents (*T. harzianum*, + *P. chlamydospora*), (*T. harzianum* + *P. fluorecens*) and chemical (Fluopyram) treated plants showed intermediate plant height 249.67, 225.33 and 269.67 cm respectively. While minimum plant height (125.67cm) was recorded in untreated control.

4.3.1.2 Number of leaves

The results revealed that all the treatments showed significantly greater number of leaves per plant compared with inoculated control. The maximum number of leaves (87.33) per plant were recorded in *Trichoderma harzianum* + *Pachonia chlamydosporia* along with Fluopyram (T₁₁) treated plants followed by T₁₂ (*T. harzianum* + *P. chlamydosporia* + *P. fluorecens* + Fluopyram) (80.67) treated plants. Bio-agents in combination with one another and combination with nematicide showed a greater number of leaves per plant rather than individual bio control agent application. The combination treatments *viz.*, T₈ (63.67), T₁₀ (61.33) and T₇ (53.67) recorded intermediate number of leaves compared with individual bio agents *viz.*, *T. harzianum* (55.33), *P. chlamydosporia* (51.00) and *P. fluorescens* (44.33). Whereas, minimum number of leaves per plant (36.67) were recorded in untreated control.

Table 7: Effect of different treatments on growth of cucumber plants infested by root-knot nematode (*Meloidogyne incognita*)

Treatments	Plant height (cm)	Leaf numbers	Yield of cucumber / 3 plants (g)	% increase over control
T ₁ = <i>Trichoderma harzianum</i>	191.00	55.33	1103.00	59.39
T ₂ = <i>Pochonia chlamydosporia</i>	200.33	51.00	855.00	23.55
T ₃ = <i>Pseudomonas fluorescens</i>	186.67	44.33	930.33	34.44
T ₄ = Fluopyram 400 SC @ 0.13 ml /l of water	269.33	45.67	1344.67	94.32
T ₅ = <i>T. harzianum</i> + <i>P. chlamydosporia</i>	249.67	48.33	1326.33	91.67
T ₆ = <i>T. harzianum</i> + <i>P. fluorescens</i>	225.33	50.33	1476.67	113.39
T ₇ = <i>T. harzianum</i> + Fluopyram 400 SC @ 0.13 ml/l of water	212.00	53.67	2214.33	219.99
T ₈ = <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	217.00	63.67	1202.33	73.75
T ₉ = <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	297.00	52.67	1744.67	152.12
T ₁₀ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	280.67	61.33	2291.67	231.17
T ₁₁ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	287.33	87.33	2783.00	302.17
T ₁₂ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i> + Fluopyram 400 SC@ 0.13 ml /l of water	264.00	80.67	2881.00	316.33
T ₁₃ = Untreated control	125.67	36.67	692.00	0.00
S. Em ±	6.35	4.15	86.53	
CD at 5%	18.56	12.12	252.93	

*Rate of application of each bio-control agents are 10 g / kg soil and initial nematode population (INP) is 1500 J₂ / 5 kg of soil

Table 8: Effect of different treatments on fresh and dry shoot and root weight of cucumber plants infested by *Meloidogyne incognita*

Treatments	Fresh shoot weight (g)	Dry shoot weight (g)	Fresh root weight(g)	Dry root weight (g)	Root length (cm)
T ₁ = <i>Trichoderma harzianum</i>	274.00	41.87	8.27	2.30	17.33
T ₂ = <i>Pochonia chlamydosporia</i>	294.33	32.83	6.50	2.70	16.83
T ₃ = <i>Pseudomonas fluorescens</i>	260.67	40.33	6.20	1.90	14.60
T ₄ = Fluopyram 400 SC @ 0.13 ml /l of water	266.33	69.77	9.30	2.74	18.00
T ₅ = <i>T. harzianum</i> + <i>P. chlamydosporia</i>	310.00	65.47	8.00	2.93	29.00
T ₆ = <i>T. harzianum</i> + <i>P. fluorescens</i>	373.00	71.43	10.33	2.80	28.13
T ₇ = <i>T. harzianum</i> + Fluopyram 400 SC @ 0.13 ml/l of water	356.00	107.20	9.03	2.97	19.50
T ₈ = <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	318.67	68.17	13.17	4.00	18.17
T ₉ = <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	365.33	104.77	9.63	2.87	20.27
T ₁₀ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	404.67	97.20	11.60	3.90	23.53
T ₁₁ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	438.33	115.60	15.63	3.97	26.17
T ₁₂ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i> + Fluopyram 400 SC@ 0.13 ml /l of water	417.00	144.73	12.97	3.14	21.27
T ₁₃ = Untreated control	182.67	19.67	50.43	16.17	11.20
S. Em ±	14.70	11.15	1.22	0.44	1.46
CD at 5%	42.96	32.58	3.55	1.29	4.27

*Rate of application of each bio-control agents are 10 g / kg soil and initial nematode population (INP) is 1500 J₂ / 5 kg of soil

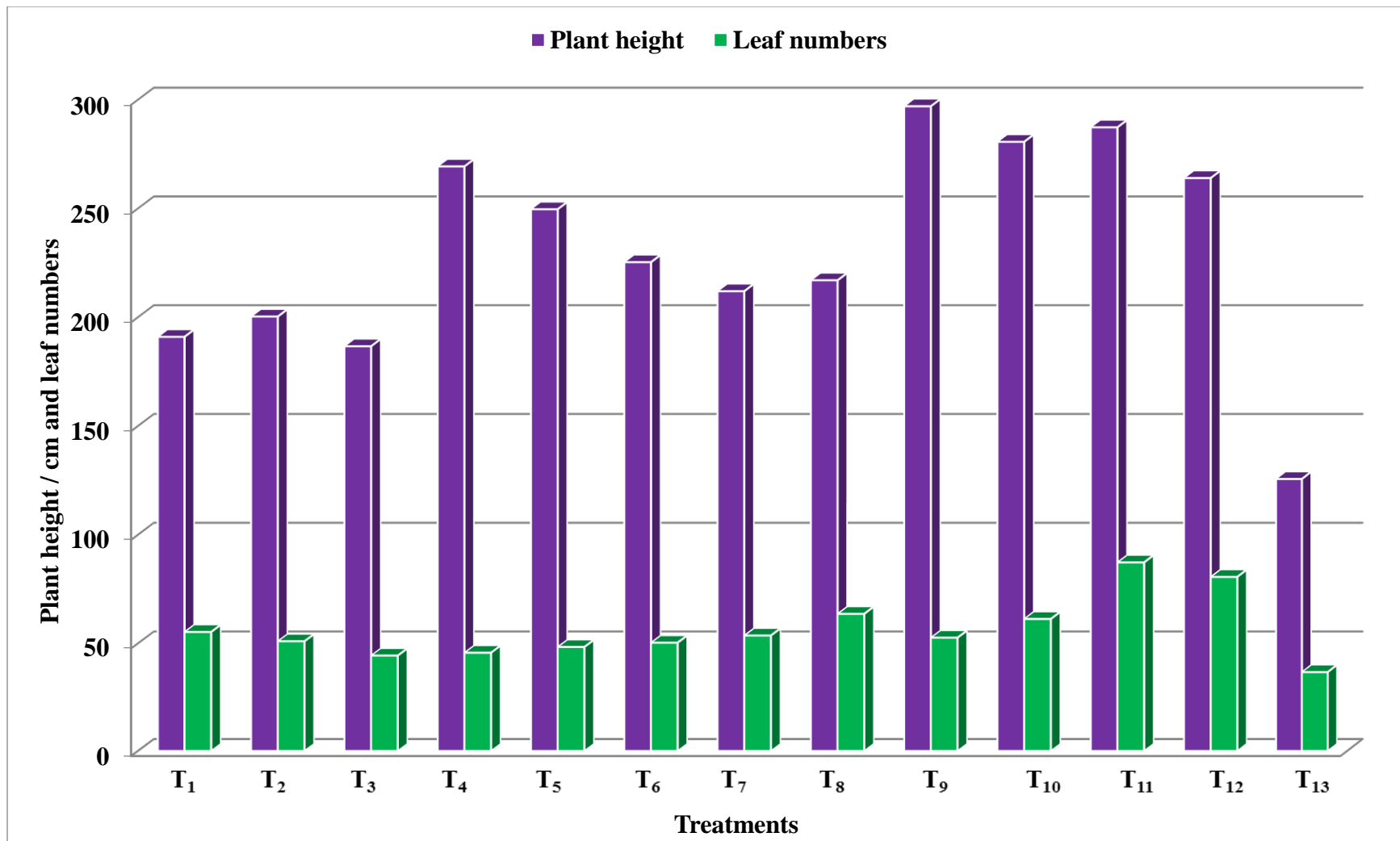


Fig. 2: Effect of different treatments on plant growth of cucumber plants infested by root-knot nematode *Meloidogyne incognita*

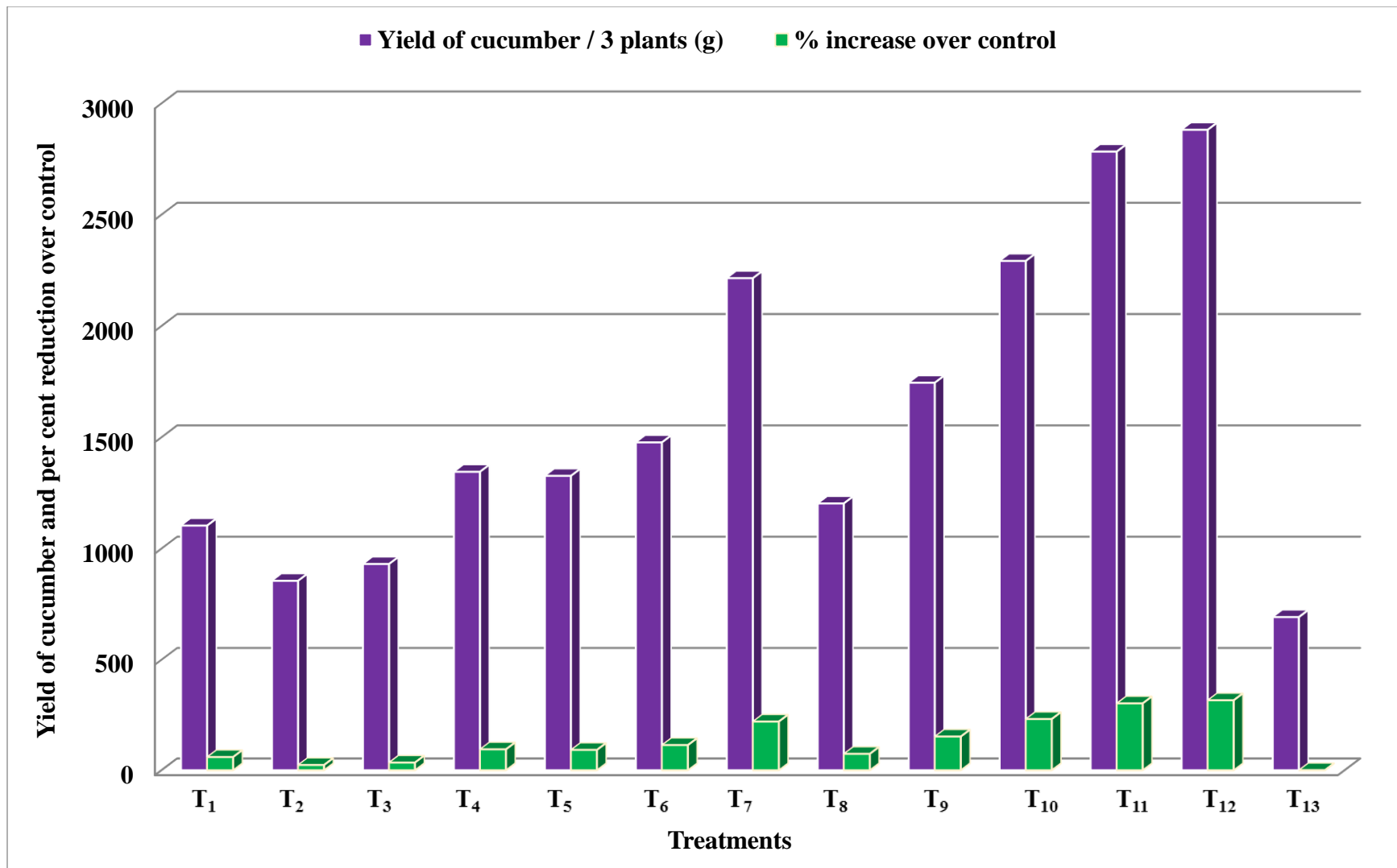


Fig. 3: Effect of different treatments on yield of cucumber plants infested by root-knot nematode *Meloidogyne incognita*

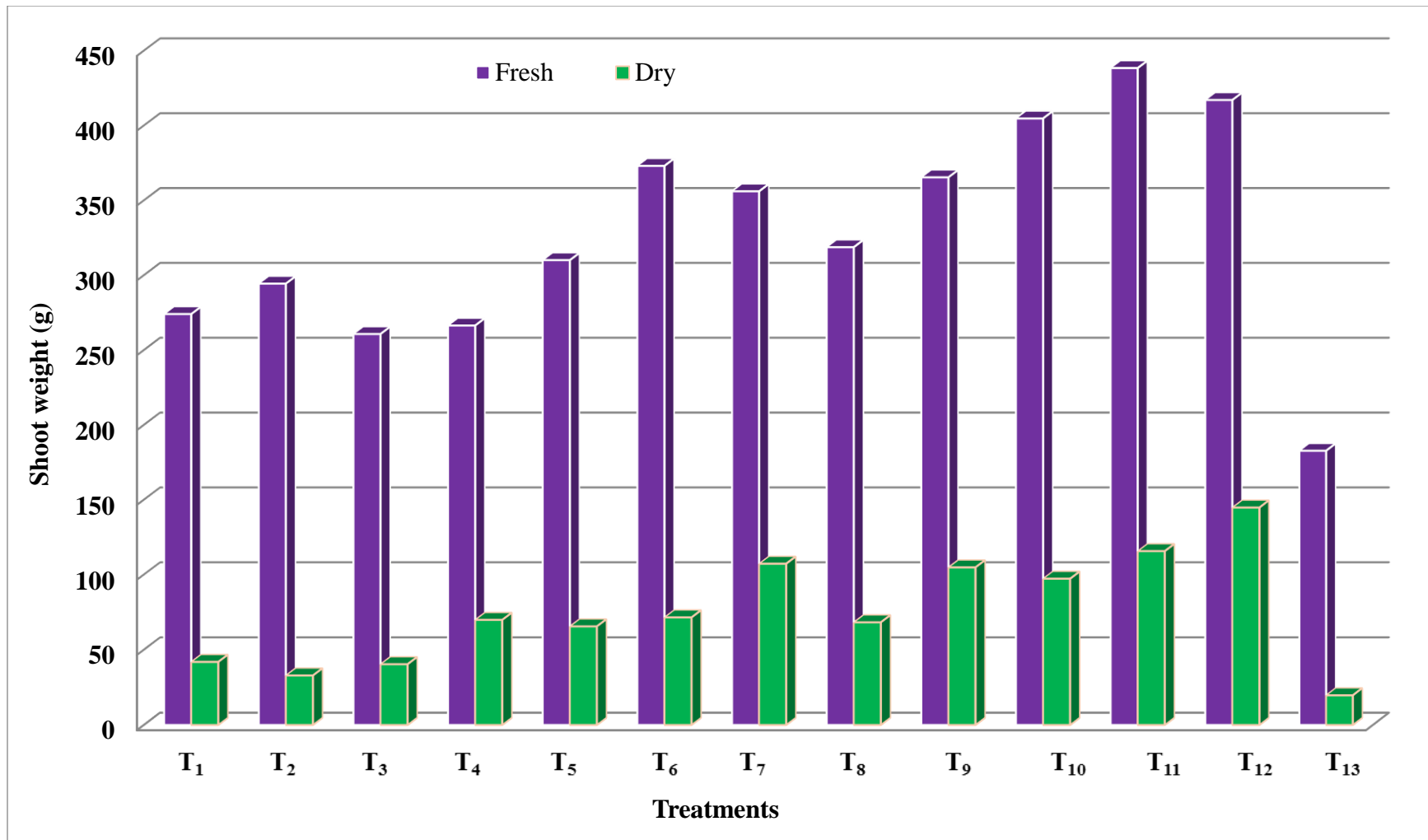


Fig. 4: Effect of different treatments on fresh and dry shoot weight of cucumber plants infested by root-knot nematode *Meloidogyne incognita*

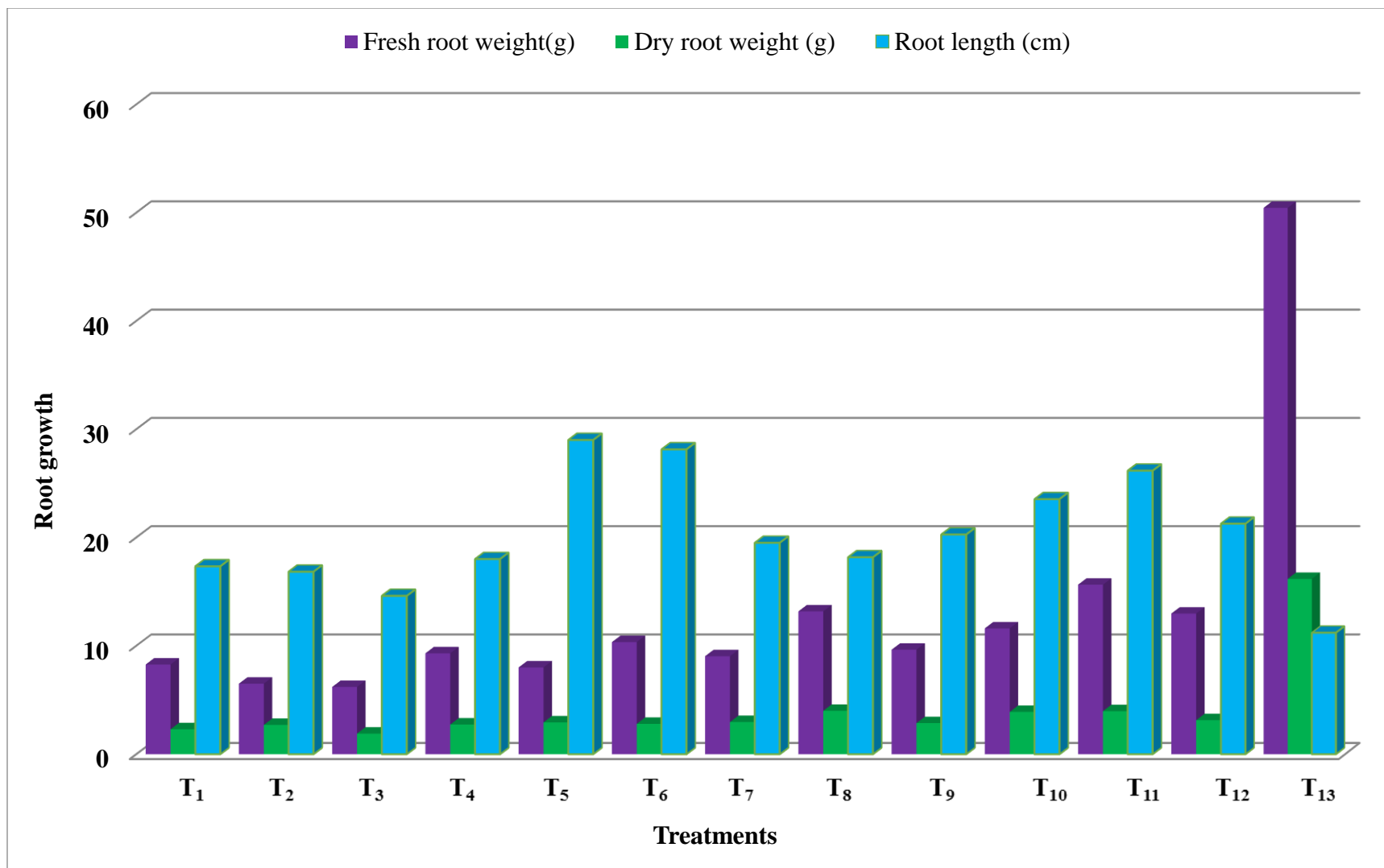


Fig. 5: Effect of treatments on root growth of cucumber plants infested by root-knot nematode *Meloidogyne incognita*



A



B

Plate 8: General view of the cucumber root-knot nematode management under polyhouse condition (A) 10 days after transplanting (B) 75 days after transplanting

4.3.1.3 Yield of cucumber

The maximum fruit yield (2881.00 g) was recorded in combination treatment *i.e.* *T. harzianum* + *P. chlamydosporia* + *P. fluorecens* + Fluopyram (Treatment 12) treated plants followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (2783.00 g) treated plants (Treatment 11). All the treatments showed significantly higher yield than control. While minimum fruit yield (692.00) was recorded in untreated control plants.

4.3.1.4 Plant weights

The results of fresh and dry shoot and root were given in table 8 along with root length (Plate 10).

1. Fresh shoot weight (g)

The fresh shoot weight ranged from 438.33 g to 182.67 g. The data of fresh shoot weight was recorded at the time of harvest. Maximum fresh shoot weight (438.33 g) of the plant was recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) treated plants followed by *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (417.00 g) treated plants (T₁₂). All the treatments were significantly superior than control plants, while minimum fresh shoot weight plant (182.67 g) was recorded in untreated control (T₁₃).

2. Dry shoot weight (g)

The dry shoot weight was recorded after dried in oven and ranged from 144.73 g to 19.67 g. All the treatments exhibited significantly higher dry shoot weight compared with inoculated control. Maximum dry shoot weight (144.73 g) was observed in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (115.60 g) and *T. harzianum* + Fluopyram (107.20 g) treated plants. Whereas, minimum dry shoot weight (19.67 g) was recorded in untreated control (T₁₃).

3. Fresh root weight (g)

The observation of fresh root weight was recorded immediately after harvest. The fresh root weight ranged from 6.20 g to 50.43 g. Maximum fresh root weight (50.43 g) was recorded in inoculated control plants, whereas, minimum fresh root weight was observed in *P. florescens* treated plants.

4. Dry root weight (g)

The observation of dry root weight was recorded after harvest and dried in oven till it obtained constant weight. The dry root weight ranged from 2.30 g to (16.17 g). The control plants (T₁₃) recorded significantly higher dry root weight (16.17 g) followed by *P. chlamydosporia* + *P. flourescens* (4.00 g) treated plants (T₈). Whereas minimum dry root weight (1.90 g) was recorded in T₃ (*P. flourescens*) treated plants.

5. Root length (cm)

The root length of each treatment was recorded after harvesting of plants. The total root system was uprooted, washed thoroughly with tap water, shade dried and root length was recorded by using scale. From the results, it was observed that maximum root length (29.00 cm) was recorded in *T. harzianum* + *P. chlamydosporia* (T₅) treated plants. The next best results were recorded in *T. harzianum* + *P. fluorecens* (28.13 cm) (T₆) and *T. harzianum* + *P. chlamydosporia* + Fluopyram (26.17 cm) treated plants (T₁₁). All the treatments were superior compare control. Minimum root length (11.20 cm) was recorded in untreated control (T₁₃).

4.3.2 Nematode parameters

The results of the efficacy of treatments on parameters viz., nematode population / 250g of soil, nematode population / 5 g of root, number of galls / root system and number of egg masses / root system were recorded, analyzed and the data is presented in the table 9 and 10, Figures 6 and 7 .

Table 9: Effect of different treatments on soil and root population of root-knot nematode (*Meloidogyne incognita*) under polyhouse condition

Treatments	Nematode population / 250 g of soil	Percent reduction over control	Nematode population / 5 g of root	Percent reduction over control
T ₁ = <i>Trichoderma harzianum</i>	218.00	67.51	104.67	45.96
T ₂ = <i>Pochonia chlamydosporia</i>	219.00	67.36	134.67	30.47
T ₃ = <i>Pseudomonas fluorescens</i>	220.00	67.21	119.67	38.21
T ₄ = Fluopyram 400 SC @ 0.13 ml /l of water	161.00	76.01	83.00	57.14
T ₅ = <i>T. harzianum</i> + <i>P. chlamydosporia</i>	203.00	69.75	88.67	54.22
T ₆ = <i>T. harzianum</i> + <i>P. fluorescens</i>	210.00	68.70	68.00	64.89
T ₇ = <i>T. harzianum</i> + Fluopyram 400 SC @ 0.13 ml/l of water	148.00	77.94	51.00	73.67
T ₈ = <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	193.00	71.24	75.67	60.93
T ₉ = <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	127.00	81.07	55.33	71.43
T ₁₀ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	164.00	75.56	49.33	74.53
T ₁₁ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	123.00	81.67	37.33	80.72
T ₁₂ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i> + Fluopyram 400 SC @ 0.13 ml /l of water	110.00	83.61	31.33	83.82
T ₁₃ = Untreated control	671.00	0.00	193.67	0.00
S. Em ±	20.22		6.92	
CD at 5%	59.10		20.23	

*Rate of application of each bio agents are 10 g / kg soil and initial nematode population (INP) is 1500 J₂ / 5 kg of soil

Table 10: Effect of different treatments on nematode population of *Meloidogyne incognita* under polyhouse condition

Treatments	Number of galls / root system	Per cent reduction over control	Number of egg masses/ root system	Per cent reduction over control
T ₁ = <i>Trichoderma harzianum</i>	112.56	76.77	18.54	77.14
T ₂ = <i>Pochonia chlamydosporia</i>	133.00	72.58	25.00	69.39
T ₃ = <i>Pseudomonas fluorescens</i>	139.48	71.20	20.47	25.31
T ₄ = Fluopyram 400 SC @ 0.13 ml /l of water	87.00	91.00	12.00	85.31
T ₅ = <i>T. harzianum</i> + <i>P. chlamydosporia</i>	96.33	80.14	11.33	86.12
T ₆ = <i>T. harzianum</i> + <i>P. fluorescens</i>	102.33	78.90	9.00	88.98
T ₇ = <i>T. harzianum</i> + Fluopyram 400 SC @ 0.13 ml/l of water	58.12	87.90	6.33	92.25
T ₈ = <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	105.36	78.21	13.61	83.27
T ₉ = <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	70.51	85.43	7.00	91.43
T ₁₀ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i>	74.33	84.67	8.14	89.39
T ₁₁ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + Fluopyram 400 SC @ 0.13 ml/l of water	44.42	90.79	5.21	93.06
T ₁₂ = <i>T. harzianum</i> + <i>P. chlamydosporia</i> + <i>P. fluorescens</i> + Fluopyram 400 SC @ 0.13 ml /l of water	27.00	94.43	2.35	96.37
T ₁₃ = Untreated control	485.00	0.00	81.67	0.00
S. Em ±	12.801		2.69	
CD at 5%	37.42		7.86	

*Rate of application of each bio-control agents are 10 g / kg soil and initial nematode population (INP) is 1500 J₂ / 5 kg of soil

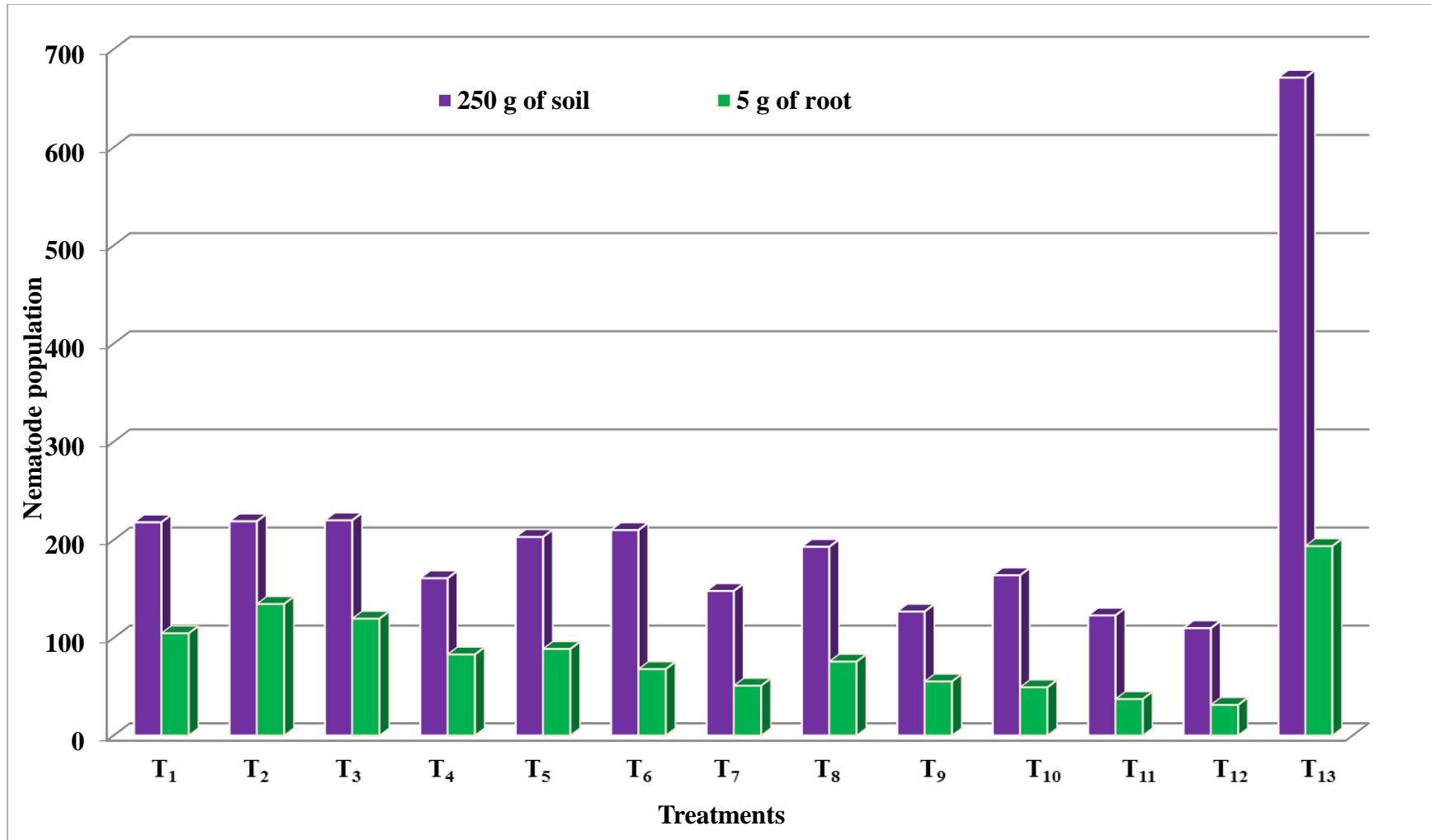


Fig. 6: Effect of different management methods on reduction of *M. incognita* in soil and root of cucumber plants under polyhouse condition

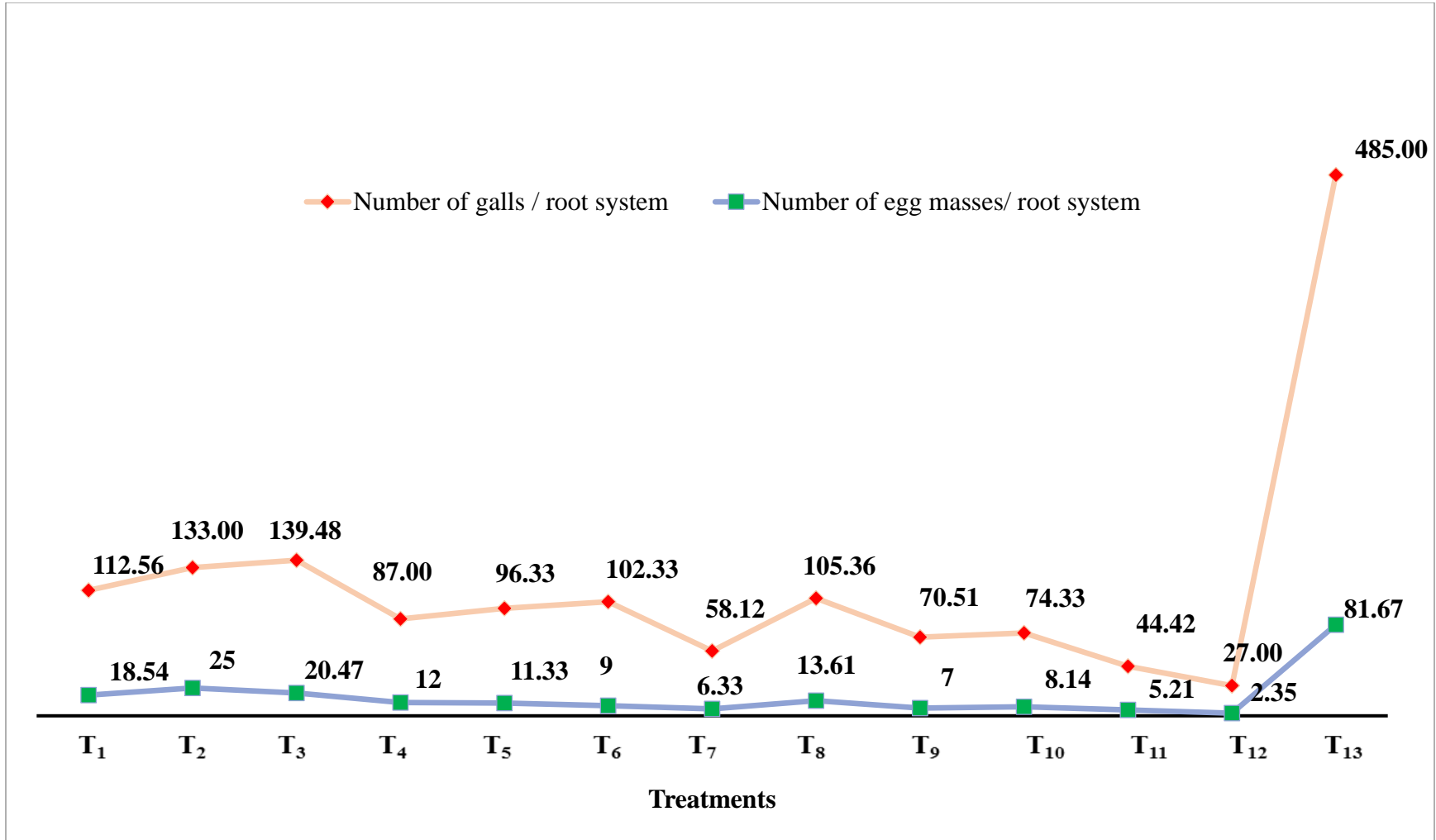


Fig. 7: Effect of different management methods on reduction of galls numbers and egg masses of *Meloidogyne incognita* on cucumber plants under polyhouse condition

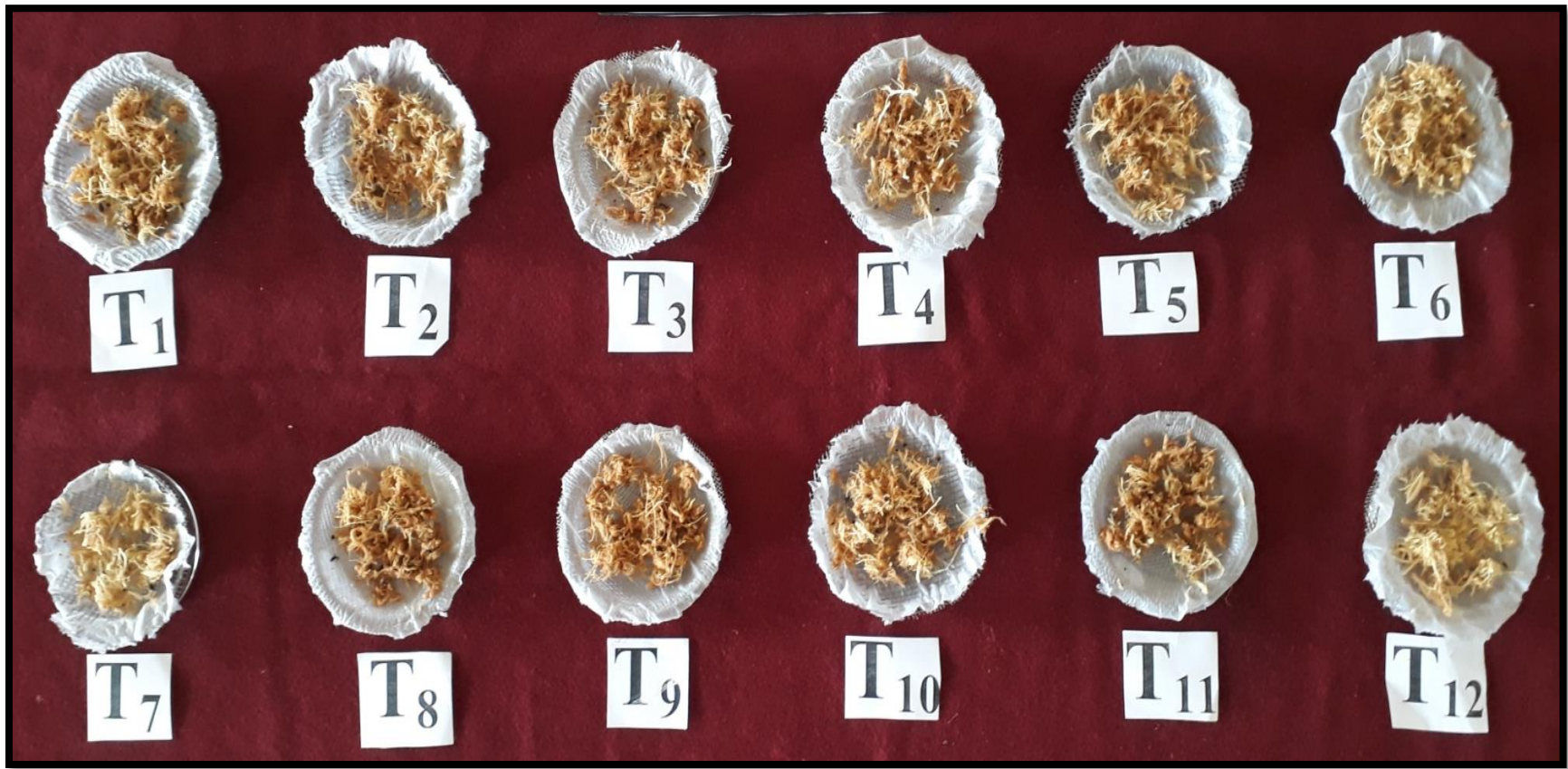


Plate 9: View of nematode extraction of 5 g. root samples from infested root-knot nematode in cucumber plants roots



Plate 10: Effect of different treatments management methods on root-knot nematode *M. incognita* under polyhouse condition

4.3.2.1 Nematode population / 250 g of soil

The population of *M. incognita* per 250 g of soil was recorded after harvest. The lowest population (110 / 250g soil) was recorded in *Trichoderma harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) treated plants with reduction of 83.61 % over inoculated control (T₁₃). The next best results were recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) treated plants with population of 123 / 250 g of soil with 81.67 % reduction over inoculated control (T₁₃). However, in inoculated control (671 / 250 g) recorded maximum nematode population.

4.3.2.2 Nematode population/ 5 g of root

The population of *M. incognita* per 5 g of root was recorded immediately after uprooting the root. The maximum decrease of nematode population / 5 g of root (31.33) was recorded in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) with 83.82% reduction over control. Followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (37.33 / 5g of root) with 80.72% reduction over control. whereas, in inoculated control plants recorded maximum nematode population (193.67 / 5g of root). (Table 9, Figure 6 and Plate 9).

4.3.2.3 Number of galls / root system

The results of the efficacy of various treatments on number of galls / root system were presented in the table 10. The results revealed that, all the treatments were significantly lower gall numbers than inoculated control (T₁₃). Among the treatments tested, *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) treated plants showed maximum reduction in number of galls / root system (27.00) and which is superior than over other treatments. The next best results (T₁₁) were reported in *T. harzianum* + *P. chlamydosporia* + Fluopyram (44.42) treated plants. The untreated control recorded significantly more galls per root system (485.00) (Plate 11).

4.3.2.4 Number of egg masses / root system

The effect of various treatments on the number of egg masses formed per root system was recorded at the end of experiment. The analyzed data is presented in table 10,

Fig 7 and plate 12. All the treatments displayed significant results compared with untreated control. The treatments, *T. harzianum* + *P. chlamydosporia*+ *P. flourescens* + Fluopyram (T₁₂) treated plants recorded fewer number of egg masses per root system (2.67) with 96.37% reduction over untreated control (T₁₃). However, the plants which recorded combination of bio-agents along with nematicide showed intermediate effect. The treatments *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) and *T. harzianum* + Fluopyram (T₇) recorded less number of egg masses per root system (5.67 and 6.33) with 93.06 and 92.25% reduction over control respectively. However, bio-agents (*T. harzianum* + *P. chlamydosporia* + *P. flourescens*) treated plants (T₁₀) recorded less number of egg masses per root system (8.67) which is superior with all treatments except those treatments which includes bio-agents along with chemical, while the inoculated control (T₁₃) recorded maximum number of egg masses per root system (81.67).

**T₁₁****T₁₃**

Plate 11: Effect of different treatments at reduction of galls on cucumber root systems of T₁₁ and Compression with T₁₃ (Untreated control)

**T₁₂****T₁₃**

Plate 12: Effect of different treatments at reduction of galls on cucumber root systems of T₁₂ and comparison with T₁₃ (Untreated control)



Discussion

V. DISCUSSION

The experimental results of the effect of *Meloidogyne incognita* on cucumber growth and yield and management of root-knot nematode are discussed briefly in this chapter. This research confirmed the experimental results of potential of combining chemical nematicides and bio-agents to suppress *M. incognita* on cucumber growth and yield. Combining bio-agents and chemicals for management practices are a good option to reduce disease and secure yield.

5.1 Survey for root-knot nematode species associated with cucumber in polyhouse in Bengaluru rural district

A survey was conducted to know the distribution of the root-knot nematode species associated with cucumber grown in polyhouse in different locations viz., Doddaballapur taluk, such as Hadonahalli, Bachhahalli, Shivalingapura, Naraganahalli, Shivalingapura villages Chikkaballapur district Gummanahalli, Chadalapura, Bandahalli villages and Devanahalli taluk; Vijayapura, Doddathamangala of Bengaluru rural district.

The soil and root samples were analyzed and it revealed that root-knot nematode, *M. incognita* was the predominant nematode (27-583 / 250 g soil) followed by *M. javanica* spp. (42 / 250 g soil), *M. arenaria* spp. (10 / 250 g soil) and *M. hapla* spp. (01 / 250 g soil) respectively.

The highest population of *M. incognita* (583 / 250 g soil) was recorded in Hadonahalli village of Doddaballapur taluk followed by Gummanahalli of Chikballapur taluk (381 / 250 g soil) and Vijayapura of Devanahalli taluk (238 / 250 g soil).

The root samples of cucumber were also examined for nematode population. The maximum population of *M. incognita* was noted in root samples collected from Hadonahalli village of Doddaballapur taluk (117 / 5 g root). The next best recorded by Gummanahalli of Chikkaballapur taluk (93 / 5 g root), Vijayapura of Devanahalli taluk (78 / 5 g root) and GKVK of Bengaluru taluk (75 / 5 g root). The least population (19 / 5 g root) was recorded in Kasvanahalli of Bengaluru.

The similar line of study was studied by Tariq *et al.* (2017) who reported that root-knot nematode (RKN) damaged more than 130 vegetable crops. Similarly, Singh *et al.* (2015) also revealed that *M. incognita* was found to be more predominant with population range (37-2547 / 200 cc soil) in major vegetable crops grown in polyhouse.

The results are also on par with Patil *et al.* (2017) who had reported that *M. incognita* infects different vegetable crops *viz.*, tomato, chilli, bell pepper and cucumber grown under polyhouse conditions. Similarly, Anupam *et al.* (2018) reported that vegetables grown under polyhouse / protected condition were majorly infected by root-knot nematode with root gall index more than 3. Khan *et al.* (2000) also stated that different species of root-knot nematode (*M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla*) were associated with cucumber, okra, pepper and tomato in Uttar Pradesh, India. Similar findings were found by Singh *et al.* (2012) who revealed that, root-knot nematodes were more frequently associated with okra in Jammu & Kashmir, India. The same line of results were mentioned by Bhati and Baheti 2020, who reported that 100 per cent occurrence of root-knot nematode with 40 to 142 galls / 5 g roots and 26 to 135 egg masses / 5 g root was observed in cucumber plants grown under polyhouse / protected conditions in different locations of Rajasthan.

The results were also in conformity with Chandel *et al.* (2010) who recorded *Meloidogyne incognita*, *Helicotylenchus dihystra* and *Pratylenchus* spp. associated with major vegetable crops (cucurbits, sweet pepper, tomato, carnation and cauliflower) grown in 214 greenhouses from Himachal Pradesh. They stated that *Meloidogyne incognita* population in soil and root were more compared to *Helicotylenchus dihystra* and *Pratylenchus* spp.

5.2. Screening of cucumber varieties for root-knot nematode (*Meloidogyne incognita*)

A total of 19 different cucumber varieties / hybrids namely, Sun-Star Rz, Kingstar Rz, Deltastar Rz, Falconstar Rz, Captainstar Rz, DWR Long, Green long, Shalini, Nalini, NS-404, Sitha ashoka, Legend cucumber, Green cucumber, Swadish cucumber, Snow white, Sunny-85, Pallavi, Kohinoor and Swarna ageti were screened against root-knot

nematode (*M. incognita*) under polyhouse conditions. From the results, it was revealed that all the screened varieties / hybrids were highly susceptible and none of the cultivars were found highly resistant, resistant or immune.

The results revealed that, among all the varieties / hybrids, Pallavi hybrid had maximum number of galls 420.6 per plant and 517.33 nematodes / 250 g of soil with gall index of 5.0 followed by Sunstar Rz with 412 galls and 493 nematodes / 250 g of soil with gall index of 5.0 representing they are very susceptible to *M. incognita*. Whereas, Green long recorded least number of galls (121.3) per plant and 88 nematodes / 250 g of soil with gall index of 5.

Similar results were reported by Krishnaveni and Subramanian (2003) who stated that cucumber hybrid Green long was susceptible to root-knot nematode and exhibited the symptoms of stunted growth, yellowing and drooping of leaves resulting reduction in plant growth and yield.

The same line of results was reported by Pavithra (2013) who revealed Green long susceptible to root-knot nematode with maximum number of galls and nematodes per plant (215.67 and 221.67 at 60 days and at harvest respectively).

Also similar result (Li and Chan 2017) screened 21 cucumber germplasm and reported seedlings exhibited little resistance to *M. incognita*, including the wild germplasm Commum CAT, which they expected would be more resistant. Most seedlings were classed as susceptible or highly susceptible to *M. incognita*, and Jin *et al.* (2010) used galls index to evaluate the resistance of cucumber rootstocks and identified two resistance and susceptibility types.

5.3. Management of root-knot nematode (*Meloidogyne incognita*) under polyhouse condition

A study was conducted to test the efficacy of different bio agent's *viz.*, *Trichoderma harzianum*, *Pochnia chlamydospora* and *Pseudomonas fluorescens* and nematicide Fluopyram 400 SC against root-knot nematode (*M. incognita*) in single and in

combination treatments. Inoculated control was maintained as check. As the variety Pallavi was highly susceptible to *M. incognita* compared to other varieties, it was selected for management studies.

5.3.1. Plant parameters

The maximum plant height (297.00 cm) was recorded in *Pachonia chlamydosporia* + Fluopyram (Treatment 9) treated plants. The subsequent best results were recorded (287.3 cm and 280.6 cm) in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) and *T. harzianum* + *P. chlamydosporia* + *P. fluorescens* treated plants respectively (T₁₀). Combination bio-agents (*T. harzianum*, + *P. chlamydospora*) (T₅), (*T. harzianum* + *P. fluorecens*) (T₆) along with chemical (Fluopyram) treated plants showed intermediate plant height 249.67, 225.33 and 269.67 cm respectively.

The maximum numbers of leaves (87.33) per plant were recorded in *T. harzianum* + *P. chlamydosporia* along with Fluopyram treated plants (T₁₁) followed by *T. harzianum* + *P. chlamydosporia* + *P. fluorecens* + Fluopyram (80.67) treated plants (T₁₂).

The maximum fruit yield (2881.00 g) was recorded in combination treatment *i.e.* *T. harzianum* + *P. chlamydosporia* + *P. fluorecens* + Fluopyram treated plants (T₁₂) followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (2783.00 g) treated plants (T₁₁).

Maximum fresh shoot weight (438.33g) and dry shoot weight (144.73g) was recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram treated plants (T₁₁) followed by *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (417.00g) and (107.20g) treated plants (T₁₂) respectively.

The fresh root weight recorded with in the range between from 6.20 g to 50.43 g Maximum fresh root weight (50.43 g) was recorded in inoculated control plants and maximum weight (16.17 g) was also recorded in inoculated control (T₁₃) followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (3.97g) treated plants.

The maximum root length (29.00cm) was recorded in *T. harzianum* + *P. chlamydosporia* treated plants (T₅). The next best results were recorded in *T. harzianum* + *P. fluorecens* (28.13 cm) (T₆) and *T. harzianum* + *P. chlamydosporia* + Fluopyram (26.17 cm) treated plants (T₁₁).

5.3.2. Nematode parameters

The maximum reduction of nematode population (110 / 250g of soil) was recorded in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) treated plants with 83.61 % reduction over inoculated control. The next best results were recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) treated plants with population of 123 / 250 g of soil with 81.67 % reduction over untreated control.

The minimum reduction of nematode population / 5 g of root (31.33) was recorded in *T. harzianum* + *P. chlamydosporia*+ *P. flourescens*+ Fluopyram (T₁₂) with 83.82 % reduction over inoculated control and *T. harzianum* + *P. chlamydosporia*+ *P. flourescens* + Fluopyram treated plants showed maximum reduction of number of galls / root system (27.00). *T. harzianum* + *P. chlamydosporia*+ *P. flourescens* + Fluopyram treated plants recorded fewer number of egg masses per root system (2.67) with 96.73 % reduction over untreated control.

The same line of results were reported by Jena *et al.* (2017); Ishrat Naz *et al.* (2020); Azeem *et al.* (2020) who reported that application of bio-agents *T. harzianum* and *P. chlamydosporia* increases the plant growth parameters *viz.*, plant height, fresh and dry shoot weight, number of leaves and yield of the plant and minimize the root-knot nematode galls and population. Similar results were observed by Ali and Zewain (2018) who reported that *T. harzianum* improves the plant height, fresh and dry shoot weight.

Sharon *et al.* (2007) showed that eggs adhered with *Trichoderma* conidia became nonviable, thus decreasing the exclusion rate. It could grow on the gelatinous matrix, which enhanced conidium germination. A biomimetic system based on gelatinousmatrix-coated nylon fibers demonstrated the role of the matrix in parasitism. *T. harzianum* is a ubiquitous free living mycoparasite that can be applied direct to the soil or on seedlings,

associated or not to organic compounds, aiming at the control of soil-borne fungal diseases in protected crops. Further-more, Sharon *et al.* (2001) carrying out *in-vitro* bioassays, verified that extracts of *T. harzianum* released in soil were capable to immobilize J₂ of *M. javanica* and reduce egg viability. These results suggest that there are both mechanisms of fungal parasitism and lethal activity of secondary metabolites on nematodes. Moreover, the increase in crop yield provided by *T. harzianum* and its nematicidal effect add advantages to its use.

Trichoderma harzianum is nematophagous fungi and is important bio agents because they possess the potential to reduce the population of root-knot nematodes (Haran *et al.*, 1996). Species of *Trichoderma*, with special attention to *Trichoderma harzianum* Sood *et al.* (2020) (Ascomycota: Hypocrea-ceae), are well-known to present biocontrol activity against several plant pathogenic fungi through various mechanisms: antibiosis, competition, mycoparasitism, and enzymatic hydrolysis (Harman *et al.*, 2004; Howell, 2003). Moreover, these fungi may also promote plant growth and induce systemic resistance in plants (Inbar *et al.*, 1994; Yedidia *et al.*, 1999). For those reasons, *T. harzianum* shows a tremendous potential for the bio-control of root-knot nematodes.

The reason behind increase of plant growth parameters is, bio-agents enhances plant growth metabolism and release toxic and anti-microbial substances which inhibit development of nematode population and galls (Jena *et al.*, 2017; Pocurull *et al.*, 2020; Baker *et al.*, 1986. Similarly, Ghahremani *et al.*, 2019, reported application of *P. chlamydosporia* reduces the root-knot nematode (*M. incognita*) population and infective juveniles. *P. chlamydosporia* inhibits the growth and development of root-knot nematode by activating the SA - mediated defence pathway.

Pochonia chlamydosporia wraps itself around the eggs, penetrate the egg shell and destroys eggs with the help of proteases enzymes. Esteves, *et al.* (2009); Kerry (2000). *P. chlamydosporia* isolated from root-knot nematodes (*Meloidogyne* spp.) Hidalgo-Diaz (2000). And cyst nematodes such as *Heterodera* spp., *Globodera* spp. Crump and Kerry (1977). This bio-agent can maintain its population densities and

survival up to five months in *in-vitro*, which makes this fungus suitable bio-agent. Atkins, *et al.* (2003).

The application of *Pseudomonas fluorescens*, increase the plant growth parameters *viz.*, shoot length, root length, dry shoot weight and dry root weight, fresh shoot weight, fresh root weight. It was mentioned that *P. fluorescens* plays a role in growth promotion by production of plant hormones and other growth-promoting substances such as auxins (Loper and Schroth, 1986) and gibberellins (Ramamoorthy and Samiyappan, 2001).

It also reduces the egg mass number and population of root knot-nematode in cucumber under protected conditions. (Patil *et al.*, 2017). Application of *P. fluorescens* significantly increased the activity of defence related enzymes *viz.*, peroxidase, polyphenol oxidase, phenylalanine ammonia lyase and total phenol content in the plant roots which was confirmed by the presence of bands in the Native PAGE and SDS Page analysis. These defence enzymes induced systemic resistance of the plants against nematodes and reduced nematode population in the roots.

In this study pots experiments fluopyram treatment at the recommended rate produced slight phytotoxicity on cucumber. The phytotoxic effect, however, did not result in poor vigor of plants. Phytotoxicity can result in vegetable crops. Usually when the higher rates of nematicides are applied as a soil drench or foliar application.

The same line of results was reported by Abolfazl *et al.*, 2019, on cucumber that fluopyram as a soil drench at 0.5 l/a.i. / ha on cucumber had a phytotoxic effect as compared with the drip application which had no phytotoxicity damage. Also Morris *et al.* 2016, reported in growth-chamber studies foliar applications of nematicides fluensulfone at 12 g a.i. / L were phototoxic to tomato and eggplant.

Dahlin *et al.*, 2019, found that combining of chemical and biological nematicides can successfully control the *M. incognita* and increases crop yields. Combination of fluopyram and *P. lilacinum* reduced the nematode population throughout the growing

season. Similarly, Abolfazl *et al.* 2019 also reported that application of fluopyram provided an increase in cucumber yield compared with the inoculated control.

The chemical nematicide fluopyram protected the plants from *M. incognita* by reducing the soil nematode population at planting and protecting the plants against the initial penetration and significant root damage. *In-vitro* experiments showed that a dose, as low as, 1.0 µg / mL fluopyram was able to paralyse *M. incognita* juveniles exposed to it for 2 h and protected tomato roots from *M. incognita* infestation (Faske and Hurd, 2015).

Generally, the nematocidal effect of fluopyram has been described for multiple nematodes (Beeman and Tylka, 2018; Faske and Hurd, 2015; Kim et al., 2016).

1. Systematic and comprehensive survey of all cucumber growing areas of Karnataka to know the incidence of root-knot nematode (*Meloidogyne incognita*) and initiate the feature line of research on potentiality of plant parasitic nematodes in causing losses on cucumber.
2. Understanding nature of resistance genotypes of cucumber cultivars to develop the resistant varieties sources against root-knot nematode (*M. incognita*) to prevent more yield losses in polyhouses condition.



Summary

VI. SUMMARY

In this investigation, the experiments were carried out and results obtained on various studies on root-knot nematode infecting cucumber under polyhouse condition. The salient features of the findings are summarized below.

Initially survey was carried out on different species of root-knot nematodes (*Meloidogyne* spp.). It revealed the occurrence of root-knot nematode infestation was more in rural district of Bengaluru and the affected plants showing symptoms of stunting plants, poor yield, weak plants and heavy root galling system of cucumber.

The highest population of *M. incognita* (583 / 250 g soil) was recorded in Hadonahalli village of Doddaballapur taluk followed by Gummanahalli of Chikballapur taluk (381 / 250 g soil), Vijayapura of Devanahalli taluk (238 / 250 g soil). The least population of root-knot nematode was recorded in Kasvanahalli of Bengaluru (27 / 250 g soil) respectively. However, the population of *M. javanica*, *M. arenaria* were comparatively very less.

The maximum population of *M. incognita* was recorded in root samples collected from Hadonahalli village of Doddaballapur taluk (117 / 5 g root) followed by Gummanahalli of Chikballapur taluk (93 / 5 g root), The least population of (19 / 5 g root) was recorded in Kasvanahalli of Bengaluru.

Pallavi hybrid had maximum number of galls 420.6 per plant and 517.33 nematodes / 250 g of soil with gall index of 5.0 followed by Sunstar Rz 412 with galls and 493 nematodes / 250 g of soil with gall index of 5.0 indicating they are highly susceptible to *M. incognita*. Whereas, Green long recorded least number of galls (121) per plant and 88 nematodes / 250 g of soil with gall index of 5.0. In this study all varieties were highly susceptible and none of the cultivars were found highly resistant, resistant or immune.

The results of the tested efficacy of the treatments on various plant growth parameters showed, maximum plant height (297.00cm) recorded in *P. chlamyosporia* +

Fluopyram (T₉) treated plants. The next best results were recorded (287.3cm and 280.6 cm) in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) respectively. But Combination bio-agents (*T. harzianum*, + *P. chlamydosporia*), (*T. harzianum*+ *P. fluorecens*) along with chemical (Fluopyram) treated plants showed intermediate plant height 249.67, 225.33 and 269.67 cm respectively. While, minimum plant height (125.67 cm) was recorded in untreated control.

The maximum number of leaves (87.33) per plant were recorded in *T. harzianum* + *P. chlamydosporia* along with Fluopyram (T₁₁) followed by Treatment 12 (*T. harzianum* + *P. chlamydosporia* + *P. fluorecens* + Fluopyram) (80.67) treated plants. Bio-agents in combination with one another and combination with nematicide showed a greater number of leaves per plant rather than individual bio control agent application. whereas, minimum number of leaves per plant (36.67) were recorded in inoculated control.

The maximum fruit yield (2881.00 gm) was recorded in combination treatment i.e. *T. harzianum* +*P. chlamydosporia* + *P. fluorecens* + Fluopyram (T₁₂) treated plants followed by *T. harzianum*+*P. chlamydosporia* + Fluopyram (2783.00 gm) treated plants (T₁₁). While minimum fruit yield (692.00) was recorded in untreated control plants.

Maximum fresh shoot weight (438.33 g) was recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) treated plants followed by *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (417.00 g) treated plants (T₁₂). While minimum fresh shoot weight (182.67 g) was recorded in untreated control.

Maximum dry shoot weight (144.73 g) was recorded in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram followed by *T. harzianum* + *P. chlamydosporia* + Fluopyram (115.60 g) and *T. harzianum* + Fluopyram (107.20 g) treated plants. Whereas, minimum dry shoot weight (19.67) was recorded in untreated control.

Maximum fresh root weight (50.43 g) was recorded in inoculated control plants. Whereas, minimum fresh root weight was recorded in *P. florescens* treated plants.

Untreated control plants recorded significantly higher dry root weight (16.17 g) while minimum dry root weight (1.90 g) was recorded in T₄ (*P. flourescens*) treated plants.

Form the results it was observed that maximum root length (29.00cm) was recorded in *T. harzianum*+*P. chlamydosporia* treated plants while minimum root length (11.20 cm) was recorded in untreated control.

The maximum reduction of population (110 / 250g of soil) was recorded in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) treated plants with 83.61 % reduction over inoculated control. The next best results were recorded in *T. harzianum* + *P. chlamydosporia* + Fluopyram (T₁₁) treated plants with population of 123 / 250 g of soil with 81.67 % reduction over untreated control.

The maximum reduction of nematode population / 5 g of root (31.33) were recorded in *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) with 83.82 % reduction over control. Whereas, in untreated control plants recorded maximum nematode population (193.67 / 5 g of root).

Among the treatments tested, *T. harzianum* + *P. chlamydosporia* + *P. flourescens* + Fluopyram (T₁₂) treated plants showed maximum reduction of number of galls / root system (27.00) and which is superior over other treatments. The next best result (T₁₁) was reported in *T. harzianum* + *P. chlamydosporia* + Fluopyram (44.67) treated plants. The untreated control recorded significantly more galls per root system (485.50).

The treatments *T. harzianum* + *P. chlamydosporia* + Fluopyram and *T. harzianum* + Fluopyram also recorded less number of egg masses per root system (5.67 and 6.33) with 93.06 and 92.25 % reduction over control respectively. While, the untreated control recorded maximum number of egg masses per root system (81.67).



References

VII. REFERENCES

- Abolfazl, H., Davis, R. F. and Timper, P., 2019, Evaluation of selected nonfumigant nematicides on increasing inoculation densities of *Meloidogyne incognita* on cucumber. *J. Pl. Dis.*,103(12): 3161-3165.
- Ali, S.F. and Zewain, Q.K., 2019, Efficiency of some Bio and organic agents to control root-knot-nematode *Meloidogyne* spp. on cucumber plants (*Cucumis sativus*. L). *TJAS*. 18(3): 117-127.
- Almohithef, A. H., Al-Yahya, F. A., Al-Hazmi, A. S., Dawabah, A. A. and Lafi, H. A., 2020, Prevalence of plant-parasitic nematodes associated with certain greenhouse vegetable crops in Riyadh region, Saudi Arabia. *J. Saudi Soc.*, 19(1): 22-25.
- Anamika, Simon, S., Singh, K. P. and Ghosh, G., 2011, Distribution of root-knot nematode on major field crops in Uttar Pradesh (India). *Arch Phytopath. Pl. Protec.*,44(2): 191-197.
- Anon, 1993, *Consolidated report on rabi pulses plant nematology*. All India co-ordinated pulses improvement project, Kanpur, 18pp.
- Anupam, N., Kaur, D. And Sukhjeet, K., 2018, prevalence and distribution of root-knot nematode in polyhouse cultivation in Punjab. *Int. J. Farm Sci.*, 8(1): 70-73
- Anwar, S. A., Mahdi, M.M., McKenry, M.V. and Qadir, A., 2013, Survey of plant-parasitic nematodes associated with four vegetable crops cultivated within tunnels. *Pakistan. J. Zool.*, 45(3): 595-603.
- Arya, HC. Root-knot diseases of tomatoes in Jodhpur. *Science and Culture*. 1957; 22:391-393.

- Atkins, S. D., Hidalgo-Diaz, L., Kalisz, H., Mauchline, T. H., Hirsch, P. R. and Kerry, B. R., 2003, Development of a new management strategy for the control of root-knot nematodes (*Meloidogyne* spp) in organic vegetable production. *Pest Manag. Sci.*, 59(2): 183-189.
- Ayoub, R.M., 1977, Plant Pathology an Agricultural training Aid. State California, Dept. *Food. Agric. Sacramento., USA*, 156pp.
- Azeem, W., Mukhtar, T. and Hamid, T., 2020. Evaluation of *Trichoderma harzianum* and *Azadirachta indica* in the management of *Meloidogyne incognita* in Tomato. *Pakistan J. Zool.*, 52(1): 1-7.
- Baker, R., Paulitz, T., Windham, M. H. and Elad, Y., 1986, Enhancement of growth of ornamentals by a biological control agent. *Colorado Greenhouse Grow. Assoc. Res. Bull.*, 431:1.
- Barber, C. A. (1901) Department Land Records and Agriculture. Pp: 227-234. Madras Agricultural Branch.
- Basyony, A. G. and Abo-Zaid, G. A., 2018, Biocontrol of the root-knot nematode, *Meloidogyne incognita*, using an eco-friendly formulation from *Bacillus subtilis*, laboratory and greenhouse studies. *Egypt. J. Biol. Pest Co.*, 28(1): 87.
- Beeman, A. Q., Tylka, G. L., 2018, Assessing the effects of Ilevo and Votivo seed treatments on reproduction, hatching, motility, and root penetration of the soybean cyst nematode, *Heterodera glycines*. *J. Pl. Dis.*, 102(1): 107-113.
- Bem, A. A., Antsa, R. T., Orpin, J. B., Bem, S. L. and Amua, Q. M., 2014, Root-knot nematode (*Meloidogyne* Species) distribution in some tomato fields in Makurdi., *J. Pharm. Biol. Sci.*, 9(4): 143-146.
- Bhati, Shakti & Baheti, B. L., (2020) Occurrence and population status of root-knot nematode, *Meloidogyne incognita* on cucumber under protected cultivation in Rajasthan. *JEZS.*, 8(4):1441-1444.

- Castagnone-Sereno, P. (2002) Genetic variability in parthenogenetic root-knot nematodes, *Meloidogyne* spp., and their ability to overcome plant resistance genes. *Nematology*, 4(1): 605-608.
- Chandel, Y. S., Kumar, S., Jain, R. K. and Vashisth, S. 2010, An analysis of nematode problems in greenhouse cultivation in Himachal Pradesh and avoidable losses due to *Meloidogyne incognita* in tomato. *Indian J. Nematol.*, 40(2): 198-203.
- Chandel, Y.S., 2017, Status of root-knot nematode (*Meloidogyne* Spp.) in polyhouses and awareness level of the farmers on the nematode problems in Himachal Pradesh. Haryana. *J. Agric. Res.*, 43(2): 97-101.
- Chandra, B. and Khan, M., 2011, Dynamics of soil nematodes in vegetable based crop sequences in West Bengal, India. *J. Pl. Prot. Res.*, 51(1): 7-13.
- Chanppa, B. S., Srivastava, A. N. and Dhavan, S. C., 2008, Effect of cell concentrations of four strains of rhizobacterium, *Pseudomonas fluorescens* on hatching and mortality of root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.*, 38(1): 189-195.
- Chitwood, B. G., 1949, Root-knot nematode- I. A. Revision of the genus *Meloidogyne goeldi*, 1887. In: *Proc. Helminthol. Soc.*, Washington. (Ed. K. K. Barker, G. C. Carter and J. N. Sasser) pp 92-104, Co-op. publ. *Dept. Plant Pathol.*, North Carolina State Univ. and USAID, Raleigh, N. C., 233pp.
- Crump, D. H. and Kerry, B. R., 1977, Observations on fungal parasites of the cereal cyst-nematode, *Heterodera avenae*, and other cyst nematodes. *Nematologica*, 23(2): 193-201.
- Dahlin, P., Eder, R., Consoli, E., Krauss, J. and Kiewnick, S., 2019, Integrated control of *Meloidogyne incognita* in tomatoes using Fluopyram and *Purpureocillium lilacinum* strain 251. *J. Crop Prot.*, 124(1): 104824

- Dhillon, N.K. and Kaur, S., 2018, Prevalence and distribution of root-knot nematode in polyhouse cultivation in Punjab. *Int. J. Farm. Sci.*, 8(1): 70-73.
- Eapen, S. J and Venugopal, M. N. 1995. Field evaluation of *Trichoderma* spp and *Paecilomyces lilacinus* for control of root-knot nematode and fungal diseases of Cardamom nurseries. *Indian J. Nematol.*, 25(1): 15-16.
- Eapen, S. J. and Venugopal, M. N. 1995. Field evaluation of *Trichoderma* spp. and *Paecilomyces lilacinus* for control of root-knot nematode and fungal diseases of cardamom nurseries. *Indian J. Nematol.*, 25(1): 15-16.
- Esfahani, M. N., 2009, Distribution and identification of root-knot nematode species in tomato fields. *J. Mycopath.*, 7(1): 45-49.
- Esteves, I., Peteira, B., Atkins, S., Magan, N., Kerry, B., (2009) Production of extracellular enzymes by different isolates of *Pochonia chlamydosporia*. *Mycol. Res.*, 113(8): 867-876.
- Faske, T. R. and Hurd, K., 2015, Sensitivity of *Meloidogyne incognita* and *Rotylenchulus reniformis* to Fluopyram. *J. Nematol.*, 47(4): 316-321.
- Faske, T. R. and Hurd, K., 2015, Sensitivity of *Meloidogyne incognita* and *Rotylenchulus reniformis* to Fluopyram. *J. Nematol.*, 47(4): 316.
- Fayzia, M. M., Amira, S. S., Khalil, A. E. M., Shawky, S. M. and Taher, A. A., 2018, Seasonal fluctuation and biological control of root-knot nematodes *Meloidogyne incognita* on cucumber. *Pakistan. J. Nematol.*, 36(1): 71-81.
- Floraceli, R. Rodillas, Matpa, 2008, Performance of the different varieties of cucumber (*Cucumis sativus*) using kakawate (*Gliricidia sepium*) leaves as mulching material. *UNP Research J.*, 17(1): 19-24.
- Fourie, H. and McDonald, A.H., 2000, Nematodes. Agricultural Research Council, LNR Leaflet. *Crop Prot. Ser.*, 18:4-4.

- Gautam, S. K., Sahu, G., Verma, B. K. and Poddar, A. N., 2014, Status of root-knot nematode (*Meloidogyne* species) disease in vegetable crops of some districts of central plain region of Chhattisgarh state, India. *Afr. J. Microbiol. Res.*, 8(16): 1663-1671.
- Ghahremani, Z., Escudero, N., Saus, E., Gabaldón, T. and Sorribas, F.J., 2019, *Pochonia chlamydosporia* Induces plant-dependent systemic resistance to *Meloidogyne incognita*. *Front. Pl. Sci.*, 10(1): 945.
- Gu, X. and Zhang, S., 2006, The screening of cucumber rootstocks resistant to southern root-knot nematode. *China vegetables*. 15 (2): 4-8.
- Hajihassani, A., Davis, R. F. and Timper, P., 2019. Evaluation of selected nonfumigant nematicides on increasing inoculation densities of *Meloidogyne incognita* on cucumber. *J. Pl. Dis.*, 103(12): 3161-3165.
- Haran, S., Schickler, H. and Chet, I., 1996, Molecular mechanisms of lytic enzymes involved in the biocontrol activity of *Trichoderma harzianum*. *J. Microbiol.*, 142(9): 2321-2331.
- Harman, G. E., Howell, C. R., Viterbo, A., Chet, I. and Lorito, M., 2004, *Trichoderma* species opportunistic, avirulent plant symbionts. *Nat. Rev. Microbiol.*, 2(1): 43-56.
- Hashem, M. and Abo-Elyousr, K. A., 2011, Management of the root-knot nematode *Meloidogyne incognita* on tomato with combinations of different biocontrol organisms. *J. Crop Prot.*, 30(3): 285-292.
- Hidalgo-Diaz, L., Bourne, J. M., Kerry, B. R. and Rodriguez, M. G., 2000, Nematophagous *Verticillium* spp. in soils infested with *Meloidogyne* spp. in Cuba: isolation and screening. *Int. J. Pest Managt.*, 46(4): 277-284

- Hidalgo-Diaz, L., Bourne, J. M., Kerry, B. R. and Rodriguez, M. G., 2000, Nematophagous *Verticillium* spp. in soils infested with *Meloidogyne* spp. in Cuba: isolation and screening. *Eur. J. Plant Pathol.*, 46(4): 277-284.
- Howell, C. R., 2003. Mechanisms employed by *Trichoderma* species in the biological control of plant diseases: the history and evolution of current concepts. *Pl. dis.*, 87(1): 4-10.
- Huang, W. K., Cui, J. K., Liu, S. M., Kong, L. A., Wu, Q. S., Peng, H., He, W. T., Sun, J. H. and Peng, D. L., 2016, Testing various bio control agents against the root-knot nematode (*Meloidogyne incognita*) in cucumber plants identifies a combination of *Syncephalastrum racemosum* and *Paecilomyces lilacinus* as being most effective. *Biol. Contr.*, 92(1): 31-37.
- Huang, W. K., Sun, J. H., Cui, J. K., Wang, G. F., Kong, L. A., Peng, H., Chen, S. L. and Peng, D. L., 2014, Efficacy evaluation of fungus *Syncephalastrum racemosum* and nematicide avermectin against the root-knot nematode *Meloidogyne incognita* on cucumber. *PLoS one.*, 9(2): 1-6.
- Hwang, S. M., Park, M. S., Kim, J. C., Jang, K. S., Choi, Y. H. and Choi, G. J., 2014, Occurrence of *Meloidogyne incognita* infecting resistant cultivars and development of an efficient screening method for resistant tomato to the Mi-virulent nematode. *Korean J. Hort. Sci. Technol.*, 32(1): 217-226.
- Inbar, J., Abramsky, M., Cohen, D. and Chet, I., 1994, Plant growth enhancement and disease control by *Trichoderma harzianum* in vegetable seedlings grown under commercial conditions. *Eur. J. Plant Pathol.*, 100(5): 337-346.
- Indian Institute of Spices Research (IISR). 1995. *Ann. Rep., 1994-95*. Calicut India. pp. 89.

- Ishrat Naza., Raja A. A. K., Tariq, M, Ayesha, B., Ifra, S., Shamsul Haq., 2020, Biological control of root knot nematode, *Meloidogyne incognita*, *in-vitro*, greenhouse and field in cucumber. *J. Biol. cont.*, 152(1): 104429.
- Ismail, M., Anwar, S.A. and Riaz, A., 2012, Incidence of *Meloidogyne incognita* in cucumber fields. *Pakistan. J. Zool.*, 44(5): 1383-1387.
- Jaydeep Patil., Goel, S. R and Saroj, Yadav., 2017, Efficacy of phytotherapeutic substances against root-knot nematode *Meloidogyne incognita cucumerinum* affecting cucumber in polyhouse under protected cultivation. *IJRSR*. 8(11): 21958-21961.
- Jena, R., Basumatary, B., Mohanta, B. and Pradhan, S. R., 2017, Comparative efficacy of bio control agents against root-knot nematode (*Meloidogyne incognita*) infecting brinjal. *J. JEZS.*, 5(6): 254-257.
- Jin G. L, Wang. F., Huo, Y. M., He, Q. W, (2010). Screening of *Cucurbits* rootstocks tolerant to root-knot nematodes. *Shandong Agric. Sci* 5(2): 89-91.
- Karssen, G. and Moens, M., 2006, Root-knot nematodes In: Perry, R. N. and Moens, M. (eds) *Plant Nematology*. CABI International, Wallingford, UK. Pp. 59-90.
- Karssen, G., Moens, M. (2006) Root-Knot Nematodes. In: Perry, R. N., Moens, M. (eds.) *Plant Nematology*. CABI, London, pp. 59-90.
- Kayani, M. Z., Mukhtar, T., Hussain, M. A. and Ul-Haque, M. I., 2013, Infestation assessment of root-knot nematodes (*Meloidogyne* spp.) associated with cucumber in the Pothowar region of Pakistan. *J. Crop Prot.*, 47(1): 49-54.
- Kayani, M. Z., Mukhtar, T., Hussain, M. A., Haque, M. I. and Perveen, R., 2012, Incidence and severity of root-knot nematodes (*Meloidogyne* spp.) on cucumber in district Rawalpindi. *Pakistan. J. Phytopathol.*, 24(2): 122-128.

- Kerry, B. (2000) Rhizosphere interactions and the exploitation of microbial agents for the biological control of plant-parasitic nematodes. *Annu. Rev. Phytopathol.*, 38(1): 423-441.
- Khan, A. A., Khan, M.W. and Badshah Khan., 2000, Preferential parasitism of different species of root-knot nematodes on vegetable crops. *Indian J. Nematol.*, 30(2): 186-188.
- Kim, J., Mwamula, A. O., Kabir, F., Shin, J. H., Choi, Y. H., Lee, J. K. and Lee, D., 2016. Efficacy of different nematicidal compounds on hatching and mortality of *Heterodera schachtii* infective juveniles. *Korean J. Pestic. Sci.*, 20(4): 293-299.
- Kokalis-Burelle, N., 2015. *Pasteuria penetrans* for control of *Meloidogyne incognita* on tomato and cucumber, and *M. arenaria* on snapdragon. *J. of Nematol.*, 47(3), p.207.
- Krishnaveni, M. and Subramanian, S., 2003, Pathogenicity of *Meloidogyne incognita* on cucumber (*Cucumis sativus* L.). In: *Proceedings Of National Symposium On Biodiversity And Management Of Nematodes In Cropping Systems For Sustainable Agriculture*, held during 11-13-November, 2003 at Jaipur, India. pp. 89-92.
- Kumar, A., Jain, R.K. and Bajaj, H.K., 2008, Occurrence and identification of populations of root-knot nematodes (*Meloidogyne* spp.) from Haryana State. *Indian J. Nematol.*, 38(2):141-145.
- Kumar, H.K. and Khan, R.M., 2015, Community analysis of plant parasitic nematodes associated with mango orchards in four districts of Uttar Pradesh, India. *Indian J. Nematol.*, 45(1): 43-47.

- Lahm, G. P., Desaeager, J., Smith, B. K., Pahutski, T. F., Rivera, M. A., Meloro, T., Kucharczyk, R., Lett, R. M., Daly, A., Smith, B. T., Cordova, D., Thoden, T. and Wiles, J. A., 2017, The discovery of fluazaindolizine: A new product for the control of plant parasitic nematodes, *Bioorg. Med. Chem. Let.*, 27(15): 72-75.
- Li, X. Z. and Chen, S. X., 2017, Screening and identification of cucumber germplasm and rootstock resistance against the root-knot nematode (*Meloidogyne incognita*). *J. Genet. Mol. Res.*, 16(2): 83-93.
- Liu, B., Ren, J., Zhang, Y., An, J., Chen, M., Chen, H., Xu, C. and Ren, H., 2015, A new grafted rootstock against root-knot nematode for cucumber, melon and watermelon. *Agron Sustain Dev.*, 35(1): 251-259.
- Loper, J. E. and Schroth, M. N., 1986, Influence of bacterial sources of indole-3-acetic acid on root elongation of sugar beet. *Phytopathology*, 76(4): 386-389.
- Lopez-Llorca, L.V., Bordallo, J. J., Salinas, J., Monfort, E. and Lopez-Serna, M. L., 2002, Use of light and scanning electron microscopy to examine colonization of barley rhizosphere by the nematophagous fungus *Verticillium chlamydosporium*. *Micron.*, 33(1): 61-67.
- Lumsden, R. D., Frias, G., GARCIA, R. and Dunn, M. T., 1982, January. Biocontrol of *Pythium aphanidermatum* on cucumber by microbial isolates from Mexican soils. In *Phytopathology.*, 72(7): 1010.
- Lutfu, A., Happy, F.A. and Yeasmin, F., 2019, Production process and marketing system of cucumber: A socioeconomic study in Mymensingh district of Bangladesh. *SAARC J. Agric.*, 17(1): 135-147.
- Madhushri, K., Mesta, Kiran, R. K. and Rudresh, D. L., 2020, Evaluation of nematicides and oil cakes against root-knot nematode caused by *Meloidogyne incognita* in Pomegranate. *Int. J. Curr. Microbiol. App. Sci.*, 9(7): 1763-1775.

- Manju, P. and Subramanian, S. 2015, Survey of plant parasitic nematodes associated with gerbera in Tamil Nadu. *Int. J. Sci. Nat.*, 6(1): 586-589.
- Mansoor, A. S., 2006, Management of plant parasitic nematodes on tomato using neem products and nematicides. *J. Ecofriendly Agric.*, 1(1): 73-74.
- Mascarin, G. M., Bonfim Junior, M. F. and de Araújo Filho, J. V., 2012. *Trichoderma harzianum* reduces population of *Meloidogyne incognita* in cucumber plants under greenhouse conditions. *J. Entomol. Nematol.*, 4(6): 54-57.
- Morris, K. A., Langston, D. B., Davis, R. F., Noe, J. P., Dickson, D. W., and Timper, P. 2016, Efficacy of various application methods of fluensulfone for managing root-knot nematodes in vegetables. *J. Nematol.*, 48(2):65-71.
- Muhammad, Z.K., Tariq, M., Muhammad, A.H., Muhammad, I.U., 2013, Infestation assessment of root-knot nematodes (*Meloidogyne* spp.) associated with cucumber in the Pothowar region of Pakistan. *J. Crop Prot.*, 47(1): 49-54.
- Mukhtar, T., 2018, Management of root-knot nematode, *Meloidogyne incognita*, in tomato with two *Trichoderma* species. Pakistan. *Pak. J. Zool.*, 50(4): 1589-1592.
- Mukhtar, T., Kayani, M.Z. and Hussain, M.A., 2013, Response of selected cucumber cultivars to *Meloidogyne incognita*. *J. Crop Protection*. 44(1): 13-17.
- Nagesh, M., Hussaini, S. S. and Chidanandaswamy, B.S., 2005, Incidence of root-knot nematode, *Meloidogyne incognita* on gherkin, *Cucumis sativus* and yield losses. *Indian J. Pl. Protec.*, 33(2): 309-311.
- NHB, 2017. State wise area and production of cucumber, Horticultural Statistics at a Glance. [http:// www.nhb.gov.in](http://www.nhb.gov.in)
- Pandey, R. K., Nayak, D. K. and Mallik, S. K., 2018, Screening and evaluation of cucumber cultivars for resistance to root-knot nematode, *Meloidogyne incognita*. *J. Plant Prot. Env.*, 15(2): 66-68.

- Parihar, K., Rehman, B., Ganai, M. A., Asif, M. and Siddiqui, M. A., 2015, Role of oil cakes and *Pochonia chlamydosporia* for the management of *Meloidogyne javanica* attacking *Solanum melongena* L. *Int. J. Plant Pathol.*, 6(1): 12-20.
- Patel, A. D., Panickar, B. K., Patel, B. A. and Patel, D. J. 2008, Community analysis of plant parasitic nematodes associated with agricultural crops in Junagadh district of Gujarat and Diu-Union Territory. *Indian J. Nematol.*, 38(1): 53-56.
- Patil, J., Goel, S. R. and Yadav, S., 2017, Bio-management of cucumber wilt complex caused by root-knot nematode, *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *cucumerinum* in Polyhouse under Protected Cultivation. *J. Pure Appl. Microbio.*, 11(4): 1909-1917.
- Patil, J., Kumar, A. and Goel, S. R., 2017, Incidence of plant-parasitic nematodes associated with polyhouses under protected cultivated in Haryana. *J. Environ. Ecol.*, 35(3): 1870-1873.
- Pavithra, R. S., 2013, Studies on plant parasitic nematodes associated with cucumber (*Cucumis sativus* L.) with emphasis on root-knot nematode (*Meloidogyne* spp.). *M.Sc. (Agric.) Thesis*, Univ. Agric. Sci., Bengaluru (India).
- Pocurull, M., Fullana, A. M., Ferro, M., Valero, P., Escudero, N., Saus, E., Gabaldón, T. and Sorribas, F. J., 2020, Commercial formulates of *Trichoderma* induce systemic plant resistance to *Meloidogyne incognita* in tomato and the effect is additive to that of the Mi-1.2 resistance gene. *Front. Microbiol.*, 10(1): 30-42.
- Praveen, H. M. and Gowda, D. N., 2004, Screening of gherkin (*Cucumis anguria* L.) cultivars against root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.*, 34(1): 109-111.
- Pursglove, J.W. 1969. Tropical crops dicotyledons I. longamans. Green and Co. Ltd. London and Harlow.

- Ramamoorthy, V. and Samiyappan, R., 2001, Induction of defense-related genes in *Pseudomonas fluorescens* treated chilli plants in response to infection by *Colletotrichum capsici*. *J. Mycol. Pl. Pathol.*, 31(2): 146-155.
- Sellitto, V. M., Curto, G., Dallavalle, E., Ciancio, A., Colagiero, M., Pietrantonio, L., Bireescu, G., Stoleru, V. and Storari, M., 2016, Effect of *Pochonia chlamydosporia*-based formulates on the regulation of root-knot nematodes and plant growth response. *Front Life Sci.*, 9(3): 177-181.
- Sharon, E. Chet, I and Spiegel, Y. 2009, Improved attachment and parasitism of *Trichoderma* on *Meloidogyne javanica* in-vitro. *Eur. J. Plant Pathol.*, 123(3): 291-299.
- Sharon, E., Bar-Eyal, M., Chet, I., Herrera-Estrella, A., Kleifeld, O. and Spiegel, Y., 2001, Biological control of the root-knot nematode *Meloidogyne javanica* by *Trichoderma harzianum*. *J. Phytopathol.*, 91(7): 687-693.
- Sharon, E., Chet, I., Viterbo, A., Bar-Eyal, M., Nagan, H., Samuels, G. J. and Spiegel, Y., 2007, Parasitism of *Trichoderma* on *Meloidogyne javanica* and role of the gelatinous matrix. *Eur. J. Pl. Pathol.*, 118(3): 247-258.
- Siddiqui, I. A. and Shaukat, S.S., 2004, *Trichoderma harzianum* enhances the production of biocontrol of *Meloidogyne javanica* by *Pseudomonas fluorescens* in tomato. *Lett. Appl. microbial.*, 389(1): 169-175.
- Siddiqui, I. A., Shaukat, S. S. and Hamid, M., 2003, Suppression of *Meloidogyne incognita* by *Pseudomonas fluorescens* strain CHA0 and its genetically modified derivatives: I. The influence of oxygen. *Nematol. Meditt.*, 31(1): 105-109.
- Silva, J. D. O., Loffredo, A., da Rocha, M. R. and Becker, J. O., 2019, Efficacy of new nematicides for managing *Meloidogyne incognita* in tomato crop. *J. Phytopathol.*, 167(5): 295-298.

- Singh, H., 2017, Integrated management of root-knot nematode in cucumber cultivation, *M.Sc. (Agri.) Thesis*, PAU., Ludhiana (India).
- Singh, K. P., Sharma, G. C., Thakur, N. and Kumari, S., 2015, Incidence of phytoparasitic nematodes in vegetable crops grown under protected cultivation in Himachal Pradesh. *Indian J. Nematol.*, 45(1): 7-11.
- Singh, K. P., Sharma, G. C., Thakur, N. and Kumari, S., 2015. Incidence of phytoparasitic nematodes in vegetable crops grown under protected cultivation in Himachal Pradesh. *Indian J. Nematol.*, 45(1): 7-11.
- Singh, P. and Khanna, A., 2015, Incidence of phytoparasitic nematodes in vegetable crops grown under protected cultivation in Himachal Pradesh. *Int. J. Environ. Sci. Te.*, 4(1): 1640-1646.
- Singh, V. K., Singh, V.B. and Zalpuri, L., 2012, Survey pathogenic effect and management of root-knot nematode, *Meloidogyne incognita* on okra. *Indian J. Nematol.*, 42(2): 161-168.
- Sood, M., Kapoor, D., Kumar, V., Sheteiwiy, M. S., Ramakrishnan, M., Landi, M., Araniti, F. and Sharma, A., 2020, *Trichoderma*: The “Secrets” of a Multitalented Bio-control Agents. *J. Plants.*, 9(6): 762.
- Suarez, B., Rey, M., Castillo, P., Monte., E. and Llobell, A., 2004, Isolation and characterization of PRA1, a trypsin like protease from biocontrol agent *Trichoderma harzianum* CECT 2413 displaying nematocidal activity. *Appl. Microbiol. Biotechnol.*, 65(1): 46-55.
- Suresh, P., Poornima, K., Sivakumar, M. and Subramanian, S., 2017, Current status of root-knot nematodes (*Meloidogyne* spp.) in Tamil Nadu. *J. Entomol. Zool. Stud.*, 5(6): 610-615.

- Tariq-khan, M., Munir, A., Mukhtar, T., Hallmann, J. and Heuer, H., 2017, Distribution of root-knot nematode species and their virulence on vegetables in northern temperate agro-ecosystems of the Pakistani-administered territories of Azad Jammu and Kashmir. *J. Pl. Dis., Prot*, 124(3): 201-212.
- Thangamani, C., Pugalendhi, L. and Punithaveni, V., 2018, screening of wild and cultivated cucurbits against root-knot nematode to exploit as rootstocks for grafting in cucumber. *J. Hortic. Sci.*, 13(1): 32-41.
- Walters, S. A., Wehner, T. C. and Barkel, K. R., 1993, root-knot nematode resistance in cucumber and horned cucumber. *Hort. Sci.*, 28(2): 151-154.
- www.research.bayer.com/en/The_Bayer_Scientific_magazine_on_revolution-from-the-ground-up.aspx. Accessed 8 Nov 2017.
- Yadav, S., Patil, J. and Kumar, A., 2018, Bio-nematicidal effect of *Azadirachta indica*, against *Meloidogyne incognita* in tomato. *IJCS.*, 6(3): 2757-2761.
- Yedidia, I., Benhamou, N. and Chet, I., 1999, Induction of defense responses in cucumber plants (*Cucumis sativus* L.) by the bio-control agent *Trichoderma harzianum*. *J. AEM.*, 65(3): 1061-1070.
- Zare, R., Gams, W. and Evans, H. C., 2001, A revision of *Verticillium* section Prostrata. V. The genus *Pochonia*, with notes on *Rotiferophthora*. *Nova Hedwigia.*, 73(2): 51-86.
- Zewain, Q. K. And Ali, S. F., (2019) Evaluation of some organic formulations and their combinations as integrated management programs for root-knot nematode *Meloidogyne* spp. on cucumber plants under greenhouse condition. *Pl. Arch.*, 19(2):106-110.



Appendices

APPENDIX- I

Monthly meteorological data during the experimental period at the experimental site from January 2019 – October 2019

Month	Rainfall (mm)	Temperature (° C)		Relative Humidity (%)	
		Maximum	Minimum	I h	II h
January- 2019	0.00	27.9	13.1	90	54
February- 2019	24.0	30.6	17.4	88	49
March- 2019	0.00	33.8	20.0	81	37
April- 2019	22.60	34.73	20.73	78	36
May- 2019	89.20	30.61	19.46	86	48
June- 2019	65.4	28.6	20.1	89	54
July- 2019	34.40	29.47	18.83	90	53
August- 2019	204.60	27.54	18.13	92	62
September-2019	186.60	27.90	18.52	92	57
October -2019	243.10	27.74	18.27	93	58

Source - AICRP on Agro meteorology, University of Agricultural Sciences, GKVK, Bangalore-560065

APPENDIX – II

Available nutrient, Physical and physico-chemical properties of soil of the pots experimetns

PARTICULARS	VALUES	METHOD ADOPTED
Physical properties		
Soil type	Red sandy loam	International pipette method (Piper, 1966)
Sand (%)	69.32	
Clay (%)	16.38	
Silt (%)	14.3	
Physico-Chemical properties		
Soil pH	5.4	pH meter (Jackson, 1973)
EC (ds/m at 25 °C)	0.29	Conductivity bridge (Jackson, 1973)
Available Nitrogen (Kg/ha)	320.7	Titrated against standard H ₂ SO ₄ solution as described by Subbiah and Asija (1956).
Available P ₂ O ₅ kg/ha	40.355	Brays method with the help of using a spectrophotometer-contents were calculated by referring to its standard curve (Jackson, 1973)
Available K ₂ O kg/ha	131.15	With the help Flame Photometer Elico CL 378. (Black, 1965).

APPENDIX – III

LIST OF ABBREVIATIONS

<i>et al.</i>	(et albi) and else where	C°	Degree centigrade
etc.	(et cetera) and so on	Sec.	Seconds
Fig.	Figure	wt	Weight
G	Gram	v	Volume
Kg	Kilo gram	<i>viz.</i>	(videlicet) namely
Hrs	Hours	@	At the rate
i.e.	(id est) that is	ha	Hectare
min.	Minutes	cm	Centimetre
ml	Milliliter	Cv.	Cultivar
Mm	Millimeter	Var.	Variety
Q	Quintal	SEm±	Standard error of mean
N	Nitrogen	CV	Coefficient of variance
P	Phosphorus	CD	Critical difference
K	Potash	FYM	Farm yard manures
J ₂	Second juveniles	d.f	Degrees of freedom
CRD	Completely Random Design	INP	Initial nematode population