EVALUATION OF BIOINOCULANT CONSORTIA FOR ORGANIC CULTIVATION OF GINGER

By

HARITHA T.R.

(2013-11-174)

THESIS

Submitted in partial fulfilment

of the requirement for the degree of

Master of Science in Agriculture

(Agricultural Microbiology)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF AGRICULTURAL MICROBIOLOGY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

2015

DECLARATION

I hereby declare that the thesis entitled **"Evaluation of bioinoculant consortia for organic cultivation of ginger "** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 4.9.15

Haritha T.R.

(2013-11-174)

CERTIFICATE

Certified that this thesis entitled **"Evaluation of bioinoculant consortia for organic cultivation of ginger"** is a bonafide record of research work done independently by **Ms. Haritha T.R.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Vellanikkara

Date: 4/9/15

Dr. K. Surendra Gopal

(Major Advisor, Advisory committee)

Associate Professor

Dept. of Agricultural Microbiology

College of Horticulture,

Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Haritha T.R.,** a candidate for the degree of **Master of Science in Agriculture,** agree that this thesis entitled **"Evaluation of bioinoculant consortia for organic cultivation of ginger"** may be submitted by **Ms. Haritha T.R.,** in partial fulfillment of the requirement for the degree.

Dr. K. Surendra Gopal 4/9/15

(Major Advisor, Advisory committee)

Associate Professor

Dept. of Agricultural Microbiology

College of Horticulture, Vellanikkara

Dr. D. Girija 4/9/15

(Member, Advisory committee)

Professor and Head

Department of Agricultural Microbiology

College of Horticulture, Vellanikkara

Dr. Sally K. Mathew 4/9/15

(Member, Advisory committee)

Professor

Department of Plant Pathology

College of Horticulture, Vellanikkara

Dr. N. Mini Raj 04/09/15

(Member, Advisory committee)

Professor

Department of Plantation Crops and Spices

College of Horticulture, Vellanikkara

EXTERNAL EXAMINER

Dr. P. Sriparna

ACKNOWLEDGEMENT

And so comes the time to look back on the path traversed during the endeavour and to remember the faces behind the action with a sense of gratitude. Nothing of significance can be accomplished without the acts of assistance, words of encouragement and gestures of helpfulness from others.

First and foremost I bow my head before the **Almighty** *God who enabled me to successfully complete the thesis work.*

It is with immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude and indebtedness to my major advisor Dr. **K. Surendra Gopal**, *Associate Professor, Department of Agricultural Microbiology, for his expert advice, inspiring guidance, valuable suggestions, constructive criticisms, constant encouragement, affectionate advice and above all, the extreme patience, understanding and wholehearted co-operation rendered throughout the course of my study. I really consider it my greatest fortune in having his guidance for my research work and my obligation to him lasts forever.*

I place a deep sense of obligation to **Dr. D. Girija** , *Professor and Head, Department of Agricultural Microbiology and member of my Advisory Committee for her unwavering encouragement, well timed support and help rendered which made the successful completion of this thesis.*

I would like to express my deep sense of gratitude to Dr. **Sally K. Mathew**, *Professor, Department of Plant Pathology, for her expert advice, precious suggestions, generous support and constructive criticisms during my entire study which helped in successful completion of this work.*

I am deeply obliged to **Dr. N. Mini Raj**, *Professor, Department of Plantation crops and Spices for her invaluable help, guidance and critical assessment throughout the period of work. I thank her for all the help and cooperation she has extended to me.*

I express my sincere gratitude to **Dr. S. Krishnan**, *Associate Professor, Head of the Department, Department of Agricultural Statistics for the statistical analysis of the data and his sincere advices.*

I express my unreserved gratitude and thanks to ***Sunil and Neena,*** *Teaching Assistant, Department of Agricultural microbiology for his patience, guidance, encouragement, love and support that helped to complete this venture successfully.*

I take this opportunity to thank my seniors ***Mrs. Rekha, Mrs. Athira , Ms. Athulya and Ms. Saranya*** *for their valuable suggestions, help, support and encouragement.*

My heartfelt thanks to ***Arshana, Aswini, Chitra, Nayana, Vinni, Beenu, and Divya*** *,Department of Agricultural Microbiology, for their timely help and co-operation.*

Words cannot really express the help that I relished from my dear friends ***Fathima, Bavyasree, Lishma, Ashly, Greeshma, Sumbula, Nesmi*** *and* ***Nithya*** *and immense thanks to all M.Sc. classmates for their moral support and encouragement. I thank my juniors* ***Manju, Janish and Sreevidhya*** *and for the heartfelt help, timely suggestions and back-up which gave me enough mental strength to get through all mind-numbing circumstances.*

My heartfelt thanks to ***Sony*** *and* ***Sumathi,*** *,Department of Agricultural Microbiology for helping me in lab experiments and in field experiments.*

I am also thankful to ***Shantha*** *for her timely help and assistance in the field experiments.*

I am in dearth of words to express my love towards ***my beloved family*** *for their boundless affection, moral support, eternal love, deep concern, prayers and personal sacrifices which sustains peace in my life.*

I owe special thanks to Library, College of horticulture. ***Dr. Francis*** *and all other staff members of Library, who guided me in several ways, which immensely helped for collection of literature for writing my thesis.*

I express my deep sense of gratitude to Kerala Agricultural University for financial and technical support for persuasion of my study and research work.

It would be impossible to list out all those who have helped me in one way or another in the successful completion of this work. I once again express my heartful thanks to all those who helped me in completing this venture in time.

Haritha T.R.

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ABBREVIATIONS

CD	Critical Difference
cfu	Colony forming unit
DAP	Days After planting
FYM	Farm Yard Manure
g	gram
h	Hour(s)
HCN	Hydrogen cyanide
IAA	Indole Acetic Acid
INM	Integrated Nutrient Management
K	Potassium
KAU	Kerala Agricultural University
kg	Kilo gram
KSB	Potassium solubilizing bacteria
MAP	Month After Planting
mm	Milli metre
m	Minutes
N	Nitrogen
NS	Not significant
P	Phosphorus
PGPR	Plant growth promoting rhizobacteria
pH	Hydrogen ion concentration
POP	Package of Practices
PSB	Phosphorus solubilizing bacteria
RCBD	Randomized complete block design

Introduction

1. INTRODUCTION

The rapid growth of food and food processing industry has led to a significant growth of India's export of value added spices during the last couple of years. Ginger is one of the major spice crops which is being cultivated in India both as a fresh vegetable and as a dried spice, since time immemorial. India ranks first with respect to ginger production contributing about 32.75% of the world's production followed by China (21.41%), Nigeria (12.54%) and Bangladesh (10.80%). During 2012-13 the country, produced 7.45 lakh tonnes of the spice from an area of 1, 57,839 hectares. Ginger is cultivated in most of the states in India but Karnataka, Orissa, Assam, Meghalaya, Arunachal Pradesh and Gujarat together contribute 65 per cent to the country's total production. In India, Kerala ranks first in terms of area and total production (Selvan *et al.,* 2002). India exports ginger mainly in the form of whole and dry ginger. Indian dry ginger is known in the global market as 'Cochin Ginger' and 'Calicut Ginger'. Cochin Ginger is considered as one of the best in the world. Ginger prices are ruling steady because of good demand from the domestic and overseas market. However, one of the major constraints in its production is its susceptibility to various diseases like soft rot, bacterial wilt, fusarium yellows and leaf spot during its growth period. Also, it is a nutrient exhausting crop which demands use of high quantities of chemical fertilizer.

Increased use of inorganic fertilizers has created environmental issues such as deterioration of soil, surface and ground water quality, air pollution, reduced biodiversity and suppressed ecosystem function (Saraswath, 1982). Moreover, indiscriminate use of synthetic chemicals for control of pathogens are causing serious ecological, economic and social problems. In recent years, much attention is being given to reverse the situation by popularising the concepts of organic farming which emphasise the need to use organic manures, biofertilizers and biocontrol agents without adversly affecting crop production. The role of microbial inoculants assumes special significance in this context because of their eco-friendly nature, growing demand for organic products, and the rising threat of

pesticide residues in food crops. Essentially, microbial inoculants when applied to the soil, improve nutrient availability, reduces input of chemical fertilizers and promote sustainable agriculture.

In the recent years, there is a steady increase in demand for these microbial inoculants as a means to reduce use of chemical fertilizers and pesticides. Microbial inoculants are formulations of beneficial microorganisms used to promote plant growth and reduce the disease incidence. Simultaneous inoculation with different Plant growth promoting rhizobacteria (PGPRs) have often resulted in increased growth and yield as compared to single inoculation through improved nutrient uptake (Bashan *et al.*, 2004). The magnitude of plant growth promoting activities are better seen in the case of consortia or mixed cultures than single strain. Consortia of microbial inoculants not only provide nutrients but also manage the plant diseases and secrete plant growth promoting substances. Therefore, microbial inoculants formulations consisting of bioagents for nutrient availability and fungicidal effect with enhanced shelf-life would be a novel technology in contemporary agriculture.

Hence, the present study was undertaken on "Evaluation of bioinoculant consortia for organic cultivation of ginger" with the following objectives.

- Study the compatibility among the biofertilizers namely *Azospirillum lipoferum*, phosphate solubilizing bacteria, potash mobilizing bacteria and bioagents like *Pseudomonas fluorescens* and *Trichoderma viride*.
- Develop a consortia for plant growth promotion and disease management in ginger under field condition.

Review of literature

2. REVIEW OF LITERATURE

2.1 GINGER AND ITS IMPORTANCE

Ginger (*Zingiber officinale* Roscoe) is believed to be native to Asia (Grieve, 1979). It has been cultivated for thousands of years as a spice and also for its medicinal purposes (Park and Pezzuto, 2002). In Sanskrit, ginger is known as Sringavera and it is speculated that this term may have given way to Zingiberi in Greek and then to the Latin term Zingiber (Vasala, 2004). This plant is thought to have originated in Southeast Asia and this area still produces the majority of ginger demanded by worldwide markets (Smith, 2004). It is an important cash crop in India and is grown primarily in the states of Kerala, Karnataka, and Northeast India (Vasala, 2004). Currently, India and China are the dominant suppliers of ginger to the world market (Vasala, 2004).

The rhizome or underground stem, of the herbaceous monocotyledon, ginger (*Zingiber officinale* Roscoe) is used as a spice, confectionary product, and component of herbal remedies (Smith 2004). Ginger has compounds which posess analgesic, anti-inflammatory, anti-tumorigenic, anti-viral and anti-coagulative properties (Kim *et al.*, 2005). Gingerols, pungent constituents of fresh ginger, were reported to relieve pregnancy, post-operative and chemotherapy associated nausea in clinical trials (Chaiyakunaprik *et al.*, 2006). A high protein meal with ginger is found to be effective in reducing the delayed nausea of chemotherapy and use of antiemetic medicines (Levine *et al.*, 2008).

In recent studies, ginger varieties have been reported as a good potential source for anti-cancer, anti-microbial and anti-inflammation (Habib *et al.*, 2008). In Malaysia, it has been used as a food and medicinal plant for over 2000 years for treating diabetes, high blood pressure, cancer and many other illnesses (Ghasemzadeh *et al.*, 2010). Ginger is considered a safe herbal medicine with only few and insignificant adverse/side effects (Bhargava *et al.*, 2012).

2.2 AREA AND PRODUCTION OF GINGER

India is the largest producer (36.5% of the world production) of ginger and exports 5000 tonnes to different countries having a value of Rs. 2340 lakhs (Vadivel *et al.,* 2006). In India, Kerala ranks first in terms of area and total production (Selvan *et al.*, 2002). During the year 2012- 2013 Kerala produced 128.9 MT of ginger from an area of 1,70,000 ha with a productivity of 8 MT (NHB 2012).

2.3 MICROBIAL INOCULANTS FOR GROWTH PROMOTION

Microbial inoculants are the formulations of beneficial living microorganism which when added to soil, directly or indirectly, improve the nutrient availability to host plant and promote plant growth.

2.3. 1 *Azospirillum*

Azospirillum is plump, slightly-curved and straight rods, often with pointed ends. They are Gram negative to Gram variable bacteria and motile in liquid medium by a polar flagellum. Colonies on potato agar is typically light or dark pink, often wrinkled and non-slimy. In complex media such as MPSS broth, *Azospirillum* grow as plump, slightly curved rods and straight cells having a diameter of ~1.0 µm (Tarrand *et al.,* 1978).

In semi-solid nitrogen free malate (Nfb) medium, *A. lipoferum* develops predominantly into pleomorphic cells within 48 hr in contrast to *A. brasilense*, which retains mainly vibroid form. On BMS agar media, after 1-2 weeks of incubation at 33-35^{0}C, colonies of *Azospirillum* are pink, opaque, irregular or round, often wrinkled and have umbonate elevation. Pigmentation is best on BMS agar medium incubated under the light (Tarrand *et al.*, 1978). The growth in NFM (nitrogen free medium) medium is always accompanied with alkali production and high rates of acetylene reduction (Hegazi *et al.*, 1979).

Azospirillum have no preference for crop plants or weeds or for annual or perennial plants and can be applied successfully to plants that have no previous

history of *Azospirillum* in their roots. Thus it appears that *Azospirillum* is a great root coloniser and is not a plant- specific bacterium (Bashan and Holguin, 1997).

2.3.1.1 *Mechanisms involved in plant growth promotion by Azospirillum*

2.3.1.1.1 *N_2 fixation by Azospirillum*

Members of the genus *Azospirillum* fix nitrogen under microaerophilic conditions and are frequently associated with root and rhizosphere of a large number of agriculturally important crops and cereals. Although, they posses N_2 fixing capability (1–10 kg N/ha), the increase in yield is mainly attributed to improved root development due to the production of growth promoting substances and consequently increased rates of water and mineral uptake (Dewan and Subha Rao, 1979; Fallik *et al.*, 1994).

Kumar *et al.* (1988) reported that *Azospirillum* is second microaerophilic nitrogen fixer after blue green algae.

Nitrogen fixation is performed by a nitrogenase complex, and occurs when the availability of nitrogen compounds and oxygen tension are low (Steenhoudt and Vanderleyden, 2000). Nitrogen fixing biofertilizers increase crop nitrogen uptake by 20 kg N $acre^{-1}$ (Saharan and Nehra, 2011).

2.3.1.1.2 Hormonal effects of Azospirillum on plants

Various authors have proposed the following direct promoting mechanisms in addition to biological nitrogen fixation: (a) production of phytohormones such as zeatin , indole 3-acetic acid (IAA), gibberellic acid (GA3) and ethylene, and abscisic acid (ABA) (Bashan *et al.*, 2004); (b) siderophore production (Saxena *et al.*, 1986) (c) phosphate solubilization (Seshadri *et al.*, 2000) (c) production of plant growth regulatory substances such as polyamines (Thuler *et al.*, 2003), particularly cadaverine (CAD), which may be correlated with root growth promotion (Niemi *et al.*, 2002) and osmotic stress response in plants (Aziz *et al.*, 1997).

2.3.1.1.3 Improvement of root development, mineral and water uptake by Azospirillum

The positive effects of inoculation with *Azospirillum* are mainly derived from phytohormone production and from induced morphological changes in plant roots, resulting in enhanced mineral and water uptake (Burdman *et al.*, 2000).

Plant inoculation with *A. brasilense* promoted greater uptake of NO^{3-}, K^{+} and H_2PO_4 (Saubidet *et al.*, 2000). The enlargement of the root surface result in better nutrient uptake and an improved water status which may be the main factors enhancing plant growth by *Azospirillum* (Bottini *et al.*, 2004).

Azospirillum sp. mainly changes the growth or morphology of roots by increasing the number of lateral roots and root hairs (Ribaudo *et al.*, 2006).

2.3.1.2 Effect of Azospirillum on plant growth

Azospirillum is considered the most important rhizobacterial genus for improvement of plant growth or crop yield worldwide (Bashan *et al.*, 2004). Patil (1987) observed an increase in dry ginger weight, N content and saving of 33 % fertilizer N due to *Azospirillum* inoculation. Fulchieri and Frioni (1994) observed that maize inoculated with *Azospirillum* had enhanced dry weight of seed by 59 per cent and also the yield which was similar to 60 kg urea N ha^{-1}. Inoculation of *Azospirillum* increases yield of maize at intermediate soil fertility and replaces 35-40 % of nitrogen fertilizers (Okon and Labandera-Gonzalez, 1994).

Azospirillum has a prominent role in increasing productivity and quality of ginger while reducing the most challenging disease *i.e* the rhizome rot of ginger. In all organic farming situations, addition or *Azospirillum* to package of practices will enhance the production of ginger (Dash *et al.*, 2008).

2.3.2 Phosphorus solubilising bacteria

Phosphorus (P) is a major growth-limiting nutrient, and unlike the case for nitrogen, there is no large atmospheric source that can be made biologically available (Ezawa *et al.*, 2002).

Organisms possessing phosphate solubilizing ability are called phosphate solubilizing organisms and they can convert the insoluble phosphatic compounds into soluble forms in soil and make them available for plants to absorb (Pradhan and Sukla, 2005).

Strains from bacterial genera *Pseudomonas, Bacillus, Rhizobium* and *Enterobacter* and *Aspergillus* are the most powerful phosphate solubilizers (Whitelaw, 2000).

2.3.2.1 Mechanisms involved in plant growth promotion by phosphate solubilizing bacteria

2.3.2.1.1 Production of organic acids

The solubility of phosphate is inhibited by the presence of iron and aluminium in acidic soils and calcium in neutral and alkaline soils. This leads to fixation of phosphorus, making it unavailable to crop plants. The phosphate solubilizing bacteria secretes organic acids which act on insoluble phosphates and convert the same into soluble form (Ponmurugan and Gopi., 2006).

A key mechanism for mineralization of Phosphates in soil is through microbial secretion of low molecular weight organic acids. These organic acids can either dissolve phosphates as a result of anion exchange or can chelate Ca, Fe or Al ions associated with the phosphates (Gyaneshwar *et al.*, 2002). However, soil microorganisms vary considerably in their ability to secrete organic acids and thereby, solubilize mineral phosphates at different extent. The phosphate solublizing bacteria (PSB) have ability to reduce the pH of the surroundings by the production of organic acids (Chen *et al.*, 2006).

Inorganic forms of P are solubilized by a group of heterotrophic microorganisms excreting organic acids that dissolve phosphatic minerals and/ or chelate cationic partners of the P ions i.e. PO_4^{3-} directly, releasing P into solution (He *et al.*, 2002). Microorganisms enhance the P availability to plants by

mineralizing organic P in soil and by solubilizing precipitated phosphates (Chen *et al.,* 2006).

PSM's produced the low molecular weight organic acids (gluconic, 2-ketogluconic, glyoxylic, citric, malic, lactic acids etc.) to solubilize the insoluble phosphates and lower the pH in the cell surroundings (Khan *et al.*, 2007). Organic acids, such as glycolic acid, oxalic acid, malonic acid, succinic acid, citric acid and propionic acid, have also been identified among phosphate solubilizers. The phosphate solublizing bacteria have ability to reduce the pH of the surroundings by the production of organic acids (Chen *et al.,* 2006). Organic acids, such as acetic, citric, lactic, propionic, glycolic, oxalic, malonic, succinic acid, fumaric, tartaric etc. have also been identified among phosphate solubilizers (Ahmed and Shahab, 2011).

Phosphate solubilizing microbes can transform the insoluble phosphorus to soluble forms $HPO4^{2-}$ and $H_2PO_4^-$ by acidification, chelation, exchange reactions and polymeric substances formation (Delvasto *et al.*, 2006; Chang and Yang, 2009).

2.3.2.1.2 Other mechanisms involved in plant growth promotion by phosphate solubilizing bacteria

The mineralization of phosphorus compound is carried out by the action of several phosphatase (also called phosphorus hydrolase), which is present in a wide variety of soil microorganism and play a significant role in assimilation of phosphate from organic compounds by plants and microorganisms (Sharma *et al.*, 2011). It involves the hydrolysis of phosphoester or phosphor anhydride bonds.

PSBs also enhance plant growth by increasing the efficiency of biological nitrogen fixation or enhancing the availability of other trace elements such as iron, zinc, etc. (Ponmurugan and Gopi, 2006). Not only proving phosphorus to the plants, the phosphate solubilizing microorganisms also facilitate the growth of plants by stimulating the efficiency of nitrogen fixation, accelerating the accessibility of other trace elements and by synthesizing important growth

promoting substances (Mittal *et al.,* 2008), and antibiotics (Lipping *et al.,* 2008), and providing protection to plants against soil borne pathogens (Hamdali *et al.,* 2008). It has also been reported that siderophores, chelating compounds and mineral acids are also responsible for P solubilization (Wu *et al.,* 2005). The PSBs are able to synthesize phytohormones like Indole acetic acid (IAA), Gibberellic acid (GA3) (Ramkumar and Kannapiran, 2011) and siderophore (Babana *et al.,* 2013).

2.3.2.2 Effect of phosphate solubilizing bacteria on plant growth

Plant growth stimulation due to inoculation of phosphate solubilizing bacteria to crops in soils containing low levels of phosphorus have been reported (Domey and Lippmann, 1989). Rock phosphates are often too insoluble to provide sufficient P for crop uptake. Use of PSMs can increase crop yields up to 70 per cent (Verma, 1993). Higher crop yields resulted from solubilization of fixed soil P and applied phosphates by PSB (Zaidi, 1999).

Phosphate solubilizing bacteria promoted P-uptake as well as yield in several crops (Khalid *et al.,* 2004). An increase in growth and P uptake of mung bean plants due to inoculation of PSB strains was observed by Jha *et al.* (2011). Microorganisms, especially the use of such phosphate solublizing bacteria (PSB) as inoculants simultaneously increases P uptake by the plant and therefore can be used as bio fertilizer (Nico *et al.,* 2012). PSBs have a high potential to be used for the management of phosphorus in P deficient soils as well as disease suppression (Panhwar *et al.,* 2012).

2.3.3 Potash solubilizing bacteria

A wide range of bacteria namely *Pseudomonas, Burkholderia, Acidothiobacillus ferrooxidans, Bacillus mucilaginosus, Bacillus edaphicus, Bacillus circulans* and *Paenibacillus* sp. have been reported to release potassium in accessible form from potassium-bearing minerals in soils (Sheng, 2005).

2.3.3.1 *Mechanism of plant growth promotion by potash solubilising bacteria*

The application of K solubilizing microorganisms (Barker *et al.,* 1998) is a promising approach for increasing K availability in soil. Production of carboxylic acids like citric, tartaric and oxalic acids is also associated with feldspar solubilization by microrganisms (Malinovskaya *et al.,* 1990; Sheng *et al.,* 2002).

Potash solubilising bacteria are able to solubilize potassium rock through production and secretion of organic acids (Han and Lee, 2005). These potassium solubilizing bacteria (KSB) were found to dissolve potassium, silicon and aluminium from insoluble K-bearing minerals such as micas, illite and orthoclases, by excreting organic acids which either directly dissolved rock K or chelated silicon ions to bring K into the solution (Aleksandrov *et al.,* 1967; Ullman, *et al.,* 1996; Bennett *et al.,* 1998).

Sheng and He (2006) reported that solubilisation of illite and feldspar by microorganisms is due to the production of organic acid like oxalic acid and tartaric acids and also due to production of capsular polysaccharides which help in dissolution of minerals to release potassium. Decomposition of silicate minerals by *B. Mucilaginosus* due to production of oxalate and citrate and the extent of which polysaccharides absorbed organic acids decomposes minerals (Liu *et al.,* 2006).

In addition, they are also known to produce amino acids, vitamins and growth promoting substances like indole-3-acetic acid (IAA) and gibberellic acid (GA3) which help in better growth of the plants (Ponmurugan and Gopi, 2006).

2.4.3.2 Effect of potash solubilizing bacteria on plant growth

The PSB, *Bacillus megaterium* var. *phosphaticum* and potassium solubilising bacteria (KSB), *Bacillus mucilaginosus,* when inoculated in nutrient limited soil showed that rock materials (P and K rocks) and both bacterial strains consistently increased mineral availability, uptake and plant growth of pepper and cucumber, suggesting its potential use as biofertilizer (Han *et al,* 2006).

Recent studies have proved that potassium can increase the plant height, fresh plant weight and also increase herbage and oil yield on the patchouli (Singh *et al.*, 2008). Similarly, *Frateuria aurantia* belonging to the family Pseudomonaceae solubilized K considerably, and this promoted the crop yield (Ramarethinam and Chandra, 2006). This solubilization effect is generally due to the production of certain organic acids and enzymes by KSB.

The application of K solubilizing bacteria as biofertilizer for agriculture improvement can reduce the use of agrochemicals and support ecofriendly crop production (Sindhu *et a.l*, 2010).

Potassium solubilizing bacteria are extensively used as biofertilizers in Korea and China as significant areas of cultivated soils in these countries are deficient in soil-available K (Xie, 1998). Inoculation with potassium solubilizing bacteria have been reported to exert beneficial effects on growth of cotton and rape (Sheng, 2005), pepper and cucumber (Han *et al.*, 2006). Similarly, inoculation of maize and wheat plants with *Bacillus mucilaginosus, Azotobacter chroococcum* and *Rhizobium* resulted in significant higher mobilization of potassium from waste mica, which in turn acted as a source of potassium for plant growth (Singh *et al.*, 2008).

Lin *et al.* (2002) as well as Egamberdiyeva and Ho flich, (2003) also demonstrated that bacterial inoculation could resulted in growth promotion and higher K contents of plant components.

2.4 MICROBIAL INOCULANTS FOR DISEASE MANAGEMENT

2.4.1 *Pseudomonas fluorescens*

Pseudomonas fluorescens encompasses a group of common, non pathogenic saprophytes that colonize soil, water and plant surface environment. It is a common gram negative, rod-shaped bacterium. As its name implies, it secretes a soluble greenish fluorescent pigment called fluorescein, particularly under conditions of low iron availability. It is an obligate aerobe, except for some

strains that can utilize NO_3 as an electron acceptor in place of O_2. It is motile by means of multiple polar flagella. *Pseudomonas fluorescens* has simple nutritional requirements and grows well in mineral salts media supplemented with any of a large number of carbon sources (Palleroni, 1984).

2.4.1.1 Mechanism of action of Pseudomonas fluorescens

2.4.1.1.2 Antibiotic Production

Certain anti-microbial secondary metabolites (e.g. DAPG) produced by *Pseudomonas fluorescens* are involved in protection of different plant species, from different phytopathogens, and by different biocontrol strains (Rezzonico *et al.*, 2005; Weller 2007).

The anti-fungal metabolite 2, 4-diacetyl phloroglucinol play a major role in the biocontrol capabilities of *P. fluorescens* (Delany ., 2000).

Production of antibiotics such as phenazine-1-carboxylic acid (PCA), pyocyanin, 2-acetamidophenol, pyrrolnitrin, pyoluteorin, Phenazine-1-Carboxylic acid, 2, 4-diacetylphloroglucinol, viscosinamide and tensin in different species of pseudomonads has been reported (Kumar *et al.*, 2005).

2.4.1.1.3 Siderophore production

Paul *et al.* (2001) reported siderophore mediated antagonism in *Pseudomonas fluorescens* antagonistic system. Flourescent pseudomonads are known to suppress soil-borne fungal pathogens by producing antifungal metabolites and by sequestering iron in the rhizosphere through release of iron-chelating siderophores, and thus rendering it unavailable to other organisms (Dwivedi and Johri, 2003).

2..4.1.1.4 Competition

As strains from *P. fluorescens* and related species colonize the rhizosphere aggressively, competition with root pathogens for nutrients and root surface

colonization has been proposed as an important trait for biological control (Haas and Defago, 2005).

2.4.1.1.5 *Hydrogen cyanide Production*

Many biocontrol agents from *P. fluorescens* and closely related species are well characterized for their ability to produce antimicrobial compounds, including 2,4-diacetylphloroglucinol (DAPG), phenazines, hydrogen cyanide and surfactants (Haas and Defago, 2005).

2.4.4.2 Effect of Pseudomonas fluorescens on plant growth

Fluorescent pseudomonads are effective candidates for biological control of soil borne plant pathogens owing to their versatile nature, rhizosphere competence and multiple modes of action besides being endophytic in the plant system including black pepper (Kloepper *et al.*, 1980, Weller *et al.*, 1988, Diby *et al.*, 2001). Jubina and Girija (1998) found that inoculation of antagonistic rhizobacteria improved the growth characteristic of black pepper in terms of shoot length, fresh weight and dry weight *Pseudomonas fluorescens* (IISR-6) promoted growth and vigour of black pepper, ginger and cardamom and suppressed soil-borne fungal pathogens in field conditions also (Jisha *et al.*, 2002). Significant uptake of nitrogen and pottasium was reported in black pepper treated with *Pseudomonas fluorescens* (Diby *et al.*, 2005).

2.4.2 *Trichoderma*

The most common BCAs of the Trichoderma genus are strains of *Trichoderma. virens, Trichoderma viride* and, above all, *Trichoderma harzianum*, which is a species aggregate that includes different strains used as BCAs of phytopathogenic and viral vector fungi (Grondona ,1997).

The reverse side of colonies is often uncolored, buff, yellow, amber, or yellow-green, and many species produce prodigious quantities of thick- walled spores (chlamydospores) in submerged mycelium (Gams and Bisset, 1998).

Fungal species belonging to the genus *Trichoderma* are worldwide in occurrence and easily isolated from soil, decaying wood, and other forms of plant organic matter .They are classified as imperfect fungi, in that they have no known sexual stage. *Trichoderma* species are fungi with teleomorphs belonging to the Hypocreales order of the Ascomycota division (Kredics *et al.*, 2003).

2. 4.2.1 Mechanism of action of Trichoderma

2.4.2.1.1 Mycoparasitism

Studies indicated that mycoparasitism is one of the main mechanisms involved in the antagonism of *Trichoderma* as a biocontrol agent (Sharon *et al.*, **2001).**

Mycoparasitism involves morphological changes, such as coiling and formation of appressorium-like structures, which serve to penetrate the host and contain high concentrations of osmotic solutes such as glycerol (McIntyre *et al* ., 2014).

2.4.2.1.2 Antibiosis

Trichoderma release antibiotics and other metabolites that are harmful to the pathogen and inhibit their growth. Many antibiotics have been isolated and characterized. These include gliotoxin and glyoviridin from *Trichoderma vi*rens ; viridian, alkyl pyrones, isonitriles, polyketides, peptaibols, diketopiperazines sesquiterpenes and some steroids from *Trichoderma* spp. (Howell, 2003).

Most *Trichoderma* strains produce volatile and non-volatile toxic metabolites like tricholin, peptaibols, antibiotics, massoilactone, viridin, gliovirin, glisoprenins that impede colonization by antagonized microorganisms; among these metabolites, the production (Vey , 2001).

2.4.2.1.3 Siderophore production

Different fungi are also reported to produce siderophores involved in iron uptake and these are commonly short peptides containing non-protein amino acids (Lorito *et al.*, 1993).

2.4.2.1.4 Induced systemic resistance

Harman (2000) reported that *Trichoderma* spp gave long term protection due to mechanism like rhizosphere competition, induced resistance and tolerance to stress through enhanced root and plant development.

Some ***Trichoderma*** strains clearly show induced resistance like responses. It was reported that xylanase from ***Trichoderma*** spp. is responsible for induction of systemic resistance in cotton, tobacco, grapevine, etc (Yedidia *et al.*, 2008).

Trichoderma strains establish long-lasting colonization of plant roots and penetrate into the epidermis. There, they produce or release compounds that induce localized or systemic plant resistance responses (Harman *et al*, 2004).

2.4.2.1.5 Competition

Trichoderma has a superior capacity to mobilize and take up soil nutrients compared to other organisms. The efficient use of available nutrients is based on the ability of *Trichoderma* to obtain ATP from the metabolism of different sugars, such as those derived from polymers wide-spread in fungal environments: cellulose, glucan and chitin among others, all of them rendering glucose (Chet *et al* ., 1997).

Trichoderma has a strong capacity to mobilize and take up soil nutrients, thus making it more efficient and competitive than many other soil microbes. *Trichoderma* spp. also produce organic acids, such as gluconic, citric or fumaric acids, that decrease soil pH and permit the solubilization of phosphates, micronutrients and mineral cations like iron, manganese and magnesium, useful for plant metabolism. (Benitez *et al.*, 2004).

Root colonization by *Trichoderma* strains frequently enhances root growth and development, crop productivity, resistance to abiotic stresses and the uptake and use of nutrients. *Trichoderma* spp. produces auxins that are able to stimulate plant growth and root development (Contreras-Cornejo *et al.*, 2009).

2.4.2.2 Effect of Trichoderma viride on plant growth

According to Harman (2000) *Trichoderma* sp. can increase the rate of plant growth and development and also produced more robust roots. Madhaiyan *et al.* (2003) studied the effect of *Trichoderma* in vanilla and he found that *Trichoderma viride* increased the shoot and dry weight over control.

The strains of *Pseudomonas fluorescens* and *Trichoderma* spp. are potential biocontrol agents for controlling foot rot disease in black pepper (Sarma *et al.*, 2000). The increased growth response induced by *Trichoderma* sp. has been reported for pepper (*Capsicum annum*) (Lo and Lin, 2002).

Kannan and Revathy (2002) found that inoculation of *Trichoderma viride* reduced the foot rot of pepper caused by *Phytophthora capsici*. Application of rhizobacteria and *T. harzianum* is also reported to significantly enhance growth of black pepper plants in the nursery (Anandaraj and Sarma, 2003). Vijayaraghavan (2003) noted that inoculation of *Trichoderma viride* in solarised potting mixture increased the height and number of leaves of pepper cutting in nursery.The uptake of nitrogen, phosphorus and potassium by ginger plants increased with the application of AMF and *Trichoderma* (Sreekala, 2004).

2.5 DISEASES OF GINGER

Soft rot, bacterial wilt, fusarium yellows, phyllosticta leaf spot are major diseases that cause economic losses. *Pythium aphanidermatum, Ralstonia solanacearum, Fusarium oxysporum* and *Phyllosticta zingiberi* are the potent pathogens causing soft rot, bacterial wilt, fusarium yellows, phyllosticta leaf spot respectively.

2.5.1 Soft rot

Soft rot is also called rhizome rot or *Pythium* rot. Butler (1907) recorded the incidence of this disease for the first time from Surat (Gujarat) in India. The two species *viz Pythium aphanidermatum* and *Pythium myriotylum* are reported to cause severe damage in warm humid climates and these two have been reported in

Kerala as soft rot pathogens in addition to *Fusarium oxysporum*, *Fusarium solani* and *Pseudomonas solanacearum* (Dake & Edison, 1989). Soft rot is caused mostly by *P. aphanidermatum* but other species, *P. deliense, P. myriotylum, P. pleroticum, P. vexans* and *P. ultimum* were also reported by many worker from different states (Sarma, 1994).

In ginger, both pre-emergence and post emergence rhizome rots are noticed. Initial symptoms appear as water soaked patches at the collar region of the pseudostem. The affected rhizomes rot, emit a foul smell and the pseudostems come off with a gentle pull. In the early stages, the root infection often reaches the germinating sprouts leading to the rhizome rot (Anandaraj & Sarma, 1993).

Soft rot reduces the potential yield to a great extent in the field storage and market and may cause losses of even more than 50 % (Joshi and Sharma, 1980). Moderate to severe incidence leading to crop loss of more than 50 to 80% have been reported on account of this disease (Joshi and Sharma, 1982). Crop loss depends on the stage of crop growth at which the infection starts. If it occurs early, total crop loss of the affected clump results, where as the crop loss is partial if affected at a later stage (Sarma, 1994). Rhizome rot of ginger caused by *Pythium aphanidermatum* is a major constraint for the production of healthy rhizome, some times causing total failure of crop (Fageria *et al.*, 2006). In the recent years soil solarisation coupled with biocontrol was found to be effective in reducing the disease incidence of rhizome rot (Balakrishnan, 1997).

2.5.2 Fusarium yellows

Simmonds (1955) described ginger yellows for the first time in Queensland and later in India (Haware and Joshi, 1973). It is a serious stem rot disease that in its severe form can devastate the ginger crop almost totally. Later on Trujillo (1963) made elaborate studies on cause and symptoms of the disease. Plants infected by the fungus, *Fusarium oxysporum* f. *zingiberi*, do not wilt rapidly as in bacterial wilt. Instead, infected ginger plants are stunted and yellowed. The lower leaves dry out over an extended period of time (Trujillo, 1963).

2.5.3 Bacterial wilt

Orian reported this disease for the first time from Mauritius. This disease is caused by bacterium *Pseudomonas solanacearum* (Orian, 1953) now known as *Ralstonia solanacearum* (Yabuuchi *et al.*, 1994). However, this disease occurred in India from the middle of the century but Mathew *et al.* (1979) reported it in 1979 from Kerala.

Wilting and yellowing of the lower leaves, which extends upward until all the leaves appear golden yellow in appearance is the first recognizable symptom of bacterial wilt in ginger. As the disease progresses, the pseudostem becomes water soaked and readily breaks away from the underground rhizome. The vascular tissue of the stem darkens to a black color and symptoms progress very rapidly until the ginger plant collapses (Pegg *et al.*, 1974) .Three biotypes of this bacterium have been described and out of this biotype III causes the wilt in India (Dake *et al.*, 1989).

2.5.4 Leaf spot

Leaf spot is caused by *Phyllosticta zingiberi* and the disease is noticed on the leaves from July to October. The disease starts as water soaked spot and later turns as a white spot surrounded by dark brown margins and yellow halo. The lesions enlarge and adjacent lesions coalesce to form necrotic areas. The disease spreads through rain splashes during intermittent showers. The incidence of the disease is severe in ginger grown under exposed conditions (Ishii and Aragaki, 1963).

2.6 COMPATIBILITY AMONG THE MICROBIAL INOCULANTS

Compatibility of *Trichoderma viride* with *Azospirillum* under *in vitro* has been proved by Sankar and Jayarajan (1996). They also noted that *Azospirillum* did not inhibit the antagonists under *in vivo* condition and there was cumulative effect in disease reduction. *Bacillus megaterium* and *Pseudomonas fluorescens* was found to be compatible with each other through cross streak assay and hence able to grow simultaneously without any inhibition in growth. (Yogesh, 2012)

The compatibility of the inoculants *Trichoderma viride, Pseudomonas fluorescence* and *Azotobacter chroococcum* were tested through cross streak plate assay. The inoculants were found to be compatible with each other and were able to grow simultaneously without any inhibition in growth (Hafeez *et al.*, 2006).

Azospirillum lipoferum, Bacillus megaterium var phosphaticum, Pseudomonas fluorescens were found to be compatible with each other (Raja *et al.,* 2006b). *Pseudomonas flouresence* and *Azospirillum lipoferum* were found to be compatible with each other (Khorshidi, 2011).

2.7 USE OF VERMICOMPOST AS CARRIER MATERIAL FOR MICROBIAL INOCULANTS

Vermicompost is one of the best source of nutrients and improves the physical and chemical properties of crops (Tolanur, 2009) . Due to absence of toxic enzymes, it is also eco friendly and has beneficial effect on the biochemical activities of the soil (Sinha, 2010). It also increases the quality, fertility, mineral content of the soil structure and at the same time enhances soil aeration, texture and there by reducing soil compaction (Ali *et al.*, 2001). It also build up water retention capacity of soil because of its high organic matter content and promotes root growth and nutrient absorption (Nourbaksh, 2007). Vermicompost can be used as a potential carrier material for bacterial inoculants (Muthuselvam and Tholkappian, 2008). Shelf life of *Azospirillum lipoferum, Bacillus megaterium* and *Pseudomonas fluorescens* in vermicompost carrier was found to be more effective than lignite carrier (Saravanakumar and Gandhi, 2009)

An experiment was conducted on rice crop for the selection of suitable carrier material. For this purpose, four different carriers such as vermicompost, cured compost, lignite and charcoal were used along with *Azotobacter chroococcum.* Among these carriers vermicompost was found to be the best for a PGPR strain by producing highest bacterial colonies during six month period and better results for growth and yield parameters (Roy *et al.,* 2010).

Vermicompost can be an essential carrier material for *Azospirillum* and phosphobacteria (Muthuselvam and Tholkappian , 2008). *Azospirillum* species showed more compatibility with vermicompost than coir pith (Bagyalakshmi, 2012).

2.8 EFFECT OF CONSORTIA OF MICROBIAL INOCULANTS ON PLANT GROWTH AND DISEASE MANAGEMENT

Sarma and Anandaraj (1998) suggested the consortium approach for disease management in plantation and spice crops.

Sarma *et al.* (2000) has established the biocontrol consortium for black pepper, ginger and cardomom. The maximum disease suppression obtained by treatment combination, *Trichoderma harzianum* (IISR,1998) and *Pseudomonas fluorescens* (IISR 6) in black pepper and cardamom. For example, by introducing KSB and phosphate solubilizing bacteria (PSB),primary macronutrient of nitrogen, phosphate and potassium uptake is increased in pepper and lead to higher yield (Han *et al.,* 2006). Han *et al.* (2006) evaluated the potential of PSB and KSB inoculated in nutrient limited soil planted with pepper and cucumber results showed that coinoculation of PSB and KSB showed high P and K content and plant growth compare to control. Mathew (2009) reported the effectiveness of consortia consisting of *Pseudomonas fluorescens* and *Trichoderma* for enhancing biometric characters and management of rhizome rot in ginger.

Accordingly, these microbial communities when used singly (Chen *et al.*, 2008) or in combination with other rhizosphere microbes (Wani *et al.*, 2007) have shown substantial measurable effects on plants in conventional agronomic soils. The inoculation of PSB and plant growth-promoting rhizobacteria (PGPR) together could reduce 50% of P fertilizer application without any significant decrease of crop yield (Sharma *et al.*, 2011) .Findings of Mohammadi *et al.* (2011) showed that application of biofertilizers had a significant effects on nutrient uptake of chickpea. Combined application of phosphate solubilizing

bacteria and *Trichoderma harzianum* produced the highest leaf P content (0.33%) and grain P content (279 mg 100 g-1).

Co-inoculation of phosphate solubilizing bacteria (PSB) *Pseudomonas* sp.and *B. japonicum* (TAL 379) significantly increased nodulation, plant total N, P uptake, seed yield and yield components of soybean over negative control and chemical fertilizers (Argaw, 2012).

Azospirillum brasilense and Trichoderma harzianum individually or in combination have a great potential to increase the growth and yield of wheat and corn in the field or in pot experiment. (Ezzat *et al.*, 2014).

Eventhough, there is a good deal of literature on individual biofertilizers and biocontrol agents like *Azospirillum,* phosphate solubilising bacteria, potash solubilising, *Pseudomonas fluorescens* and *Trichoderma,* not much literature is available on the effect in growth promotion and disease management in ginger. Also currently, very little information is available on mineral potassium solubilization by bacteria, their mechanisms of solubilization and their effect on growth, K uptake and yield of several crops including ginger.

Materials and methods

3. MATERIALS AND METHODS

A study was conducted on " Evaluation of bioinoculant consortia for organic cultivation of ginger " during 2013-2015 at the department of Agricultural Microbiology, College of Horticulture, Vellanikkara. The materials used and methodologies adopted in this study are presented below :

3.1 COLLECTION OF MICROBIAL CULTURES

The efficient cultures of *Azospirillum lipoferum,* phosphate solubilizing bacteria (PSB), potash solubilizing bacteria (KSB), *Pseudomonas fluorescens* and *Trichoderma viride* were obtained from the Department of Agricultural Microbiology, College of Agriculture, Vellayani. The isolates were purified and maintained for further studies. The media used for the maintenance of isolates are given in Table 1.

Table 1. Media used for purification and maintainence of microbial isolates

Media	Target organism
Okons Nitrogen free media (Okon *et al.*, 1977)	*Azospirillum lipoferum*
Pikovskaya's agar (Pikovskaya, 1948)	Phosphate solubilizing bacteria
Glucose Yeast Calcium agar media (Willems *et al.*, 1987)	Potash solubilizing bacteria
King's B agar (King *et al.*, 1954)	*Pseudomonas fluorescens*
Potato dextrose agar (Harrigan , 1998)	*Trichoderma viride*

3.2 MORPHOLOGICAL, CULTURAL AND BIOCHEMICAL CHARACTERIZATION OF THE BACTERIAL CULTURES

3.2.1 Morphological characterization of bacterial isolates

For morphological studies, 24 h old culture was used. Gram staining was employed to study the gram reaction. The shape and gram reaction of the bacteria were observed under oil immersion objective of the microscope.

3.2.1.1 Gram's staining

Gram's staining was done as described by Hucker and Conn (1923). The colour of the cells indicated the gram reaction.

3.2.2 Cultural characterization of bacterial cultures

Cultural characters of *A. lipoferum*, PSB, KSB, *P. fluorescens* were studied in their respective growth media. Colony characters like colour, form, elevation and margin were noted.

3.2.3 Biochemical characterization of bacteria

3.2.3.1 Citrate utilization test

Bacterial cultures (24 h old) were streaked on Simmon's citrate agar slants and observed for colour change of the medium (Schaad, 1992). A change in colour from green to blue in the medium indicated a positive test for growth using citrate.

3.2.3.2 Catalase test

Growth from an overnight culture of the isolate was smeared on a microscope slide. A drop of 3 % hydrogen peroxide solution was added on it. Cultures showing immediate effervescence were treated as positive for catalase activity (Taylor and Achanzar, 1972).

3.2.3.3 Starch hydrolysis

Starch agar plates were prepared and streaked with each isolate separately. The isolates were allowed to grow at 32^0C for 48 h. Iodine solution was poured on to the plate. The blue-black colour appears due to formation of starch-iodine complex (Priest, 1977).The clear zone around the colony indicated positive for amylase production.

3.2.3.4. Glucose fermentation test

Glucose fermentation broth was prepared in test tube. A durham's tube is put in inverted position into the broth. The test bacteria is inoculated into the broth. The inoculated tubes are incubated at 37°C for 24 h. A change in colour

from red to yellow and appearance of bubbles indicated positive test for glucose fermentation (Cowan, 1974).

3.3 MORPHOLOGICAL AND CULTURAL CHARACTERIZATION OF *Trichoderma viride*

Morphological and cultural characters of *T. viride* was studied in detail on PDA medium. Observations on shapes and colours of conidia, the branching patterns of conidiophores were observed under microsope. Cultural characters like colony form, colony colour were studied in PDA.

3.4 COMPATIBILITY STUDIES AMONG THE MICROBIAL CULTURES

The compatibility among the isolates of *A.lipoferum*, PSB, KSB, *P. fluorescens* and *T. viride* were studied.

3.4.1 *In vitro* evaluation of mutual compatibility between bacteria and bacteria

3.4.1.1 Cross streaking method

The bacterial cultures *Azospirillum lipoferum*, PSB, KSB, *Pseudomonas fluorescens* were studied for their mutual compatibility with each other by cross-streak assay method (Raja *et al.*, 2006). For this nutrient agar medium was prepared, autoclaved and plated. To test the compatibility between *Azospirillum lipoferum*, and PSB, *Azospirillum lipoferum* was streaked at one end of the Petri plate as a single streak and PSB was streaked vertically to this and plates were incubated at 32^0C for one week. Inhibition activity was recorded around the colonies of each organism. Three such replications were maintained in same plate. Same procedure was followed for testing the mutual compatibility between all the other cultures.

3.4.2. In vitro evaluation of mutual compatibility between bacteria and *T. viride*

3.4.2.1 Dual culture technique

This test was performed to test the compatibility of *Azospirillum lipoferum,* PSB, KSB, Pseudomonas fluorescenswith *T. viride.* To test the compatibility between *Azospirillum lipoferum and T. viride,* a mycelia disc of 10 mm size of *T. viride* was inoculated at the centre of Petri dish plated with PDA medium. *Azospirillum lipoferum* was inoculated as a line of streak on either side of disc, leaving 2.25 cm from periphery of Petri dish. The plates were then incubated at 28± 2^0C and observed daily for any type of inhibition. The absence of inhibition indicated compatibility. The same procedure was performed with all other bacterial cultures and *T. viride.* Per cent inhibition was calculated using the formula,

$$\text{Per cent Inhibition (PI)} = \frac{C-T}{C} \times 100$$

C = Growth of fungus in control

T = Growth of fungus in dual culture

3.4.2.2 Seeding technique

To test the compatibility between *Pseudomonas fluorescens* and *T. viride* seeding technique was carried out. A 6 mm disc of *T. viride* was kept at centre of nutrient agar plate seeded with *Pseudomonas fluorescens.*The Petri dish was incubated at room temperature and observations on inhibition zone and growth of fungus were recorded till full growth in the control plate .The per cent inhibition over control was calculated as mentioned in 3.4.2.1

3.5 PREPARATION OF CARRIER- BASED FORMULATION OF THE MICROBIAL CULTURES

Carrier-based formulation consisting of individual microbial culture and consortia of microbial cultures was prepared. Consortia of microbial inoculants selected were : consortia of compatible biofertilizers (*A. lipoferum*, PSB, and KSB), consortia of compatible biocontrol agents (*P. fluorescens, T. viride*), consortia of compatible biofertilizers and biocontrol agents (*A. lipoferum*, PSB, KSB, *P. fluorescens, T. viride*).

3.5.1 Preparation of inoculum

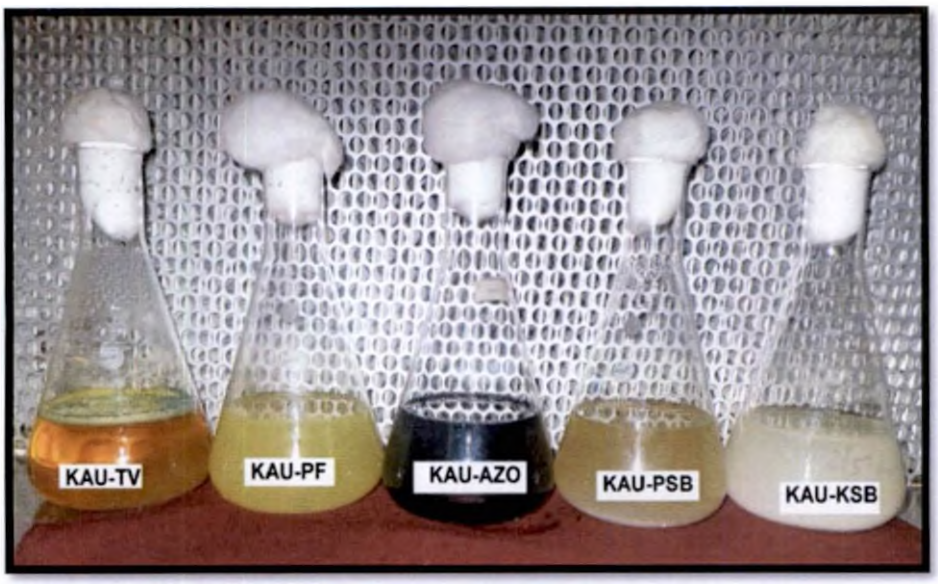
For the preparation of bacterial inoculum two loops full of bacterial culture was inoculated into 50 ml of broth specific for its growth. After 2 days of inoculation, 5 ml of inoculum was taken from this 50 ml and transferred to 300 ml of respective broth for 3 days. In the case of fungus, 2 discs (10 mm) were transferred into 50 ml of PDA broth and incubated for 2 days for inocubation following which 5 ml was taken from this and transferred into 300 ml of PDA broth and kept for 5 days for incubation. (Zaidi *et al*, 2014) (Plate 1).

3.5.2 Mixing of inoculums with carrier material

For formulation containing individual organism of *A. lipoferum,* PSB, KSB, *P. fluorescens and T. viride*, 300 ml of inoculum was mixed with one kg of vermicompost. In case of consortia of microbial inoculants, 300 ml of each compatible isolates were mixed with 1 kg of vermicompost . It is then air dried to make the final moisture content of 25-30 %. (Zaidi *et al*, 2014) (Plate1).

3.6 FIELD EVALUATION OF MICROBIAL INOCULANT CONSORTIA FOR GROWTH PROMOTION AND DISEASE MANAGEMENT IN GINGER

The five microbial cultures *viz., A. lipoferum,* PSB, KSB, *P. fluorescens* and *T. viride*, were evaluated for their efficacy in enhancing growth and disease management of ginger under field conditions. The experiment was conducted during May 2015 to December 2015 at College of Horticulture, Vellanikkara.



A. **Inoculum of microbial isolates**

B. Broth culture of KAU-AZO in vermicompost

Plate 1. Preparation of carrier- based formulation of the microbial cultures

Variety : Himachal

Design : RCBD

Replication : 3

Bed size : 2 m x 1 m

Spacing : 25 cm x 25 cm

No. of plants / bed : 32

Time of application of treatments: At the time of planting

Treatment détails

T_1 : *Azospirillum lipoferum*

T_2 : PSB

T_3 : KSB

T_4 : *Pseudomonas fluorescens*

T_5 : *Trichoderma viride*

T_6 : *A. lipoferum* + PSB + KSB

T_7 : *A. lipoferum* + PSB + KSB + *P. fluorescens*

T_8 : *A. lipoferum* + PSB + KSB + *T. viride*

T_9 : PGPR Mix I

T_{10} : PGPR Mix II

T_{11} : Organic adhoc package (KAU, 2009) (Appendix II)

T_{12} : POP recommendation (KAU, 2011) (Appendix III)

T_{13} : Control

Farm yard manure was applied for all the treatments @ 30 tons / ha. Treatments T_1 to T_8 were applied @160 g per $2m^2$ and T_9 to T_{12} as per KAU POP recommendation. Mulching was done for all the treatments.

3.7 OBSERVATIONS

Observations on number of days taken for germination, germination percentage, number of tillers, plant height, rhizome yield, pest and disease incidence, soil microbial population, available NPK content, organic carbon and pH of soil were recorded at frequent intervals. B: C ratio was also calculated.

3.7.1 Number of days taken for early sprouting

Number of days taken for seed germination was recorded.

3.7.2 Germination Percentage

$$\text{Germination percentage} = \frac{\text{No. of plants germinated}}{\text{Total no. of plants per treatment}} \times 100$$

3.7.3 Number of tillers

Number of tillers was recorded by counting the fully emerged ones.

3.7.4 Plant Height

The distance from the base of the plant to the tip was taken as plant height and expressed in centimeters.

3.7.5 Rhizome yield

The fresh rhizome yield from each treatment was recorded at the time of harvest and which was expressed as Kg / bed. Yield per plant was also recorded.

3.7.6 Pest and disease incidence

Pest and disease incidence on plants were recorded throughout the period of study.

3.7.7 Soil Reaction (pH)

The pH of the soil was recorded before planting the crop and also 3 months and 6 months after planting. The pH of the soil was determined in 1:2.5 soil-water suspensions (Metson, 1956). Ten gram of air-dried and 2 mm sieved soil was taken in a 50 ml beaker. Twenty five milliliter of distilled water was added, stirred well for about 5 min and kept for half an hour and Stirred well again and took the reading using the pH meter (ELICO L1 120).

3.7.8 Organic Carbon

The organic carbon content of the soil was recorded before planting the crop and also 3 months and 6 months after planting. The soil organic carbon was determined by using Walkley–Black wet digestion method (Walkley, 1947). The soil was ground to pass though a 0.5 mm sieve transferred 0.5 to 1.0 g soil, into a 500 ml wide mouth conical flask. 10 ml of 1N $K_2Cr_2O_7$ was added and swirled the flask gently to disperse the soil in the solution. Then, 20 ml of concentrated H_2SO_4 was added rapidly. Immediately the flask was swirled gently until the soil and the reagents were mixed. The flask was allowed to stand on an asbestos sheet for about 30 min. Then 200 ml of water was added to the flask along with 3-4 drops of ferroin indicator and titrated the solution with 0.5 N ferrous ammonium sulphates.

As the end point approached, the solution attained a greenish cast and then changed to a dark green colour. At this point, the ferrous ammonium sulphate was added drop by drop until the colour changed sharply from blue to red. A blank determination was also made in the same manner, but without soil, to standardize the $Cr_2O_7^{2-}$.

$$OC\ (\%) = \frac{(\text{meq } K_2Cr_2O_7 - \text{meq } Fe(NH_4)_2SO_4) \times 0.003 \times 100 \times 1.3}{\text{weight of soil (g)}}$$

3.7.9 Available nitrogen

The available nitrogen content of the soil was recorded before planting the crop and also 3 months and 6 months after planting. Place 5 g of soil sample in Kjeldahl tube. Add 30 ml of .32 % $KMnO_4$. Place a 250 ml conical flask containing 25 ml of 2.5 % boric acid with mixed indicator at the end of delivery tube .Tap water is allowed to run through condenser unit. To the contents of Kjeldhal flask, add 30 ml of NaOH (2.5 %) automatically and keep the flask in place. Start the distillation process and continue until about 100 ml of distillate is collected in the conical flask. The completion of the distillation can be confirmed by moist litmus paper. After completion of distillation, take out the conical flask containing the distillate from the unit and titrate the contents against standard H_2SO_4 (0.01 N) till the bluish green colour turns light red. Run a blank distillation without soil and note down the blank titre value. (Subbia and Asija, 1956).

$$\text{mg of N/ g of C source} = \frac{TV - BV \times N \times 0.014 \times 1000}{Y}$$

Where, TV = Titre value

BV = Blank value

N = Normality of H_2SO_4

Y = Weight of C source

3.7.10 Available Phosphorus

The data on available phosphorus content of the soil was recorded before planting the crop and also 3 months and 6 months after planting. Available 'P' was extracted using Bray No. 1 (Bray and Kurtz, 1945), which consisted of 0.03 N NH_4F and 0.025 N HCl. Add five grams of soil to a 250 ml conical flask with 50 ml of Bray No.1 reagent and shake for five minutes. Filtering was done though Whatman No. 42 filter paper and to avoid interference of fluoride, 7.5 ml of 0.8 M (10 ml, 4%) boric acid (50 g H3BO3 per litre) was added to 5 ml of the extract. Estimation was done by reduced molybdate blue colour method (Olsen *et al.*, 1954).

Five milliliter of the extract was pipetted out into a 25 ml volumetric flask and diluted to approximately 20 ml. Four milliliter of reagent B (Appendix Ii) was added and the volume was made up with distilled water and mixed the contents well. After 10 min, the intensity of colour was read at 660 nm. The colour was stable for 24 h and the maximum intensity developed within 10 min. The concentration of P in the sample was computed using standard curve.

For the preparation of standard curve, different concentrations of P at 1, 2, 3, 4, 5 and 10 ml of 2 µg ml-1 P solution was prepared in 25 ml volumetric flasks. Five milliliter of the extracting reagent (Bray No.1) was added and colour developed as described above by adding reagent B. The concentration vs. absorbance curve was plotted on a graph paper.

$$\text{Available P (mg/kg soil)} = \frac{\text{Absorbance for sample}}{\text{Slope of standard curve}} \times \frac{50}{5} \times \frac{25}{5}$$

3.7.11 Available Potassium

The available potassium content of the soil was recorded before planting the crop and also 3 months and 6 months after planting. Estimation was done by flame photometric method (Jackson, 1973). Five gram of soil was mixed with 25 ml of neutral normal potassium acetate for five minutes and filtered immediately through a Whatman No. 42 filter paper. First few ml of the filtrate was discarded. Potassium concentration in the extract was determined using flame photometer after necessary settings and calibration of the instrument.

Standard curve for potassium was prepared by using standard solution of ammonium acetate. Measured aliquots were diluted from the standard solution using ammonium acetate solution to give concentrations of 5 to 20 µg ml^{-1} of K. After attaching the appropriate filter and adjusting the gas and air pressure, the reading was set in the flame photometer as zero for the blank (ammonium acetate) and at 100 for 20 µg/ml of K. The curve was obtained by plotting the readings against the different concentrations (5, 10, 15 0and 20 µg/ml) of K.

$$\text{Available K (mg kg}^{-1}\text{ soil)} = \text{µg K per ml of aliquot} \times \frac{25}{5}$$

3.7.12 Enumeration of inoculated microbial isolate population

Enumeration of population from the soil applied with different microbial inoculants were done at bimonthly interval. Individual population of respective individual microbial inoculants were recorded in treatments wherever individual isolates were used. However, in the case of consortial treatments, the population was recorded for the respective selected isolates. The rhizosphere soils of ginger from all the treatments were collected and *P. fluorescens*, PSB and KSB *and Trichoderma* sp. were quantitatively estimated by serial dilution and plating technique (Johnson and Curl, 1972). For enumeration of *Azospirillum* , test tubes containing 5.0 ml Nfb semi-solid medium (Okon *et al.*, 1977) was inoculated with 0.1 ml of appropriate dilutions (10^{-4}, 10^{-5}, 10^{-6} , 10^{-4}) of soil suspension and enumeration was performed using MPN method (Dobereiner, 1995). White pellicle formation and blue colour development in the media were taken as positive for *Azospirillum*.

3.7.13 Benefit cost ratio

Benefit – cost ratio for the different treatments were calculated

3.2.14 Statistical analysis

Analysis of variance was done on the data collected using the statistical package MSTAT (Freed, 1986). Multiple comparisons among the treatment means were done using DMRT.

4. RESULTS

An experiment on "Evaluation of bioinoculant consortia for organic cultivation of ginger" was carried out to develop a consortium for growth promotion and disease management in ginger under field condition. The results obtained from the experiments are provided in this chapter.

4.1 SOURCE OF MICROBIAL ISOLATES

Five efficient beneficial microbial isolates were obtained from the Department of Agricultural Microbiology, College of Agriculture, KAU, Vellayani (Table 2).

4.2 MORPHOLOGICAL, CULTURAL AND BIOCHEMICAL CHARACTERIZATION OF THE BACTERIAL CULTURES

4.2.1 *Azospirillum lipoferum*

The bacterium was found to be Gram negative and slightly curved in shape. The colonies were circular in shape, convex and glistening with entire margin. It was positive for catalase and produced acid from glucose utilization. However, there were negative results for starch hydrolysis (Plate 2). They formed white pellicle at the sub-surface (1-2mm) in nitrogen free malate (Nfb) medium and turned the pH of the media to alkaline.

4.2.2 Phosphate solubilizing bacteria

The bacteria were Gram positive and rod shaped. The colonies were circular, flat with entire margin. It recorded positive for catalase test, starch hydrolysis, citrate utilization and acid production from glucose (Plate 2). However, there was no gas formation from glucose utilization. The bacteria formed solubilization zone in Pikovskaya's agar media.

Table 2. List of microbial isolates

Sl .No.	Microbial isolates	Isolate code
1	*Azospirillum lipoferum*	KAU-AZO
2	Phosphate solubilizing bacteria	KAU-PSB
3	Potash solubilizing bacteria	KAU-KSB
4	*Pseudomonas fluorescens*	KAU-PF
5	*Trichoderma viride*	KAU-TV

4.2.3 Potash solubilizing bacteria

The bacterium was Gram negative and rod shaped. The colonies were circular, flat with entire margin. On GYC agar media they formed solubilisation zone. They were positive for catalase and negative for indole formation (Plate 2).

4.2.4 *Pseudomonas fluorescens*

The isolates were Gram negative and curved rods. The colonies were circular and raised with entire margin.They exhibited positive reaction for glucose fermentation and were negative for starch hydrolysis (Plate 2). They produced fluorescent pigments which was visible under ultra violet light.

4.3 MORPHOLOGICAL AND CULTURAL CHARACTERIZATION OF *Trichoderma viride*

Morphological and cultural characters were studied on potato dextrose agar media. Colonies were smooth surfaced, became hairy and colour changed from whitish green to dark green. The hyphae were septate and hyaline. Conidiophores were hyaline and conidia green in colour.

4.4 COMPATIBILITY BETWEEN THE MICROBIAL ISOLATES

4.4.1 *In vitro* evaluation of mutual compatibility between bacteria and bacteria

All the four bacterial isolates *viz., A lipoferum,* PSB, KSB and *P. fluorescens* were checked for their mutual compatibility by using cross streak method. No lysis was observed at the juncture indicating their compatibility to each other (Plate 3).

4.4.2 *In vitro* evaluation of mutual compatibility between bacteria and *T. viride*

All the bacterial isolates *viz.*, *A. lipoferum,* PSB, KSB and *P. fluorescens* were tested for their compatibility with *T. viride* by dual culture technique (Plate 4). All the isolates of bacteria were compatible except for *P. fluorescens* which was incompatible with *T. viride* (56.77 % inhibition).

4.4.3 Selection of isolates for field evaluation based on compatibility studies

Based on compatibility studies, the consortia of biofertilizers alone and biofertilizer cum bioagents were selected for the field evaluation (Table 3). Consortia of *P. fluorescens* + *T. viride* were not selected for further studies as they were incompatible with each other.

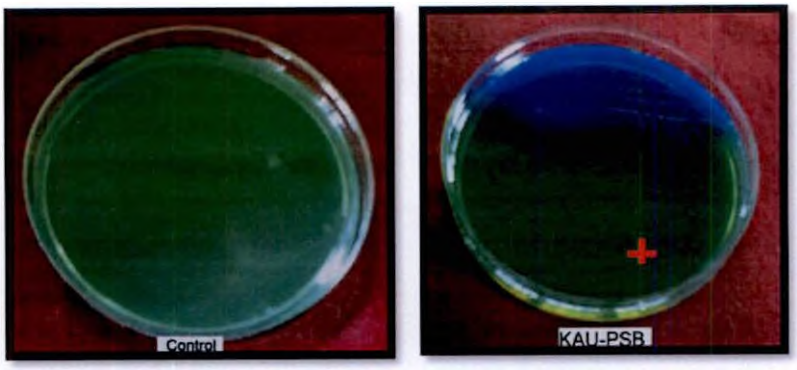
4.5 POPULATION OF MICROBIAL CULTURES IN VERMICOMPOST BASED FORMULATION

4.5.1 Population of bacterial and fungal isolates in the broth before mixing with vermicompost

The population of *A. lipoferum* in the broth before mixing with vermicompost was 3.6×10^{8} MPN/ml. The PSB, KSB, *P. fluorescens* and *T. viride* recorded 2×10^{8} cfu ml^{-1}, 3.1×10^{8} cfu/ml , 6.3×10^{8} cfu ml^{-1} and 7.3×10^{6} cfu ml^{-1} respectively (Table 4, Plate 5).

4.5.2 Population of individual and consortial microbial isolates in unsterile vermicompost

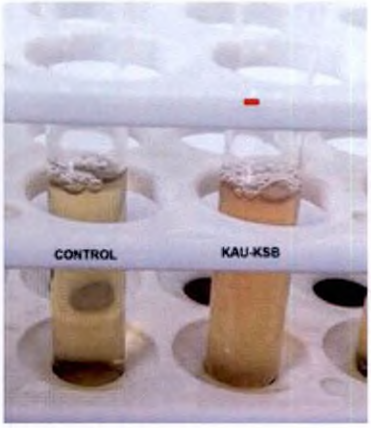
Population count of the microbial isolates were taken 72 h after mixing with the carrier material (Table 5). In the unsterilized vermicompost , *A. lipoferum* population was 14.33×10^{8} MPN/g in KAU-AZO formulation, 12×10^{8} MPN/g in KAU-AZO + KAU-PSB + KAU-KSB formulation, 6×10^{8} MPN/g in KAU-AZO + KAU-PSB +KAU-KSB + KAU-PF formulation and 10.66×10^{8} MPN/g



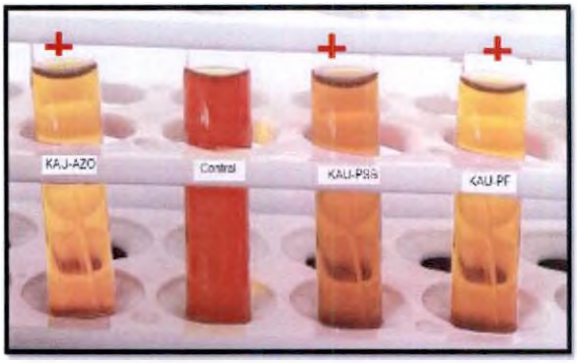
A. Citrate test

B. Starch hydrolysis test

C. Catalase test



D. Indole test



E. Glucose fermentation test

Plate 2. Biochemical test

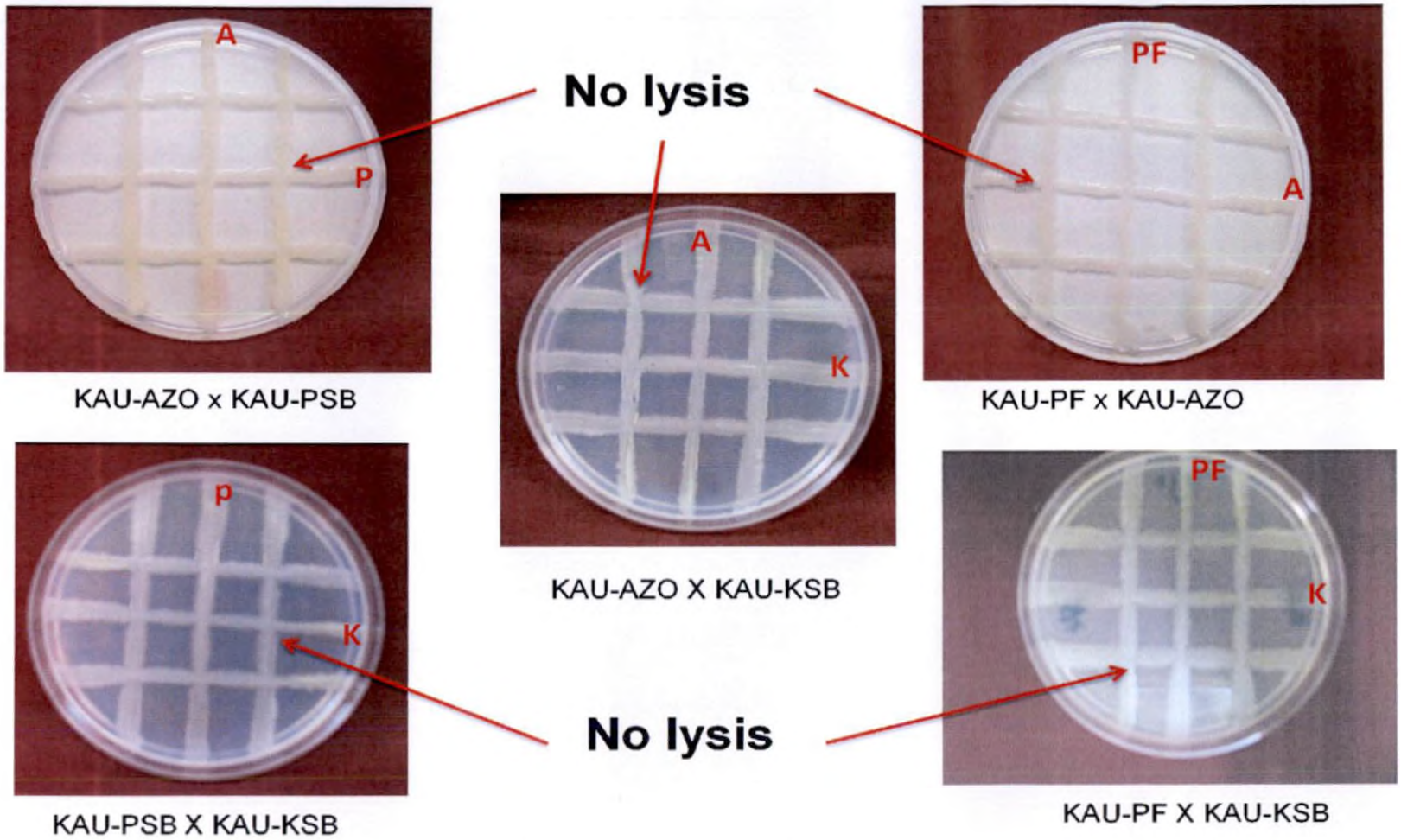


Plate 3 . ***In vitro*** **evaluation of mutual compatibility between bacteria and bacteria**

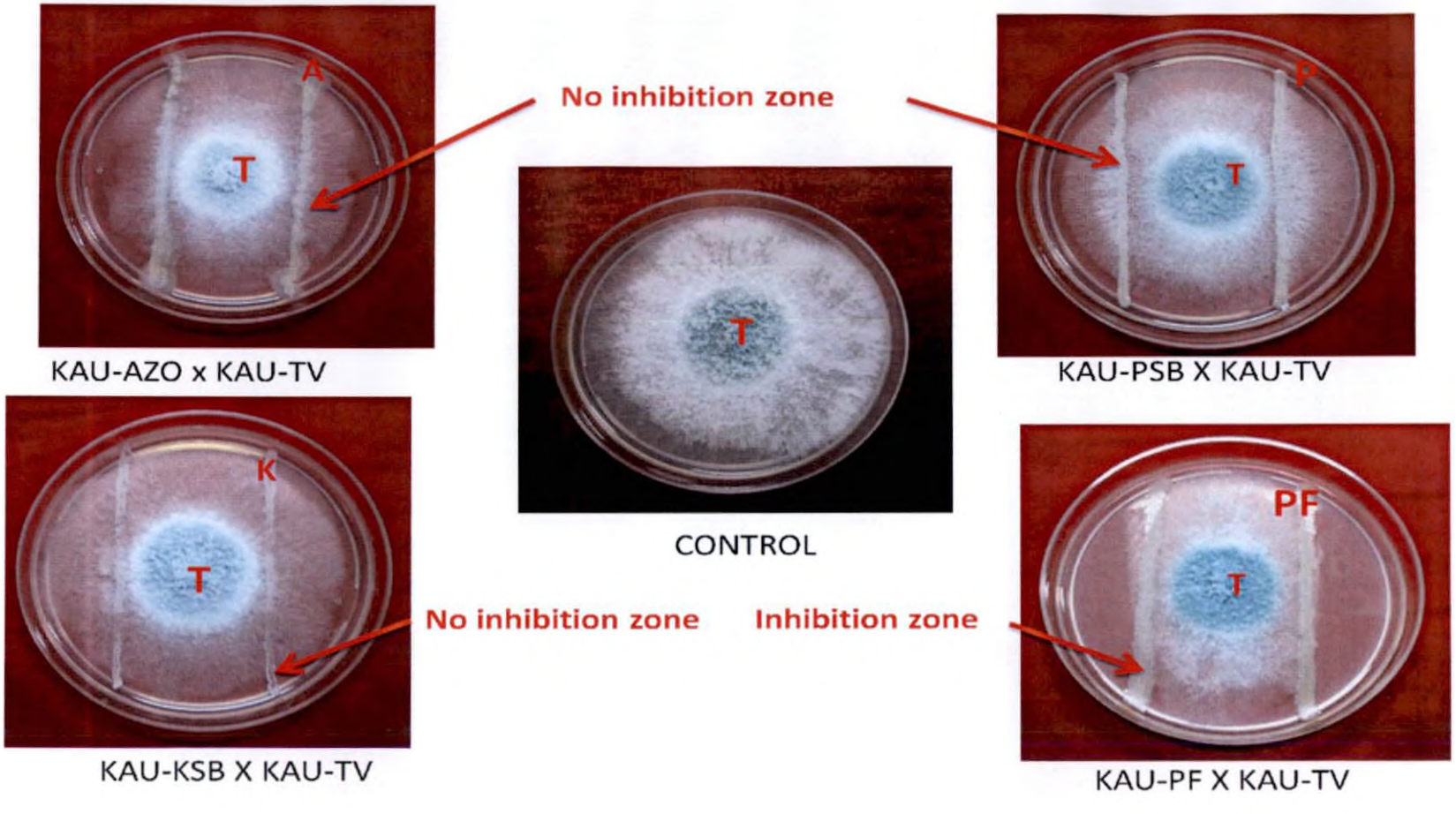
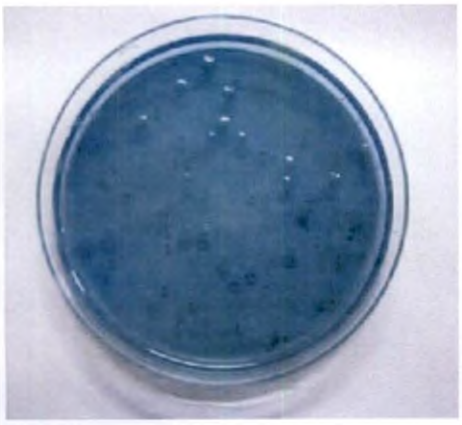
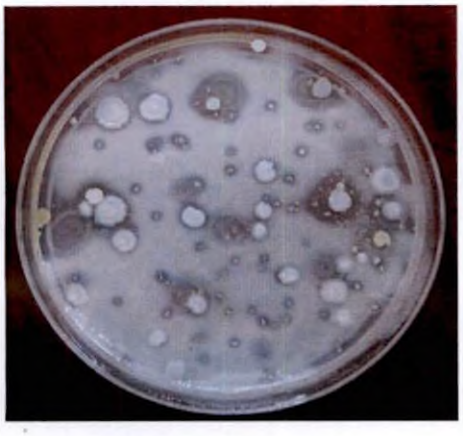


Plate 4. ***In vitro*** **evaluation of mutual compatibility between bacteria and** ***Trichoderma viride***

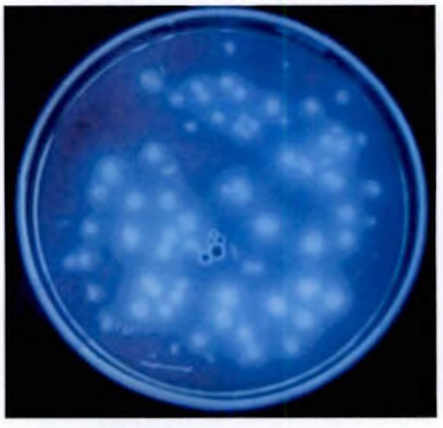


KAU-AZO

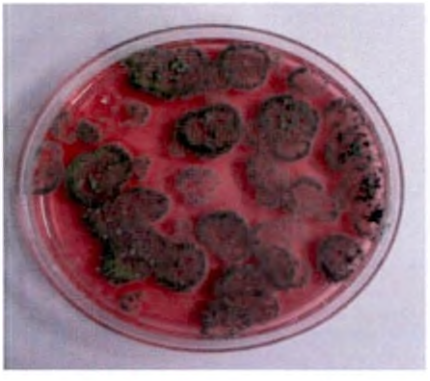
KAU-PSB



KAU-KSB



KAU-PF



KAU-TV

Plate 5. Population of bacterial and fungal isolates in the broth before mixing with vermicompost

Table 3. List of compatible isolates selected for the field

Consortium		Isolates selected
Biofertilizers		*A. lipoferum* + Phosphate solubilizing bacteria + Potash solubilizing bacteria
Biofertilizer + Biocontrol agent	1	*A. lipoferum* + Phosphate solubilizing bacteria + Potash solubilizing bacteria + *P. fluorescens*
	2	*A. lipoferum* + Phosphate solubilizing bacteria + Potash solubilizing bacteria + *T. viride*

Table 4. Population of selected isolates in the inoculum before mixing with the vermicompost as carrier material

Sl. No.	Isolate	Count (cfu/ml) *
1	KAU-AZO	3.6×10^8 (MPN/ml)
2	KAU-PSB	2×10^8
3	KAU-KSB	3.1×10^8
4	KAU-PF	6.3×10^8
5	KAU-TV	7.3×10^6

* Each value represent mean of three replications

in KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV carrier-based formulation . Highest population was in KAU-AZO (14.33 x 10^8 MPN/g) formulation and lowest was in KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF (6 x 10^8 MPN/g) formulation.

The population of PSB was 8 x 10^8 cfu ml^{-1} in KAU-PSB formulation , 6.33 x 10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB formulation , 7 x 10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB+ KAU-PF formulation and 6.66 x 10^8 cfu ml^{-1} in KAU-AZO+KAU-PSB+ KAU-KSB+KAU-TV formulation. The highest population of phosphate solubilizing bacteria was found in KAU-PSB (8 x 10^8 cfu ml^{-1}) formulation and the lowest population of 6.33 x 10^8 cfu ml^{-1} was in KAU-AZO + KAU-PSB + KAU-KSB formulation and KAU-AZO + KAU-PSB + KAU-KSB formulation.

Population of KSB was absent in KAU-KSB, KAU-AZO + KAU-PSB +KAU-KSB formulation, KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF formulation and KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV formulations.

Population of *P. fluorescens* was 18.33 x 10^8 cfu ml $^{-1}$ in KAU-PF formuation and 17.66 x 10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF formulation while population of *T. viride* was 15.66 x 10^6 cfu ml^{-1} in KAU-TV formulation and 13.33 x 10^{-6} cfu ml^{-1} in KAU- AZO + KAU-PSB + KAU-KSB +KAU-TV formulation.

4.5.3 Population of individual and consortial microbial isolates in sterilized vermicompost

The population of individual and consortial microbial isolates in sterilized vermicompost are given in Table 5. *A. lipoferum* population was 3.7 x 10^8 MPN/g in KAU-AZO formulation , 3.13 x 10^8 MPN/g in KAU-AZO + KAU-PSB + KAU-KSB formulation, 3.2 x10^8 MPN/g in KAU-AZO + KAU-PSB +KAU-KSB + KAU-PF formulation and 3.5 x 10^8 MPN/g in KAU-AZO + KAU-

able 5. Population of selected isolates in vermicompost

Treatment	KAU-AZ0 ($x10^8$ MPN/g)		KAU-PSB ($x10^8$cfu/g)		KAU-KSB ($x10^8$cfu/g)		KAU-PF ($x10^8$cfu/g)		KAU-TV ($x10^6$ cfu/g)	
	Unsterle	Sterile	Unsterile	Sterile	Unsterile	Sterile	Unsterile	Sterile	Unsterile	Sterile
T_1 : KAU-AZO	14.33	3.7	ND	ND	ND	ND	ND	ND	ND	ND
T_2 : KAU-PSB	ND	ND	8	2.4	ND	ND	ND	ND	ND	ND
T_3 : KAU-KSB	ND	ND	ND	ND	Absent	7.1	ND	ND	ND	ND
T_4 : KAU-PF	ND	ND	ND	ND	ND	ND	18.33	4.6	ND	ND
T_5 : KAU-TV	ND	ND	ND	ND	ND	ND	ND	ND	15.66	4.6
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	12	3.13	6.33	2.2	Absent	4	ND	ND	ND	ND
T_7 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF	6	3.2	7	2.2	Absent	5.2 .	17.66	3.7	ND	ND
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV	10.66	3.5	6.66	2.3	Absent	5	ND	ND	13.33	4.2

Each value represent mean of three replications., ND-Not determined

PSB + KAU-KSB + KAU-TV formulation. Highest population was in KAU-AZO (3.7×10^8 MPN/g) formulation and lowest was in KAU-AZO + KAU-PSB + KAU-KSB (3.13×10^8 MPN/g) formulation.

However the population of PSB was 2.4×10^8 cfu ml^{-1} in KAU-PSB formulation , 2.2×10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB formulation , 2.2×10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB+ KAU-PF formulation and 2.3×10^8 cfu ml^{-1} in KAU-AZO+KAU-PSB + KAU-KSB+KAU-TV formulation. The highest population of PSB was found in KAU-PSB (2.4×10^8 cfu ml^{-1}) formulation and the lowest population of 2.2×10^8 cfu ml^{-1} was in KAU-AZO + KAU-PSB + KAU-KSB formulation and KAU-AZO + KAU-PSB + KAU-KSB+ KAU-PF formulation .

Population of KSB was 7.1×10^8 cfu ml^{-1} in KAU-KSB formulation, 4×10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB formulation , 5.2 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF formulation and 5 cfu ml^{-1} in KAU- AZO + KAU-PSB + KAU-KSB +KAU-TV formulation.

Population of *P. fluorescens* was 4.6×10^8 cfu ml $^{-1}$ in KAU-PF formulation and 3.7×10^8 cfu ml^{-1} in KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF formulation while population of *T. viride* was 4.6×10^6 cfu ml^{-1} in KAU-TV formulation and 4.2×10^{-6} cfu ml^{-1} in KAU- AZO + KAU-PSB + KAU-KSB +KAU-TV formulation.

4.6 EVALUATION OF CONSORTIAL INOCULANTS FOR GROWTH PROMOTION AND DISEASE MANAGEMENT IN GINGER UNDER FIELD CONDITION

The compatible microbial cultures were evaluated for their efficacy in enhancing growth and disease management in ginger under field conditions (Plate 6).

Plate 6. Overview of the field

4.6.1 Effect of microbial inoculants on germination

Number of days taken for sprouting ranged from 16-20 days (Table 6). The results indicated no significant differences in the treatment with respect to number of days taken for early sprouting. However, the minimum number of days (16.67) was recorded in the case of T_4 (KAU-PF) whereas a maximum (20.33 days) was recorded in the case of T_{10} (PGPR Mix II). Among the consortia, T_6 (KAU-AZO+KAU-PSB+KAU-KSB) recorded minimum number of days (17.33The control plants (T_{13}) recorded 18 days for sprouting. Cent percent germination was recorded in the treatment T_{10} (PGPR Mix II) while among consortia, T_6 (KAU-AZO + KAU-PSB + KAU-KSB) and T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF) recorded maximum per cent (91.67) germination after 45 days of planting.

4.6.2 Effect of microbial inoculants on plant height (cm)

The plant height recorded at monthly interval till harvest is given in Table 7 which showed significant difference among the treatments (Plate 7).

After one month of planting T_{11} (Organic adhoc package) recorded maximum plant height (19.76 cm) which was found to be on par with all other treatments exept for T_1 (KAU-AZO), T_2 (KAU-PSB) and T_3 (KAU-KSB). Minimum plant height (13.37 cm) was observed in T_2 (KAU-PSB). All the consortial treatments were on par with each other.

After two months of planting, T_{11} (Organic adhoc package) recorded maximum plant height (37.04 cm) which was found to be on par with T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF), T_8 (KAU-AZO + KAU-PSB +KAU-KSB + KAUTV), T_9 (PGPR Mix I) and T_{10} (PGPR Mix II) .Among the consortia T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded maximum plant height (35.65) which was on par with T_7.

Three month after planting T_{11} (Organic adhoc package) was found to be on par with T_{12} (POP recommendation) and recorded a maximum height (51.15 cm). T_{13} recorded the minimum plant height (31.57 cm). Among the consortia T_8

A. T_{11}: Organic POP

B. T_8: KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV

C. T_{13}: Control

Plate 7. Effect of bioinoculants on plant

Table 6. Effect of microbial inoculants on germination

Treatments	No of days taken for early sprouting *	Germination percentage	
		30 DAP *	45 DAP*
T_1 : KAU-AZO	18.0	44.79	84.37
T_2 : KAU-PSB	17.67	41.67	89.59
T_3 : KAU-KSB	18.33	32.30	85.42
T_4 : KAU-PF	16.67	45.84	89.59
T_5 : KAU-TV	17.67	45.84	90.63
T_6 : KAU-AZO + KAU-PSB + KAU- KSB	17.33	45.827	91.67
T_7 : KAU-AZO + KAU-PSB + KAU- KSB + KAU-PF	19.33	43.75	91.67
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV	18.0	26.04	87.50
T_9 : PGPR MIX I	18.33	48.96	92.71
T_{10}: PGPR MIX II	20.33	52.083	100
T_{11} : Organic adhoc package (KAU, 2009)	18.0	43.75	92.71
T_{12} : POP recommendation (KAU,2011)	17.67	42.34	88.54
T_{13} : Control	18.0	44.80	83.33
CD	NS	NS	NS

Each value represent mean of three replications, * Significantly not different

DAP - Days after planting NS-Not significant

Table 7. Effect of microbial inoculants on plant height (cm)

Treatments	Plant height (cm)				
	Months after planting				
	1	2	3	4	5
T_1 : KAU-AZO	14.96^{bc}	27.61^{e}	36.04 ^{f}	59.74 ^{bcd}	72.23 ^{cd}
T_2 : KAU-PSB	13.37^{c}	26.23 ^{ef}	35.71 ^{f}	55.61^{de}	71.13^{de}
T_3 : KAU-KSB	15.24^{bc}	23.233 ^{f}	32.54 ^{g}	50.21^{ef}	65.67 ^{ef}
T_4 : KAU-PF	16.14^{abc}	28.68 ^{de}	37.5 ^{ef}	59.08^{cd}	72.73^{cd}
T_5 : KAU-TV	16.68^{abc}	31.72 ^{cd}	39.42 ^{e}	60.95^{bcd}	73.78^{bcd}
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	18.15^{ab}	32.16 ^{bcd}	39.34 ^{e}	61.03^{bcd}	73.55 ^{bcd}
T_7 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF	17.62^{ab}	33.56 ^{abc}	39.72 ^{e}	61.94^{bc}	74.80^{bcd}
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV	18.21^{ab}	35.65^{ab}	43.08 ^{d}	62.03^{bc}	74.86 ^{bcd}
T_9 : PGPR Mix I	18.52^{ab}	35.91^{ab}	47.57 ^{bc}	65..43^{ab}	78.51^{abc}
T_{10} : PGPR Mix II	19.76^{a}	36.93 ^{a}	45.55 ^{cd}	63.14 ^{ab}	77.66^{abc}
T_{11} : Organic adhoc package (KAU, 2009)	18.80^{ab}	37.04 ^{a}	51.15 ^{a}	68.17^{a}	82.45^{a}
T_{12} : POP recommendation (KAU,2011)	18.81^{ab}	34.92 ^{abc}	49.95 ^{ab}	65.27^{ab}	79.36^{ab}
T_{13} : Control	13.51^{c}	22.97 ^{f}	31.57 ^{g}	48.09^{f}	62.15^{f}
CD (0.05)	4.08	3.78	2.57	5.99	6.33

Each value represent mean of three replications

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(KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded maximum plant height (43.08 cm).

Four and five months after planting showed similar results. T_{11} was found to be on par with T_9 (PGPR Mix I), T_{10} (PGPR Mix II) and T_{12} (POP recommendation) whereas the consortia T_8 (KAU-AZO+ KAU-PSB + KAU-KSB + KAU-TV) was found to be on par with T_6 (KAU-AZO + KAU-PSB + KAU-KSB) and T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF).

4.7.3 Effect of microbial inoculants on number of tillers

The results indicated that the influence of different treatments on the number of tillers was statistically significant at fourth and sixth month of planting (Table 8). However, there were no significant differences in the number of tillers at two months of planting.

Four months after planting, T_{11} (Organic adhoc package) recorded maximum tiller number (7.93) while T_{13} recorded least number of tillers (5.33). T_{11} was found to be on par with T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF), T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) T_9 (PGPR Mix I), T_{10} (PGPR Mix II) and T_{12} (POP recommendation). Among the consortia T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded maximum tiller number (6.72) which was on par with T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF).

After six months of planting, maximum number of tillers (8.14) was recorded in T_{11} and the least number (5.18) was found in T_{13} (Control). T_{11} was found to be on par with T_9 (PGPR Mix I), T_{10} (PGPR Mix II) and T_{12} (POP recommendation). T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAUTV) recorded maximum number of tillers (7.06) among the consortia which was on par with T_7 (KAU- AZO + KAU-PSB + KAU-KSB + KAU-PF).

Table 8. Effect of microbial inoculants on number of tillers

Treatments	Months after planting		
	2 *	4	6
T_1 : KAU-AZO	1.52	6.21^{bcd}	6.33^{cde}
T_2 : KAU-PSB	1.50	5.67^{cd}	6.09^{de}
T_3 : KAU-KSB	1.56	5.38^{d}	5.89^{ef}
T_4 : KAU-PF	1.55	5.81^{bcd}	5.92^{ef}
T_5 : KAU-TV	1.53	6.25^{bcd}	6.70^{cde}
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	1.72	6.23^{bcd}	6.87^{cd}
T_7 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF	1.78	6.53^{abcd}	6.94^{bcd}
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAUTV	1.81	6.72^{abcd}	7.06^{bc}
T_9 : PGPR Mix I	1.61	7.19^{abc}	7.80^{ab}
T_{10} : PGPR Mix II	1.70	7.16^{abc}	7.78^{ab}
T_{11} : Organic adhoc package (KAU, 2009)	1.78	7.93^{a}	8.14^{a}
T_{12} : POP recommendation (KAU,2011)	1.72	7.39^{ab}	7.78^{ab}
T_{13} : Control	1.41	5.33^{d}	5.18^{f}
CD (0.05)	NS	1.43	0.79

Each value represent mean of three replications; * No significant difference

NS-Not significant

4.7.4 Effect of microbial inoculants on rhizome yield

The data on the average yield of ginger rhizomes per bed are presented (Table 9, Plate 8). Plants in T_{11} (Organic adhoc package) produced the maximum yield of 11.04 t/ha which was on par with T_{12} (POP recommendation) while the lowes yield of 5.67 t/ha was recorded in T_{13} (Control). All the consortial reatments were statistically on par with each other. T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded lowest percentage of infected rhizome (0.89).

Among the treatments T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum percent of infected rhizome 0.89 % against 3.7 % in control.

4.7.5 Pest and disease incidence

4.7.5.1 Effect of microbial inoculants on disease incidence

The diseases noticed during the crop period were rhizome rot and leaf blight (Table 10). The results revealed that the different treatments had significant effect on the per cent incidence of rhizome rot (Plate 9)

Observations recorded at 3 MAP showed no rhizome rot incidence in T_{11} (Organic adhoc package) and T_5 (KAU-TV). Among the consortia, T_6 (KAU-AZO + KAU-PSB + KAU-KSB) recorded the minimum per cent incidence (2.78%). Control plants (T_{13}) recorded maximum per cent incidence of rhizome rot (6.25 %).

At four months after planting minimum per cent incidence (1.04 %) of rhizome rot was noticed in T_{11} (Organic adhoc package) and T_5 (KAU-TV). Among the consortia T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum per cent incidence (3.14%). Maximum per cent incidence (6.28 %) was found in T_{13} (Control).

Table 9. Effect of microbial inoculants on rhizome yield

Treatments	Yield (t/ha) (Marketable)	Yield (g) / plant	Non marketable yield (%)
T_1 : KAU-AZO	7.39^{d}	96.146^{d}	1.96^{bcd} (1.4)
T_2 : KAU-PSB	6.49^{ef}	84.366^{ef}	2.23^{abc} (1.46)
T_3 : KAU-KSB	5.76^{fg}	74.912^{fg}	3.37^{ab} (1.79)
T_4 : KAU-PF	6.88^{de}	89.509^{de}	1.51^{cd} (1.22)
T_5 : KAU-TV	7.64^{cd}	99.370^{cd}	1.17^{cd} (1.07)
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	8.25^{bc}	107.293^{bc}	2.10^{abc} (1.44)
T_7 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF	8.82^{b}	114.735^{b}	1.55^{cd} (1.24)
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV	8.93^{b}	116.158^{b}	0.89^{d} (0.94)
T_9 : PGPR Mix I	9.01^{b}	117.179^{b}	1.47^{cd} (1.17)
T_{10} : PGPR Mix II	8.72^{b}	113.375^{b}	1.41^{cd} (1.18)
T_{11} : Organic adhoc package (KAU, 2009)	11.04^{a}	143.592^{a}	1.37^{d} (1.15)
T_{12} : POP recommendation (KAU,2011)	10.47^{a}	136.212^{a}	2.03^{bcd} (1.39)
T_{13} : Control	5.67^{fg}	73.855^{g}	3.7^{a} (1.89)
CD (0.05)	0.79	10.33	1.56

Each value represent mean of three replication Figures in paranthesis are square root transformed values

A. T_{11}: Organic POP

B. T_8: KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV

C. T_{13}: Control

Plate 8. Effect of different treatments on yield/ 6m^2

Table 10. Effect of microbial inoculants on per cent incidence of rhizome rot and *Rhizoctonia* leaf blight

Treatments	Per cent incidence					
	Rhizome rot			*Rhizoctonia* leaf blight		
	3 MAP	4 MAP	5 MAP	3 MAP	4 MAP	5 MAP
T_1 : KAU-AZO	5.21^{a} (2.37)	5.23^{a} (2.37)	8.37^{abc} (2.97)	4.17(2.14)	5.21(2.15)	7.29 (2.73)
T_2 : KAU-PSB	4.17^{ab} (2.14)	5.23^{a} (2.27)	8.37^{abc} (2.97)	4.17(2.14)	8.34(2.94)	10.43(3.27)
T_3 : KAU-KSB	5.21^{a} (2.15)	5.23^{a} (2.37)	7.33^{a} (3.3)	4.17(2.14)	8.34(2.89)	9.39(3.12)
T_4 : KAU-PF	2.78^{abc} (1.87)	3.14^{abc} (1.9)	6.28^{abc} (2.6)	1.04(1.92)	4.17(1.92)	5.18(2.5)
T_5 : KAU-TV	0.00^{c} (0.7)	1.04^{c} (1.12)	6.28^{abc} (2.55)	2.08(1.51)	6.26(2.6)	6.26(2.6)
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	2.78^{abc} (1.81)	4.19^{ab} (2.14)	7.33^{abc} (2.79)	3.13(1.74)	7.30(2.71)	9.39(3.04)
T_7 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF	4.17^{ab} (2.14)	5.23^{a} (2.37)	6.28^{abc} (2.55)	2.08(1.51)	4.17(2.14)	5.21(2.37)
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV	3.13^{ab} (1.91)	3.14^{abc} (1.9)	5.23^{a} (2.37)	5.21(2.15)	6.26(2.55)	6.26(2.55)
T_9 : PGPR Mix I	1.04^{bc} (1.11)	2.09^{bc} (1.51)	8.37^{abc} (2.97)	3.13(1.91)	6.26(2.55)	8.34(2.94)
T_{10} : PGPR Mix II	1.04^{bc} (1.11)	2.09^{bc} (1.51)	5.23^{cd} (2.15)	3.13(1.74)	6.26(2.33)	6.26(2.33)
T_{11} : Organic adhoc package (KAU, 2009)	0.00^{c} (0.7)	1.04^{c} (1.12)	2.09^{d} (1.51)	1.04(1.11)	3.13(1.74)	4.17(1.97)
T_{12} : POP recommendation (KAU,2011)	3.13^{abc} (1.74)	5.23^{a} (2.37)	8.37^{abc} (2.97)	3.13(2.14)	5.21(2.78)	8.34(2.96)
T_{13} : Control	6.25^{a} (2.55)	6.28^{a} (2.6)	9.42^{ab} (3.12)	7.30(2.71)	9.38(3.12)	12.51(3.59)
CD (0.05)	3.7	2.9	4.23	NS	NS	NS

Each value represents mean of three replications, MAP - Months after planting
Figures in parenthesis are square root transformed values

Rhizome rot

Rhizoctonia leaf blight

Rhizome maggot incidence

Plate 9. Disease and pest incidence

Similar trend was observed at five months after planting. T_{11} (Organic adhoc package) recorded minimum per cent incidence of rhizome rot (2.09 %) while T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum per cent (5.23%) incidence among consortia. Maximum rhizome rot incidence was in T_{13} (Control) with a per cent incidence of 9.42 %.

The results on per cent incidence of leaf blight indicated that the different treatments had no significant influence on the per cent incidence. Treatment T_{11} (Organic adhoc package) recorded the minimum per cent incidence (4.17%). Among the consortia, T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF) recorded minimum per cent incidence (5.21 %) of leaf blight. Control plants (T_{13}) recorded maximum per cent incidence (12.51 %).

4.7.5.2 Effect of microbial inoculants on pest incidence

The per cent incidence of pest were at 3, 4 and 5 months after planting (Table 11). The pests noticed were rhizome maggot and shoot borer (Plate 9). No significant differences were found among the treatments for rhizome maggot and shoot-borer infection . However, plants in T_6 (KAU-AZO + KAU-PSB + KAU-KSB) and T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAUTV) were found to be more succeptible to shoot-borer attack. It was noticed that T_1 (KAU-AZO) was comparatively more tolerant to shoot-borer attack than other treatments. Per cent incidence of rhizome maggot was maximum in the case of T_1 (KAU-AZO) which recorded 37.5 per cent while minimum of 4.17 per cent was recorded in T_5 (KAU-TV). Among the consortia, T_7 was the most succeptible to rhizome maggot attack (36.46 %) while T_6 (6.25 %) was the least succeptible.

4.7.6 Effect of microbial inoculants on pH and soil nutrient status at different stages of plant growth

4.7.6.1 *Soil pH*

The pH of the soil was recorded at three months and six months after planting. The application of different microbial inoculants resulted in significant change in soil pH (Table 12). The initial pH of the soil was 5.6.

Table 11. Effect of microbial inoculants on percent incidence of rhizome maggot and shoot borer in ginger

Treatments	Per cent incidence					
	Rhizome maggot			Shoot borer		
	3 MAP	4 MAP	5 MAP	3 MAP	4 MAP	5 MAP
T_1 : KAU-AZO	5.22 (2.14)	17.71 (3.4)	37.5 (5.07)	1.04(1.11)	1.04(1.12)	2.08 (1.34)
T_2 : KAU-PSB	6.26 (1.94)	6.27 (2.33)	10.43(2.86)	1.04(1.11)	2.09(1.52)	4.17 (2.14)
T_3 : KAU-KSB	11.47(4.62)	27.13 (4.51)	35.42(4.44)	2.09(1.51)	1.04(1.12)	3.13 (1.74)
T_4 : KAU-PF	14.61(3.16)	22.95 (4.15)	37.50(5.02)	2.08(1.34)	3.13(1.74)	4.17 (1.92)
T_5 : KAU-TV	2.08 (1.34)	4.17 (2.14)	4.17 (2.14)	1.04(1.11)	2.09(1.51)	3.13 (1.74)
T_6 : KAU-AZO + KAU-PSB + KAU-KSB	2.09(1.51)	6.26 (1.97)	6.25 (2.55)	3.13(1.74)	5.22(2.37)	8.34 (2.96)
T_7 : KAU-AZO+ KAU-PSB + KAU-KSB + KAU-PF	21.91(3.68)	28.17 (4.34)	36.46(4.84)	2.09(1.51)	3.13(1.74)	4.17 (1.92)
T_8 : KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV	7.30(2.44)	9.39 (2.84)	8.34 (2.84)	3.13(1.74)	5.22(2.32)	7.29 (2.70)
T_9 : PGPR MIX I	4.17 (2.14)	4.17 (2.37)	6.25 (2.55)	2.09(1.51)	4.17(2.14)	4.17 (2.14)
T_{10} : PGPR MIX II	4.17(1.92)	7.30 (2.78)	8.33 (2.96)	3.13(1.74)	4.17(1.92)	6.25 (2.30)
T_{11} : Organic adhoc package (KAU, 2009)	3.13(1.74)	8.35 (2.78)	9.38 (3.12)	1.04(1.11)	3.13(1.74)	4.17 (1.92)
T_{12} : POP recommendation (KAU,2011)	3.13 (1.74)	4.17 (2.14)	6.25 (2.55)	2.09(1.51)	4.17(1.97)	5.21 (2.15)
T_{13} : Control	5.22 (2.55)	7.29 (2.78)	8.34 (2.84)	3.13(1.91)	3.13(1.74)	3.13 (1.74)
CD (0.05)	NS	NS	NS	NS	NS	NS

Each value represents mean of three replications; MAP - Months after planting
Figures in parenthesis are square root transformed values NS – Not significant

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At three months after planting, highest pH (5.5) was observed in treatments T_3 (KAU-KSB), T_6 (KAU-AZO + KAU-PSB + KAU-KSB) and (T_{12} POP recommendation). These were on par with all other treatments exept T_8 (KAU-AZO + KAU-PSB + KAU-KSB+ KAU- PF+ KAU-TV)and T_9 (PGPR MIX I). The lowest pH (5.3) was observed in the case of T_9 (PGPR MIX I). Among the consortia, T_6 (KAU-AZO + KAU-PSB + KAU-KSB) recorded the highest pH.

At six months after planting , highest pH (5.5) was recorded in T_3 (KAU-KSB). It was on par with T_1 (KAU-AZO), T_4 (KAU-PF), T_{12} (POP recommendation) and T_{13} (Control) while the lowest pH (5.2) was recorded in T_2 (KAU-PSB). All the consortial treatments were on par with each other.

4.7.6.2 *Organic carbon*

Percentage of organic carbon in the soil was recorded at three and six months after planting. Microbial inoculation had significant effect on the organic carbon percentage (Table 12). Initial organic carbon of the field was 1.4 %.

Three months after planting T_4 (KAU-PF) recorded the highest organic carbon content (1.59 %) which was on par with T_{10} (PGPR MIX II) while lowest value (1.5 %) was recorded in T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-PF+ KAU-TV). T_7 (KAU-AZO+KAU-PSB+KAU-KSB+ KAU-PF) recorded highest value(1.55%) among the consortia.

Six months after planting the highest value (1.6 %) was recorded in T_4 (KAU-PF) while lowest value of 1.52 % was recorded in T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV).

4.7.6.3 *Available nitrogen*

The results of available nitrogen content of the soil are given in Table 12. Data was recorded at three months and six months after planting. Analysis of data

revealed significant difference among the treatments. The initial available nitrogen content of the soil was 230.36 kg/ha which was found to decrease after planting of ginger. After three months, T_{12} (POP recommendation) registered the highest value (228.59 kg/ha) and T_3 (KAU-KSB) recorded the lowest value (174.08 kg/ha). T_{13} (Control) recorded 189.76 kg/ha. Among the consortia, T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+KAU-TV) recorded the highest value (197.39 kg/ha).

Six months after planting , the highest nitrogen (223.2 kg/ha) was recorded in T_{12} (POP recommendation) while lowest value (171.3 kg/ha) was found in T_2 (KAU-PSB). Control recorded a value of 181.3 kg/ha. T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) registered maximum value (188.68 kg/ha) among the consortia.

4.7.6.4 *Available phosphorus*

The results of available phosphorus content of the soil are presented in Table 12. The available phosphorus content of the soil was significantly affected by different treatments. The initial available phosphorus content of the soil was 50.13 kg/ha.

Three months after planting, available phosphorus content was maximum (48.69 Kg/ha) in T_{12} (POP recommendation) and among the consortia T_7 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) recorded maximum value (42.09 kg/ha). Minimum (36.15 kg/ha) was in T_{13} (Control).

Six months after planting, maximum value (43.06 kg/ha) was recorded in T_{12} (POP recommendation) and the minimum (33.93 kg/ha) was recorded in T_{13} (Control). T_7 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) recorded maximum value (37.44 kg/ha) among the consortia.

4.7.6.5 *Available potassium*

The results of available potassium content of the soil are given in Table 12. The data revealed significant differences among different treatments. The initial content was found to be 203.1 kg/ha.

After three months of planting, highest content (199.67 kg/ha) was recorded in T_{12} (POP recommendation) which was on par with T_{11} (Organic adhoc package). Control plants (T_{13}) recorded the lowest value of 190.67 kg/ha.

At six months after planting, T_{12} (POP recommendation) recorded the maximum available potassium content (220.5 kg/ha) which was on par with T_{11} (Organic adhoc package) while lowest (180.67) was recorded in the case of T_3 (KAU-KSB). All the consortial treatments were on par with each other with respect to available potassium content in soil.

4.7.7 Population of individual and consortial isolates in the soil

The population count of the individual and consortial isolates were taken at bimonthly interval till harvest . Initial population count revealed that all the five organisms were absent in soil. The population of *Azospirillum* sp, PSB, KSB, *Pseudomonas fluorescens* and *Trichoderma* sp. at bimonthly intervals are presented below.

After two months of planting highest population of *Azospirillum lipoferum* 60.7 x 10^6 MPN/g was found in T_{11} (Organic adhoc package) whereas T_{13} (Control) showed the lowest population of 2.23 x 10^3 MPN/g . Among the consortia, T_8 (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV) recorded the highest population (28.3 x 10^6 cfu/g). All the consortial treatments were on par with each other (Table 13). Highest population of PSB was recorded in T_2 (KAU-PSB) with a population of (44.7 x 10^6 cfu/g) which was on par with all other treatments exept T_{13} (Control) (0.39 x10^3 cfu/g) (Table 14). Among the

Table 12. Effect of microbial inoculants on soil pH and soil nutrient status at different stages of plant growth in ginger

Treatments	pH		Organic carbon %		Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP	3 MAP	6 MAP
T_1 : KAU-AZO	5.47^{a}	5.4^{ab}	1.53^{bc}	1.57^{b}	197.23^{d}	192.73^{de}	37.07^{gh}	35.07^{de}	193.53^{b}	180.9^{c}
T_2 : KAU-PSB	5.40^{abc}	5.2^{e}	1.56^{b}	1.56^{b}	188.27^{ef}	171.3^{h}	40.27^{de}	37.34^{ab}	193.77^{b}	181.06^{c}
T_3 : KAU-KSB	5.50^{a}	5.5^{a}	1.55^{b}	1.57^{b}	174.08^{g}	183.8^{g}	36.64^{hi}	34.8^{ef}	193.57^{b}	180.67^{c}
T_4 : KAU-PF	5.43^{ab}	5.4^{ab}	1.59^{a}	1.6^{a}	185.53^{f}	194.9^{d}	40.19^{de}	35.89^{cd}	193.77^{b}	181.47^{c}
T_5 : KAU-TV	5.40^{bc}	5.23^{de}	1.55^{b}	1.56^{bc}	188.83^{ef}	185.28^{fg}	37.47^{g}	34.2^{ef}	192.9^{b}	181.2^{c}
T_6 : KAU-AZO + KAU-PSB + KAU- KSB	5.50^{a}	5.33^{bcd}	1.51^{cd}	1.52^{d}	194.99^{de}	185.75^{fg}	40.73^{bcd}	36.38^{b}	194.13^{b}	181^{c}
T_7 : KAU-AZO+KAU-PSB+KAU-KSB + KAU-PF	5.43^{ab}	5.30^{bcde}	1.55^{b}	1.55^{bc}	194.35^{de}	184.9^{fg}	42.09^{a}	37.44^{ab}	193^{b}	180.9^{c}
T_8 : KAU-AZO+ KAU-PSB + KAU-KSB + KAU- PF+ KAU-TV	5.33^{bc}	5.30^{bcde}	1.50^{d}	1.52^{d}	197.39^{d}	188.68^{ef}	41.17^{bc}	36.68^{bc}	193.8^{b}	181.13^{c}
T_9 : PGPR Mix I	5.30^{bc}	5.27^{cde}	1.55^{b}	1.56^{b}	206.3^{c}	200.5^{c}	41.27^{b}	38.06^{a}	199.67^{a}	184.83^{a}
T_{10}: PGPR Mix II	5.40^{ab}	5.33^{bcd}	1.56^{ab}	1.57^{ab}	194.98^{de}	189.1^{ef}	39.56^{f}	36.77^{bc}	193.53^{b}	182.6^{b}
T_{11}: Organic adhoc package (KAU, 2009)	5.47^{a}	5.37^{bc}	1.56^{ab}	1.56^{b}	214.4^{b}	206.3^{b}	40.07^{ef}	37.43^{ab}	199.5^{a}	184.76^{a}
T_{12} : POP recommendation (KAU,2011)	5.50^{a}	5.40^{ab}	1.55^{b}	1.57^{b}	228.59^{a}	223.2^{a}	48.69^{a}	43.06^{a}	220.5^{a}	210.83^{a}
T_{13} : Control	5.47^{a}	5.40^{ab}	1.53^{bc}	1.53^{cd}	189.76^{def}	181.3^{g}	36.15^{i}	33.93^{f}	190.67^{c}	181.26^{c}
CD (0.05)	0.11	0.12	0.03	0.025	7.87	4.71	0.92	0.57	1.04	1.21

Each value represents mean of three replications MAP: Months after planting

Initial soil pH=5.6 Initial organic carbon % =1.4 Available nitrogen= 230.3 kg/ha

Available phosphorus = 50.13 kg/ha Available potassium=203.1 kg/ha

KSB highest population was obtained in T_{11} (Organic adhoc package) which was on par with T_9 (PGPR MIX I) while lowest population of 0.3 x 10^3 cfu/g was recorded in T_{13} (Control) (Table 15) . Highest population of *Pseudomonas fluorescens* (35.3 x10^6 cfu/g) was seen in the case of T_{10} (PGPR MIX I) which was found to be on par with T_4 (KAU-TV) . T_{13} (Control) recorded the lowest population of 0.6 x 10^3 cfu/g (Table 16). Highest population (49.9x 10^4 cfu/g) of *Trichoderma* sp. was recorded in T_{11}(Organic adhoc package) while T_{13} (Control) recorded the lowest population (0.5x 10^2 cfu/g) (Table 17).

Four months after planting , highest population of *Azospirillum* sp 34 x 10^4 MPN/g was found in T_8 (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV) whereas T_{13} (Control) recorded the lowest population of 5.1 x 10^3 MPN/g. T_8 (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV) was found to be on par with T_7 (KAU-AZO + KAU-PSB +KAU-KSB+ KAU-PF), T_9 (PGPR MIX I) and T_{11}(Organic adhoc package) (Table 13). Highest population of PSB was recorded in T_9 (KAU-PSB) with a population of (41.3 x 10^4 cfu/g) while T_{13} (Control) recorded the lowest population (1.6 x10^3 cfu/g)(Table 14). Among the KSB, highest population was obtained in T_{11}(Organic adhoc package),. while lowest population (0.17 x 10^3 cfu/g) was recorded in T_{13}(Control) (Table 15). Highest population of *Pseudomonas fluorescens* (25 x10^4 cfu/g) was seen in tha case of T_{10} (PGPR MIX II) which was found to be on par with T_7 (KAU-AZO + KAU-PSB +KAU-KSB+ KAU-PF). T_{13} recorded the lowest population of 1.3 x 10^3 cfu/g (Table 16). Highest population (20x 10^3) of *Trichoderma* sp. was recorded in T_{11}(Organic adhoc package) while T_{13}(Control) recorded the lowest population (1.3 x 10^2 cfu/g) (Table 17).

After six months of planting, highest population (12 x 10^5 cfu/g) of *Azospirillum lipoferum* was recorded in T_{11} (Organic adhoc package). It was on par with T_7 (KAU-AZO + KAU-PSB +KAU-KSB+ KAU-PF) and T_8 (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV). Lowest population (3.2 x 10^3 cfu/g) was recorded in T_{13} (Control) (Table 13). Among PSB T_{11} (Organic adhoc package) recorded the highest population (3.6 x 10^5 cfu/g) while T_{13} (Control) recorded the

lowest population (2.3x10 ^{3} cfu/g) (Table 14). Among the KSB highest population (3.8 x 10 ^{5} cfu/g) was obtained from T_{11} (Organic adhoc package) while lowest population (2.5 x 10^{3}) in T_{13} (Control) (Table 15). Highest population of *Pseudomonas fluorescens* (4.5 x10^{5} cfu/g) was seen in the case of T_{11} (Organic adhoc package) while all other treatments were on par with each other (Table 16). Highest population (3.9 x 10^{2} cfu/g) of *Trichoderma* sp. was recorded in T_{8} (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV). It was found to be on par with T_{11} (Organic adhoc package) and T_{5} (KAU-TV) while T_{13} (Control) recorded the lowest population (2.5 x 10^{2} cfu/g) (Table 17).

4.7.8 Benefit –cost ratio

Highest benefit:cost ratio (1.56) was obtained in case of T_{11} (Organic adhoc package) while among the consortia T_{8} (KAU-AZO + KAU-PSB + KAU-KSB+ KAU-TV) recorded maximum benefit:cost ratio (1.26) (Table 18)

able 13. Population of *Azospirillum* in the soil at bimonthly intervals

Treatment	Population (MPN/g)		
	2 MAP	4 MAP	6 MAP
T_1 : KAU-AZO	$20.3^{ab}x10^6(12.73)$	$13.7^c \times 10^4$ (11.81)	$6.5^{bcd} \times 10^3$ (8.78)
T_2 : KAU-PSB	ND	ND	ND
T_3 : KAU-KSB	ND	ND	ND
T_4 : KAU-PF	ND	ND	ND
T_5 : KAU-TV	ND	ND	ND
T_6 : KAU-AZO+ KAU-PSB + KAU- KSB	$16.6^b \times 10^6$ (12.61)	$21.0^{bc} \times 10^4$(12.23)	$5.1^{cd} \times 10^3$ (8.48)
T_7 : KAU-AZO+KAU- PSB+KAU- KSB+KAU-PF	$13.7^b \times 10^6$ (12.6)	$28.3^{ab} \times 10^4$(12.53)	$7.3^{bcd} \times 10^3$ (8.72)
T_8 : KAU-AZO+ KAU-PSB + KAU- KSB+ KAU-TV	28.3^{ab}x 10 (12.79)	$34^a \times 10^4$(12.73)	$9.2^b \times 10^3$ (9.11)
T_9 : PGPR Mix I	$38.7^a \times 10^6$ (12.90)	$22.7^{ab} \times 10^4$(12.32)	$7.7^{bc} \times 10^3$ (8.86)
T_{10} : PGPR Mix II	ND	ND	ND
T_{11} : Organic adhoc package (KAU, 2009)	60.7×10^6 (12.93)	$33.3^a \times 10^4$ (12.71)	$12.0^a \times 10^5$ (14.19)
T_{12} : POP recommendation (KAU,2011)	ND	ND	ND
T_{13}: Control	$2.23^c \times 10^3$(7.39)	$5.1^d \times 10^3$ (8.48)	$3.2^d \times 10^3$ (8.26)

Each value represents mean of three replications
Figures in parenthesis are log transformed value

MAP - Months after planting
ND - Not determined

Table 14. Population of PSB in the soil at bimonthly intervals

Treatments	Population (cfu ml^{-1})		
	2 MAP	4 MAP	6 MAP
T_1 : KAU-AZO	ND	ND	ND
T_2 : KAU-PSB	$44.7^{a} \times 10^{6}$ (17.0)	$30.0^{c} \times 10^{4}$ (17.0)	$3.8^{b} \times 10^{3}$ (8.12)
T_3 : KAU-KSB	ND	ND	ND
T_4 : KAU-PF	ND	ND	ND
T_5 : KAU-TV	ND	ND	ND
T_6 : KAU-AZO+ KAU-PSB + KAU- KSB	$40.0^{a} \times 10^{6}$ (17.4)	$30.3^{c} \times 10^{4}$ (17.4)	$3.4^{b} \times 10^{3}$ (8.04)
T_7 : KAU-AZO+KAU-PSB+KAU- KSB+KAU- PF	$34.3^{a} \times 10^{6}$ (17.1)	$36.^{abc} \times 10^{4}$ (17.13)	$2.9^{b} \times 10^{3}$ (8.02)
T_8 : KAU-AZO+KAU-PSB+KAU- KSB+KAU- TV	$32.3^{a} \times 10^{6}$ (17.2)	$40.3^{ab} \times 10^{4}$ (17.29)	$2.6^{b} \times 10^{3}$ (7.80)
T_9 : PGPR MIX I	$27.7^{a} \times 10^{6}$ (17.6)	$41.3^{a} \times 10^{4}$ (17.61)	$2.7^{ab} \times 10^{3}$ (9.52)
T_{10} : PGPR MIX II	ND	ND	ND
T_{11}: Organic adhoc package (KAU, 2009)	$25.3^{a} \times 10^{6}$ (17.35)	$34.0^{b} \times 10^{4}$ (17.35)	$3.6^{a} \times 10^{5}$ (11.13)
T_{12}: POP recommendation (KAU,2011)	ND	ND	ND
T_{13}: Control	$0.39^{b} \times 10^{3}$ (5.8)	$1.6^{d} \times 10^{3}$ (5.8)	$2.37^{b} \times 10^{3}$ (7.72)

Each value represents mean of three replications MAP - Months after planting

Figures in parenthesis log transformed values ND - Not determined

Table 15. Population of KSB in the soil at bimonthly intervals

Treatments	Population (cfu/g)		
	2 MAP	4 MAP	6 MAP
T_1 : KAU-AZO	ND	ND	ND
T_2 : KAU-PSB	ND	ND	ND
T_3 : KAU-KSB	ND	ND	ND
T_4 : KAU-PF	ND	ND	ND
T_5 : KAU-TV	ND	ND	ND
T_6 : KAU-AZO+ KAU-PSB + KAU- KSB	ND	ND	ND
T_7: KAU-AZO+KAU-PSB+KAU-KSB+KAU-PF	ND	ND	ND
T_8 : KAU-AZO+ KAU-PSB + KAU- KSB+ KAU-TV	ND	ND	ND
T_9 : PGPR Mix I	$28.3^{a}x10^{6}$(17.00)	$16.6x10^{4}$(12.01)	$3.3^{b} \times 10^{3}$ (5.34)
T_{10} : PGPR Mix II	ND	ND	ND
T_{11}: Organic adhoc package (KAU, 2009)	$31.7^{a}x10^{6}$(17.26)	$21.33^{a}x10^{4}$(12.3)	$3.8^{a}x10^{5}$ (10.58)
T_{12}: POP recommendation (KAU,2011)	ND	ND	ND
T_{13}: Control	$0.3^{b} \times 10^{3}$ (3.8)	$0.17^{c}x10^{3}$ (5.12)	$2.5^{b} \times 10^{3}$ (5.82)

Each value represents mean of three replications; MAP – Months after planting

Figures in parenthesis are log transformed values ND - Not determined

Table 16. Population of *Pseudomonas fluorescens* in the soil at bimonthly intervals

Treatments	Population (cfu/ml)		
	2 MAP	4 MAP	6 MAP
T_1 : KAU-AZO	ND	ND	ND
T_2 : KAU-PSB	ND	ND	ND
T_3 : KAU-KSB	ND	ND	ND
T_4 : KAU-PF	35.3^{a}x 106 (17.6)	$25.0^{a} \times 10^{4}$ (12.4)	$4.7^{b} \times 10^{3}$ (8.4)
T_5 : KAU-TV	ND	ND	ND
T_6 : KAU-AZO+ KAU-PSB + KAU- KSB	ND	ND	ND
T_7 : KAU-AZO+KAU-PSB+KAU- KSB+KAU-PF	$27.3^{a} \times 10^{6}$ (17.1)	$22.3^{a} \times 10^{4}$(12.31)	$4.8^{b} \times 10^{3}$ (8.4)
T8 : KAU-AZO+ KAU-PSB + KAU- KSB+ KAU-TV	ND	ND	ND
T9 : PGPR Mix I	ND	ND	ND
T10 : PGPR Mix II	$35.3^{a}x10^{6}$ (17.38)	$1.7^{c} \times 10^{4}$ (9.69)	$4.4^{b} \times 10^{3}$ (8.38)
T11 : Organic adhoc package (KAU, 2009)	$1.8^{b} \times 10^{6}$ (7.10)	$6.7^{b} \times 10^{4}$ (11.07)	$4.5^{a} \times 10^{5}$ (13.01)
T12 : POP recommendation (KAU,2011)	ND	ND	ND
T13 : Control	$0.6^{b} \times 10^{3}$ (6.32)	$1.3^{d} \times 10^{3}$ (7.19)	$4.1^{b} \times 10^{3}$ (8.30)

Each value represents mean of three replications; MAP – Months afteplanting
Figures in parenthesis are log transformed values ND - Not determined

Table 17. Population of *Trichoderma* in the soil at bimonthly intervals

Treatments	Population (cfu/g)		
	2 MAP	4 MAP	6 MAP
T_1 : KAU-AZO	ND	ND	ND
T_2 : KAU-PSB	ND	ND	ND
T_3 : KAU-KSB	ND	ND	ND
T_4 : KAU-PF	ND	ND	ND
T_5 : KAU-TV	$34.7^{b} \times 10^{4}$ (3.57)	$6.7^{c} \times 10^{3}$ (9.39)	$4.2^{a} \times 10^{2}$ (6.04)
T_6 : KAU-AZO+ KAU-PSB + KAU- KSB	ND	ND	ND
T_7 :KAU-AZO+KAU-PSB+KAU- KSB+KAU- PF	ND	ND	ND
T_8 :KAU-AZO+ KAU-PSB + KAU- KSB+ KAU-TV	$42.3^{a} \times 10^{4}$ (3.76)	$8.0^{b} \times 10^{3}$ (8.98)	$3.9^{a} \times 10^{2}$ (5.97)
T_9 : PGPR Mix I	ND	ND	ND
T_{10} : PGPR Mix II	ND	ND	ND
T_{11} : Organic adhoc package (KAU, 2009)	$49^{a} \times 10^{4}$ (3.9)	$20.0^{a} \times 10^{3}$ (9.90)	$3.8^{a} \times 10^{2}$ (5.94)
T_{12} : POP recommendation (KAU,2011)	ND	ND	ND
T_{13} : Control	$0.5^{c} \times 10^{2}$ (0.36)	$3.5^{d} \times 10^{2}$ (8.15)	$2.5^{b} \times 10^{2}$ (5.5)

Each value represents mean of three replications MAP -Months after planting,

Figures in parenthesis are log transformed value ND - Not determined

Table 18. Benefit:cost ratio of different treatments

Treatments	Cost of cultivation (Rs)	Gross return (Rs)	Benefit-cost ratio
T_1 : KAU-AZO	1,88,256.36	1,97,154.9	1.37
T_2 : KAU-PSB	1,88,256.36	1,72,998.1	1.20
T_3 : KAU-KSB	1,88,256.36	1,53,612.6	1.07
T_4 : KAU-PF	1,88,256.36	1,83,544.3	1.27
T_5 : KAU-TV	1,88,256.36	2,03,764.8	1.41
T_6 : KAU-AZO + KAU- PSB + KAU-KSB	1,88,256.36	2,20,012.3	1.53
T_7 : KAU-AZO + KAU-PSB+KAU-KSB+ KAU- PF	1,88,256.36	2,35,272.9	1.63
T_8 : KAU-AZO + KAU-PSB + KAU-KSB + KAUTV	1,88,256.36	2,38,189.8	1.65
T_9 : PGPR MIX I	1,85,845.00	2,40,282.7	1.68
T_{10} : PGPR MIX II	1,85,845.00	2,32,482.2	1.62
T_{11} : Organic adhoc package (KAU, 2009)	1,88,205.00	2,94,445.7	2.04
T_{12} : POP recommendation (KAU,2011)	1,92,209.63	2,79,311.9	1.91
T_{13} : Control	1,92,209.63	1,51,444.7	1.06

Discussion

5. DISCUSSION

Ginger is one of the prominent crops in the spice economy of India. It is being cultivated in India as a fresh vegetable as well as dried spice since time immemorial. Eventhough, it is grown all over India, the finest quality of ginger in the world market is from Kerala. Indian dry ginger is known in the global market as 'Cochin Ginger' and 'Calicut Ginger'. Cochin Ginger is considered as one of the best varieties in the world. It is valued as a culinary herb, condiment, spice, home remedy, and a medicinal agent. However, several major constraints exist in its production and one of them is its succeptibility to various diseases like soft rot, bacterial wilt, fusarium yellows and leaf spot during its growth period (Nada *et al*, 1996). This has led to the use of heavy doses of synthetic pesticides. Since ginger is a highly nutrient exhausting crop; it demands use of high dose of fertilizers. Although chemical fertilizers and pesticides are highly effective, their continous use has led to problems such as soil pollution, development of resistance by pathogens and residual toxicity (Pimentel and Greiner, 1997). Alternative approaches are needed to minimize the use of chemicals by the use of microbial inoculants for crop nutrition and protection. Due to this, potential threat for development of chemical resistance by pathogens and non-target side effects on beneficial microorganisms can be avoided. Since, the ginger is exported from Kerala, it would be advisable to popularize the cultivation of organic ginger which will not only be safe but fetches high price in the market. The health concerns associated with pesticide residue and soil pollution demands organically produced products. Organic cultivation of ginger without the use of any chemical inputs will be a boon in this regard.

In recent years, great emphasis has been laid on the development and use of microbial inoculants which is an important component of organic farming to overcome these problems. There are several studies which have indicated that the microbial inoculants not only supplies nutrients but also control various pathogens affecting the crops (Fravel D.R., 2005). Moreover, it is also reported that the quantum of plant growth promoting activities was better in the case of consortia

or mixed cultures than single strain (Bashan *et al.*, 2004). As microbial inoculants reduce the cost of production with sustainable yield and soil health, they can be used for organic ginger cultivation. Organic cultivation of ginger without the use of any chemical input comes handy in this regard. Hence, a study was undertaken to evaluate the microbial inoculant consortia for organic cultivation of ginger with an objective to find out a suitable consortia which will not only supply the major nutrients but also manage the diseases in ginger crop.

The popular and efficient cultures of *Azospirillum lipoferum.*, phosphate solubilizing bacteria, potash soubizing bacteria, *Pseudomonas flourescens* and *Trichoderma viride* developed by Kerala Agricultural University for commercial production were obtained from the Department of Agricultural Microbiology, College of Agriculture, Vellayani. The cultures were characterized with respect to morphological, cultural and biochemical characters in order to confirm its purity and identity. KAU-AZO formed white pellicle at the sub-surface (1-2mm) in nitrogen free malate (Nfb) medium and turned the pH of the media to alkaline (Hegazi *et al.*, 1979). It was found to be Gram negative and slightly curved in shape. The colonies were circular in shape, convex and glistening with entire margin. It was positive for catalase and produced acid from glucose utilization. However, there was a negative result for starch hydrolysis. KAU-PSB were Gram positive and rod shaped. The colonies were circular, flat with entire margin. It recorded positive for catalase test, starch hydrolysis, citrate utilization and acid from glucose. However, there was no gas production from glucose in durham's tube. The bacteria formed solubilisation zone in pikovskaya's agar media. In the case of KAU-KSB, it was Gram negative and rod shaped. The colonies were circular, flat with entire margin. On GYC agar, they formed solubilisation zone. They were positive for catalase and negative for indole formation. The biocontrol agents KAU-PF were curved Gram negative and rods. They exhibited positive reaction for glucose fermentation and gave negative test for starch hydrolysis. They produced fluorescent pigment which was visible under ultra violet light. On comparing the characters of isolates

with standard keys described in (Buchanan *et al.*, 1974), the isolates, KAU-AZO, KAU-PSB, KAU-KSB, KAU-PF were tentatively identified as *Azospirillum* sp., phosphorus solubilising bacteria , potash solubiliing bacteria and *Pseudomonas* sp. The KAU-TV isolates were also subjected to morphological and cultural characterization on potato dextrose agar media in order to confirm its identity. The colonies were smooth surfaced, became hairy and colour changed from whitish green to dark green. The hyphae were septate and hyaline and conidiophores were hyaline and conidia green in colour. These characters were compared with the standard keys (Chet, 1987) and was identified as *Trichoderma* sp.

As the consortia involves a mixture of more than one microorganism, it is important to determine compatibility among isolates so that they don't compete with each other (Fernando and Linderman, 1994). For this, KAU-AZO, KAU-PSB, KAU-KSB, KAU-PF and KAU-TV were subjected to compatibility test. It was observed that all the bacterial cultures tested were mutually compatible with each other. In a similar study, Raja *et al.*, (2006a) reported compatibility of *Azospirillum lipoferum, Bacillus megaterium var. Phosphaticum* and *Pseudomonas fluorescens* among each other. Khorshidi (2011) also reported that *P. flourescens* and *A. lipoferum* were found to be compatible with each other. When the bacterial cultures were tested for their compatibility with KAU-TV, it was found that KAU-PF was incompatible with KAU-TV. This was in contradiction to the findings of Manjula *et al.,* (2004) who reported *in vitro* compatibility of *P. fluorescens* and *Trichoderma* sp. in dual culture and found that *P. fluorescens* had no effect on growth of *Trichoderma* sp. or *vice versa.* In the present study , KAU-PF and KAU-TV were incompatible which might be due to antifungal effects of organic volatiles produced by KAU-PF which might have inhibited mycelial growth of the fungus (Fernando and Linderman, 1994). KAU-AZO, KAU-PSB, KAU-KSB were found to be compatible with KAU-TV. Compatibility of *T. viride* with *Azospirillum* under *in vitro* has been reported earlier (Sankar and Jayarajan, 1996). In the present study, it was found that all the

isolates tested were compatible with each other except in the case of KAU-PF and KAU-TV.

Since natural soil commonly represents a hostile environment to inoculant cells, the use of inoculant formulations involving carrier materials for the delivery of microbial cells to soil or the rhizosphere is desirable. Carrier materials are generally intended to provide a temporarily protective niche to microbial inoculants in soil, either physically via the provision of a protective surface or pore space, or nutritionally via the provision of a specific substrate (van Elsas, 1990). An optimal carrier should provide favorable conditions for survival as well as functioning of the inoculant cells, resulting in a sufficiently long shelf life as well as improved survival and activity in soil. The carrier should, further, be non-toxic, non-polluting and should have a constant quality. It should also allow an accurate release of microbial cells to the target sites in soil or rhizosphere and might even be used to inhibit the dispersal of inoculant cells to adjacent soil sites or to groundwater in cases when such spread is undesirable (Trevors *et al*, 1993). The individual and consortia of isolates were mass multiplied on vermicompost as carrier material. Inorder to determine the compatibility between the vermicompost and the beneficial microorganisms the isolates were mass multiplied and enumerated under both sterile and unsterile vermicompost. Moreover, the natural occurence of beneficial microorganisms was also assesed in the vermicompost since the sterilized vermicompost cannot be used for commercial production of microbial inoculants due to the loss in nutrient status in vermicompost. Carrier-based formulation of the microbial cultures was prepared and the population of KAU-AZO in the broth before mixing with vermicompost was 3.6×10^{8} MPN/ml of broth. KAU-PSB , KAU-KSB, KAU-PF, KAU-TV recorded 2×10^{8} cfu ml^{-1}, 3.1×10^{8} cfu/ml , 6.3×10^{8} cfu ml^{-1} and 7.3×10^{6} cfu ml^{-1} respectively. The highest population was in case of KAU-PF followed by KAU-AZO. This indicates that the broth had required population.

The population of isolates in unsterilized vermicompost were more than that of the sterile vermicompost except for KAU-KSB which was absent in all the unsterilized vermicompost. Highest population of *Azospirillum* sp. was in KAU-

AZO microbial inoculant formulation(14.33 x 10^8 MPN/g), highest population of phosphate solubilizing bacteria was in KAU-PSB microbial inoculant formulation (8 x 10^8 cfu ml $^{-1}$), population of *Pseudomonas fluorescens* was highest in (18.33 x 10^8 cfu ml $^{-1}$) in KAU-PF microbial inoculant formulation while population of *T. viride* was highest (15.66 x 10^6 cfu ml^{-1}) in KAU-TV microbial inoculant formulation. However, in the sterilized vermi-compost highest population *of Azospirillum* sp. was in KAU-AZO microbial inoculant formulation (3.7 x 10^8 MPN/g), highest population of phosphate solubilizing bacteria was in KAU-PSB microbial inoculant formulation (2.4 x 10^8 cfu ml $^{-1}$), potash solubilizing bacteria was highest (7 X10 ^{6}) in KAU-KSB microbial inoculant formulation, population of *Pseudomonas fluorescens* was highest in (4.6 x 10^8 cfu ml $^{-1}$) in KAU-PF microbial inoculant formulation while population of *T. viride* was highest (4.6 x 10^6 cfu ml^{-1}) in KAU-TV microbial inoculant formulation.The absence of KSB in unsterile vermicompost may be due to some toxic materials present in vermicompost. Although earthworms can transfer hazardous organic wastes into stabilized value-added vermicompost, it accumulates a certain amount of toxic metals in their tissues. The accumulation of chemicals in the tissues by these detritivorous organisms can, in principle, damage soil processes and local biodiversity indirectly if their activities and demographics are compromised, and directly if the residues are transferred via earthworms to organisms occupying different trophic levels (Morgan *et al.*, 2001). However, population level didn't reduce below 10^8 cfu/g for bacteria and 10^6 in the case of fungus which is the recommended standard of good quality microbial inoculant. Based on the population of the isolates in sterile and unsterile vermicompost it may be inferred that unsterile vermicompost can be used for mass multiplication of inoculants exept for KAU-KSB. Raw vermicompost is a potential carrier material than sterilized vermicompost (Muthuselvam and Tholkappian, 2008)..

Based on the compatibility studies, the consortia consisting of biofertilizers alone and biofertilizer cum biocontrol agents were selected for the field evaluation. Consortia of biocontrol agents (KAU-PF and KAU-TV) were not selected for further studies as both were incompatible with each other. The

consortia selected were KAU-AZO +KAU- PSB + KAU-KSB, KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF and KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV. These consortia were compared for their efficiency in growth promotion and disease management in ginger in comparison with treatment involving individual isolates of microbial inoculants, PGPR mix I, PGPR mix II, Organic adhoc package (KAU, 2009), POP recommendation (KAU, 2011).

The soil microbial analysis shows that initial population of *Azospirillum,* phosphate solubilizing bacteria, potash solubilizing bacteria, *Pseudomonas fluorescens* and *Trichoderma* in the experimental soil were absent. It might be due to fallow and uncultivated land before the present studies were undertaken. Therefore, the microorganisms might have been unable to colonize as there was no favourable rhizospheric environment and crop for them to colonize (Poindexter, 1981). The significance of the rhizosphere arises from the release of organic material from the root and the subsequent effect of increased microbial activity on nutrient cycling and plant growth. In the rhizosphere, the quantities and the types of substrates are different from those in the bulk soil and this leads to colonization by different populations of bacteria, fungi, and microfauna (Balmurugan *et al.,* 2013). The important role played by plants in selecting and enriching the types of bacteria by the constituents of their root exudates is important (Dakora, 2003). Thus, the bacterial community in the rhizosphere develops depending on the nature and concentrations of organic constituents of exudates, and the corresponding ability of the bacteria to utilize these as sources of energy (Curl and Truelove, 1986). Also, the occurrence and activity of soil microorganisms are affected by a variety of environmental factors (e.g. soil type, nutrient abundance, pH, moisture content) as well as plant-related factors (species, age) (Evans *et al.*,1993). In the present study, the initial absence of beneficial microflora indicated the need for inoculation of microbial inoculants in lateritic soils which are unfavourable for growth of beneficial microflora.

Number of days taken for sprouting ranged between 16-20 days. However, no significant differences were observed in the treatment with respect to number

of days taken for early sprouting. However, the minimum number of days (16.67) was recorded in the case of T_4 (KAU-PF). Complete germination was seen in case of treatment T10 (PGPR Mix II). Selvakumar *et al.* (2009) reported *Pseudomonas* and *Bacillus* can produce phytohormones or growth regulators that increase uptake of water and nutrients, rate of germination and plant biomass production. Among the consortia, both T_7 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-PF) and T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the highest per cent (91.67) germination. The increase in germination percentage after five days of consortial inoculation might be due to the production of indole acetic acid (Fallik *et al.*, 1994).

The highest plant height was recorded in the case of T_{11} (Organic adhoc package (KAU, 2009) and the consortial treated plants performed better than individual inoculants (Fig.1). Among the consortia the plant height was highest (74.86 cm) in the case of T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) (Fig.1). The maximum numbers of tillers were recorded in the treatment T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) (Fig 2.). Sumathi *et al.* (2011) reported that coinoculation of *A. lipoferum, T. viride, B. megaterium* , *P. fluorescens* resulted in maximum plant height in turmeric. Similarly, Nath and Korla (2000) reported higher tiller and leaf production per plant compared to normal dose of NPK and control in ginger due to the influence of biofertilizers. The maximum rhizome yield (8.93 t/ha) was in T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV)(Fig.3). This might be due to optimum supply of nutrients from organic sources. Microbial inoculants might have helped in better uptake of nutrients, more synthesis of nucleic and amino acids, amide substances and meristematic tissues thereby increased the growth of plants. This was in conformity with the findings of Saxena *et al.* (2001) in soybean, Nanjundappa *et al.* (2000) in maize and Shanmugam and Veeraputhran (2000) in rice. Asokan *et al.* (2000) also reported increased yield in ginger due to addition of farmyard manure and biofertilizers which improved properties and soil fertility . Similarly, Pawar and Patil (1987) observed an increase in dry ginger weight, N content and saving of 33 % fertilizer N due to *Azospirillum* inoculation. The organic manure

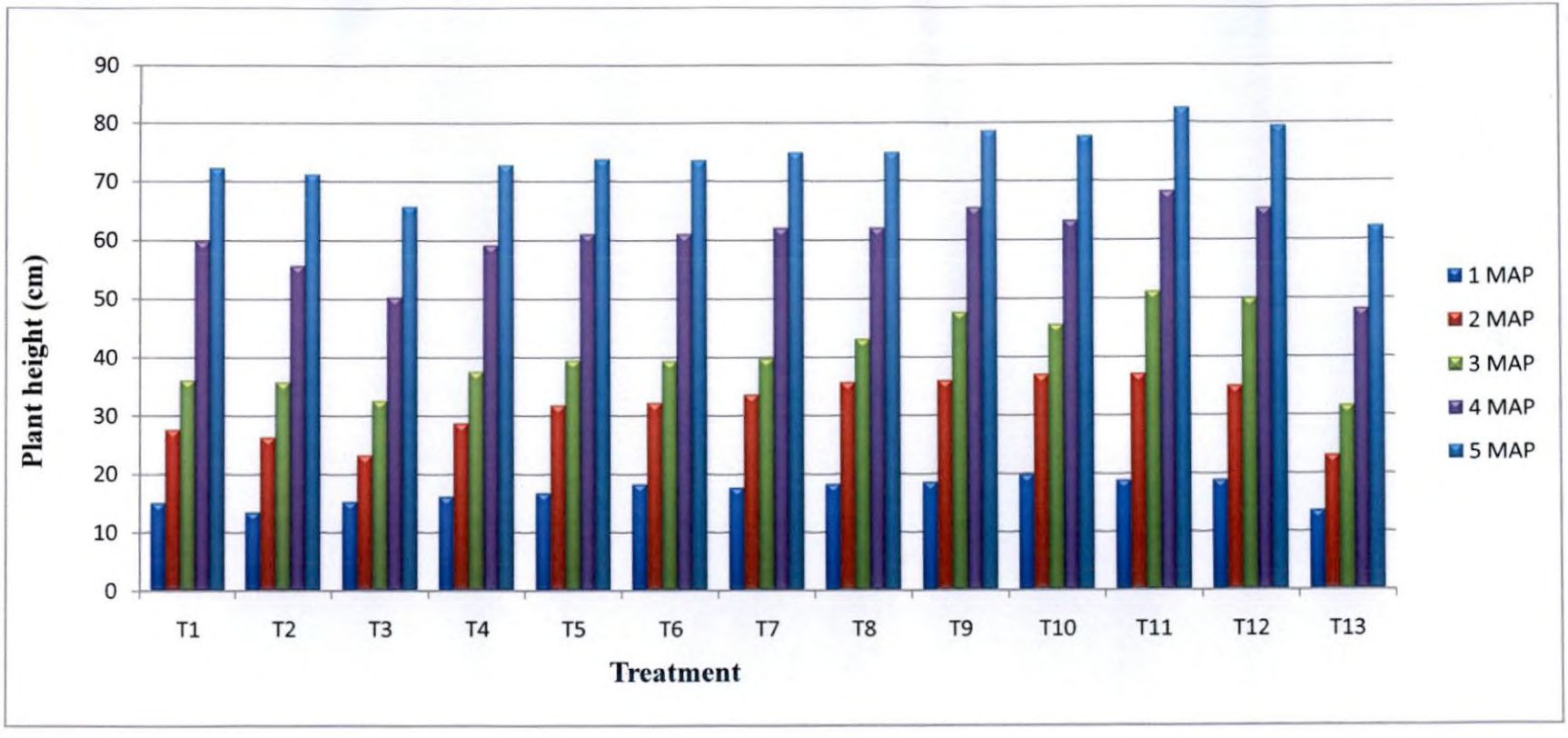

Fig 1. Effect of microbial inoculants on plant height (cm)

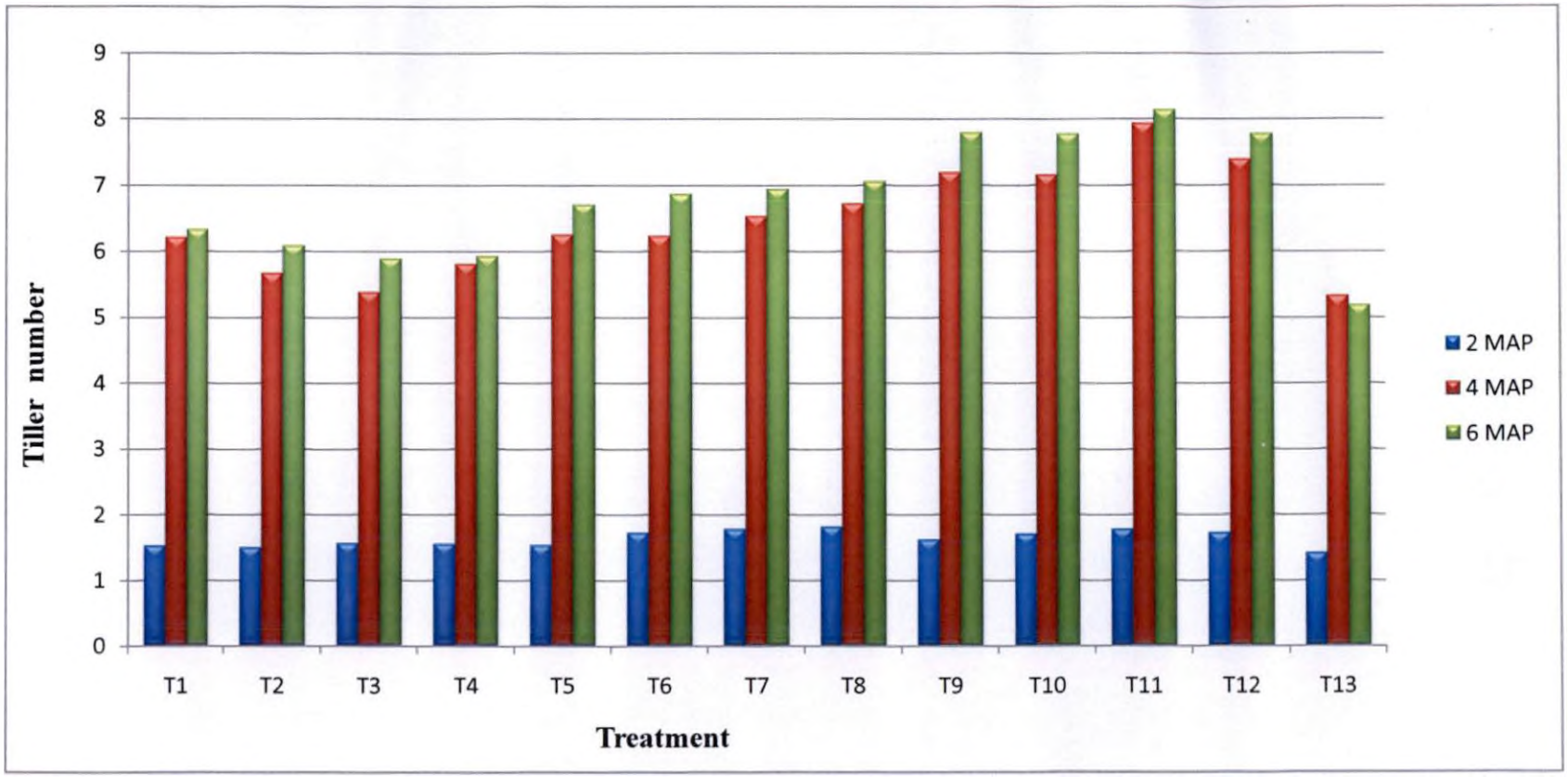

Fig 2. Effect of microbial inoculants on number of tillers

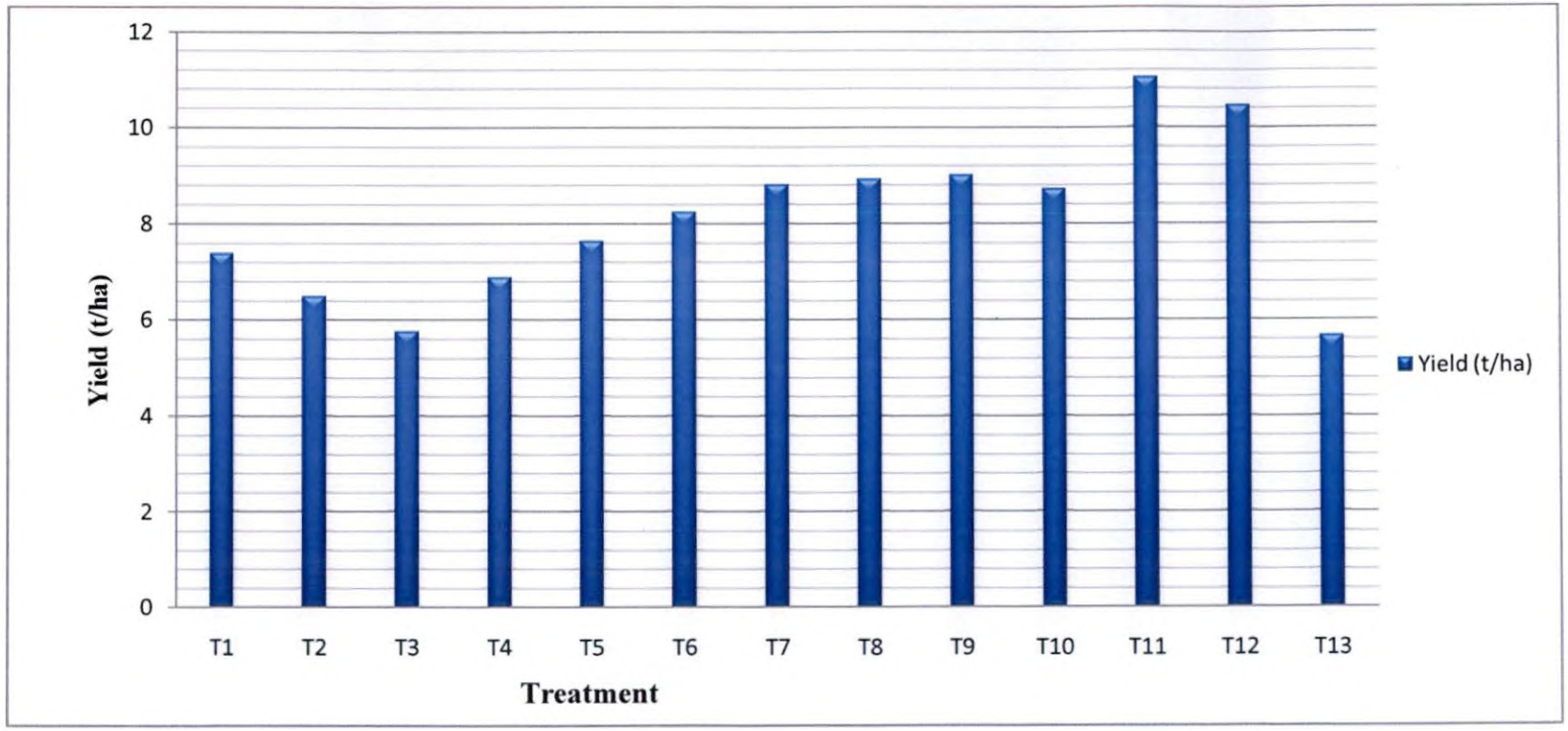

Fig 3. Effect of microbial inoculants on yield

and microbial inoculants interaction had influenced various physical parameters of the soil and improved the nutrient availability to the plants. As a result of this, higher nutrient uptake was observed leading to better crop growth, greater leaf area, better translocation of nutrients and finally higher rhizome yield (Sreekala, 2004). Based on the overall biometric and yield parameters, T_8 (AZO + KAU-PSB + KAU-KSB + KAU-TV) performed better among the consortia. However, T_{11} (Organic adhoc package, KAU, 2009) performed better than the consortia treatments which might be due to additional nutrients supplied in the form of neemcake and PGPR Mix-I (N, P, K, Ca, Mg, S, Mn, Cu, Fe, Zn).

One of the major constraints in ginger cultivation is the pest and disease incidence. In the present study, diseases noticed were rhizome rot and *Rhizoctonia* leaf blight and T_{11} (Organic adhoc package) recorded minimum per cent incidence of rhizome rot (2.09 %) among all the treatments. However, T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum per cent rhizome rot (5.23%) incidence among consortia (Fig.4). Gupta *et al.* (2010) reported *Trichoderma* spp to be one among the biocontrol fungi for growth promotion and effective against many fungal diseases particularly rhizome pathogens. *Trichoderma* strains establish long-lasting colonization of plant roots and penetrate into the epidermis and produce or release compounds that induce localized or systemic plant resistance responses (Harman, 2004). In a similar study, Ram *et al.* (2000) reported that rhizome treated with the *Trichoderma* sp. significantly reduced rhizome rot incidence and also increased the yield. *Trichoderma viride* produced non-volatile substances which inhibited the growth of the ginger rhizome rot pathogens (Rathore *et al.*, 1992). These results are in conformity with the present studies where the consortia containing *T. viride* has performed better . The results on per cent incidence of leaf blight indicated T_{11} (Organic adhoc package) with the least per cent incidence(4.17 %). However, T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF) recorded the minimum per cent incidence (5.21) of rhizoctonia leaf blight (Fig.5). Fluorescent pseudomonads exhibit strong antifungal activity against *P.oryzae* and *R. solani* mainly through the production of antifungal metabolites (Reddy and Rao, 2009). Nandakumar *et*

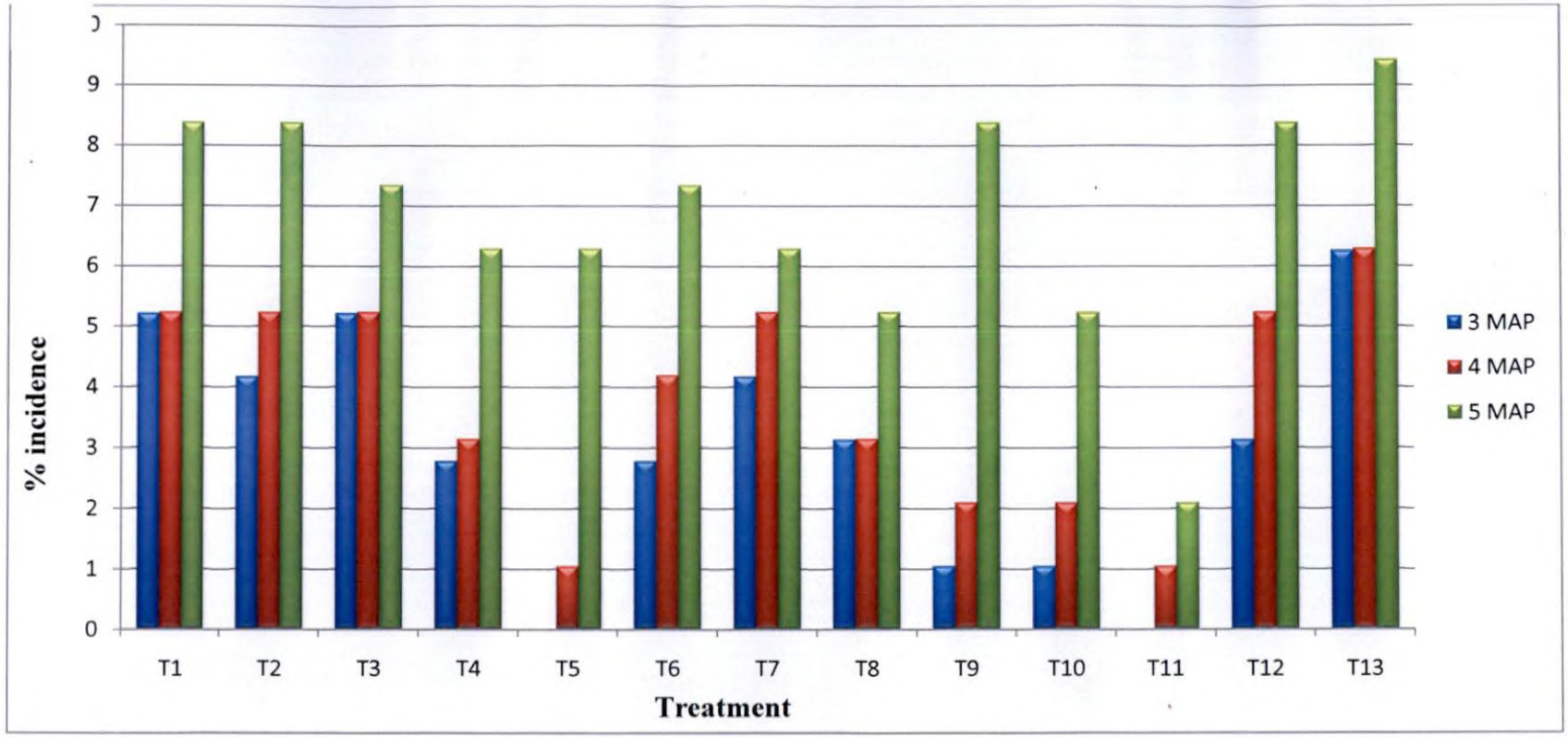

Fig 4. Effect of microbial inoculants on per cent incidence of rhizome rot

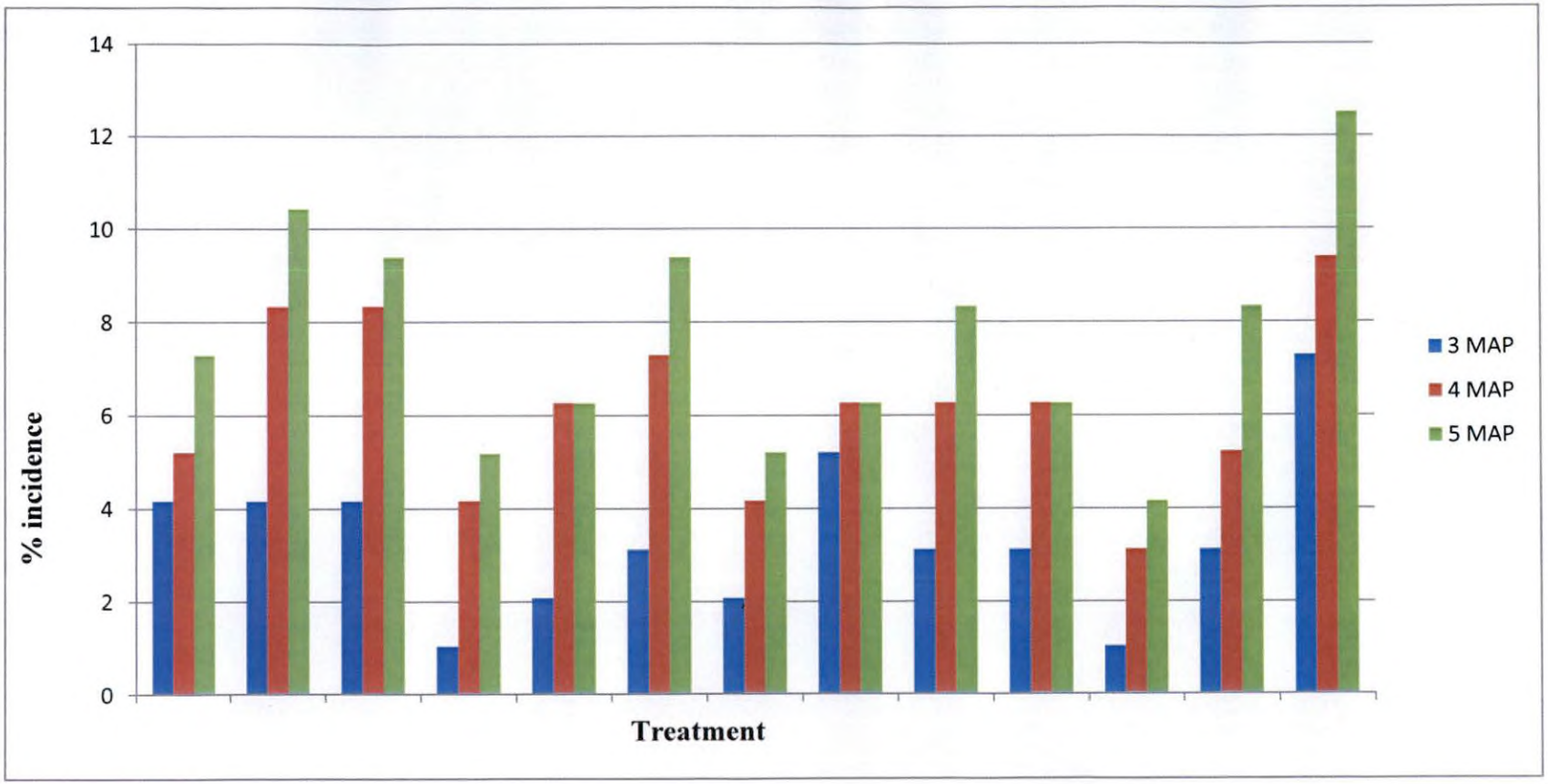

Fig 5. Effect of microbial inoculants on per cent incidence of *Rhizoctonia* leaf blight

al. (2001) reported two *P. fluorescens* strains, *viz.* PF1 and FP7 which inhibited the mycelia growth of *R. solani* and increased the seedling vigour of rice plants and yield. Bakker *et al.* (2007) reported that plant protection resulted by induced systemic resistance (ISR). In the present study, it was found that KAU-PF was more effective in the management of leaf diseases whereas consortia with *T. viride* were effective in the control of rhizome rot incidence.

The pests noticed in the present studies were rhizome maggot and shoot borer. No significant differences were observed among the treatments for rhizome fly and shoot-borer infection. Per cent incidence of rhizome maggot was minimum (4.17 %) in T_5 (KAU-TV). Among the consortia, T_6 (KAU-AZO + KAU-PSB + KAU-KSB) was the least succeptible(6.25 %). At the time of harvest, minimum rhizome maggot infection (0.89 %) was recorded in the case of T_8 (KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV). Stirling *et al.* (2009) reported that rhizome maggots bore and feed on the rhizomes of plants affected by rhizome rot disease. Treatment T_8 (KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV) recorded least rhizome rot disease incidence and rhizome maggot. However, T_1 (KAU-AZO) recorded minimum per cent incidence (2.08) of shoot-borer whereas T_7 (KAU-AZO+KAU-PSB+KAU-KSB+KAU-PF) recorded minimum per cent incidence of shoot-borer among the consortial treatments. Egan *et al.* (1989) reported that high levels of nutrients increase resistance to pests and in some cases they increased susceptibility.

The pH of the soil, organic carbon and available NPK were determined at the start of the experiment and also at 3 months after planting and at the time of harvest. The initial soil nutrient status revealed decrease in soil pH among the treatments. The soil pH and nutrient status of the experimental field recorded 5.6 pH, 1.4 % organic carbon, 230.36 kg/ha available nitrogen, 50.13 available phosphorus, available potassium 203.1 kg/ha available phosphorus. However the highest pH (5.5) was recorded in T_3 (KAU-KSB) while the lowest pH was recorded in T_2 (KAU-PSB) which might be due to organic acid production. The consortial treated plants also recorded the lowest pH. Among the consortia, T_7

(KAU-AZO+KAU-PSB+KAU-KSB+KAU-PF) and T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the lowest pH (5.30). The decrease in soil pH may be due to the organic acids produced during the decomposition of organic manures as well as the enzyme and hormonal effect of microbial inoculants (Chen *et al.*, 2006). It indirectly means enhanced microbial activity that happens in the rhizosphere region may be due to production of organic acids (Rengel and Marschne, 2005).

The organic carbon of the soil increased after the experiment. The higher organic carbon might be due to higher organic matter addition through farm yard manure and mulching (Ferrini *et al.*, 2008) and also by *Trichoderma viride.* Highest value (1.6 %) was recorded in T_4 (KAU-PF) while lowest value (1.52 %) was recorded in T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV). Among the available N content in soil, T_8 (KAU-AZO+KAU-PSB+KAU-KSB+KAU-TV) registered highest available nitrogen (188.68 kg/ha) among the consortia. Highest available N might be due to the biological nitrogen fixation by *Azospirillum* sp. which is due to increase in total N content (Tilak and Saxena, 2001). Some PGPB secrete some molecules, acting as inducers/signals to help the process of nitrogen fixation (Sharma *et al*, 2007). The microbial inoculants showed significant differences with respect to available P in soil. Available phosphorus was higher in case of T_7 (KAU-AZO+ KAU-PSB+ KAU-KSB+ KAU-PF) among the consortia. Phosphate solubilizing microbes can transform the insoluble phosphorus to soluble forms very slowly during the solubilisation process (Delvasto *et al.*, 2006; Chang and Yang, 2009). He *et al.* (2002) reported that inorganic forms of phosphorus are solubilized by microorganisms excreting organic acids that dissolve phosphatic minerals and/or chelate cationic partners of the P ions i.e. PO_4^{3-} directly, releasing P into solution. Microorganisms enhance the P availability to plants by mineralizing organic P in soil and by solubilizing precipitated phosphates (Chen *et al.*, 2006). Significant uptake of nitrogen and pottasium was reported in black pepper treated with *P. fluorescens* (Diby Paul *et al.*, 2005). Treatment T_{12} (POP recommendation) recorded the highest available phosphorus. This might be due to the availability of easily available phosphorus

due to the addition of chemical phosphatic fertilizers (Srilatha and Harish Kumar, 2015). Available K was found to be highest in T_{12} (POP recommendation) and T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) recorded maximum available potash among the consortia. Subbiah (1990) reported that when adequate amount of farm yard manure was added to soil with biofertilizer, it improved biofertilizer efficiency and ultimately nutrient status of soil. Highest available K in T_{12} (POP recommendation) might have been due to increased availability of K due to application of potash fertilizers (IISR., 1998).

In general, population sizes of bacteria decline more or less rapidly following introduction into a natural soil, and growth of introduced populations in microbiologically undisturbed soil is a rare phenomenon (Bashan *et al*, 1995). Therefore population of individual and consortial isolates in soil were recorded to know the fate and survivability of applied microbial inoculants. It was found that population of the inoculated microorganisms showed a decreasing trend from two months after planting. The population decreased from 10^8 cfu/ml to 10^4 cfu/ml in the case of bacteria and 10^6 to 10^3 in case of fungus. It might be due to abiotic soil factors such as texture, pH, temperature, moisture content, and substrate availability need critical assessment, since these largely determine the survival and activity of the introduced microorganisms (Gray, 1975). Wright *et al.* (1995) also reported reduction of the population size of bacterial inoculants due to predation by protozoa in soil which have been confirmed in a number of recent studies. In the present studies the survivability of only inoculated cultures were enumerated inorder to know how the population dynamics of inoculated microbial inoculant varies. When compared to control plants, the population of inoculated cultures were higher at time of harvest. However, further studies are required to confirm the survivability of inoculated cultures in all the treatments irrespective of the fact whether it is inoculated or uninoculated treatment.

In order to assess the feasibility of the microbial inoculant consortia, the BC ratio was determined and it was found that the maximum BC ratio was in the case of T_{11} (Organic adhoc package , KAU, 2009).

The present study indicated that ginger plants inoculated with microbial inoculants consortia performed better than the individual microbial inoculants.However, T_{11} (Organic POP) performed the best among all the treatments. Eventhough, consortia of microbial inoculants treated plants were on par,T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) performed better among the consortia. However, extensive field trials are necessary to confirm it.

Future line of work

- Studies on the suitability of cheap and locally available carrier material .
- Multilocational field trials have to be conducted to evaluate the microbial inoculants under different agro-ecological regions.
- Commercialisation of promising consortia.
- Plant uptake of nutrients have to be studied.

Summary

6. SUMMARY

The present study on "Evaluation of bioinoculant consortia for organic cultivation of ginger" was carried out in the Department of Agricultural Microbiology, College of Horticulture, Vellanikkara during 2014-2015. The major objectives were to study the compatibility among the biofertilizers namely *Azospirillum lipoferum.*, phosphate solubilizing bacteria, potash solubilizing bacteria and bioagents like *Pseudomonas fluorescens*, *Trichoderma viride* and to develop a consortia for plant growth promotion and disease management in ginger under field condition. The important findings of the study are summarized below:

- The popular and efficient cultures of *Azospirillum lipoferum.*, phosphate solubilizing bacteria, potash soubizing bacteria, *Pseudomonas flouroscens* and *Trichoderma viride* developed by Kerala Agricultural University were used for the study.
- KAU-AZO, KAU-PSB, KAU-KSB, KAU-PF and KAU-TV were subjected to compatibility test. All of the bacterial cultures tested were mutually compatible with each other. When the bacterial cultures were tested for their compatibility with KAU-TV, it was found that KAU-PF was incompatible with KAU-TV.
- The individual and consortia of isolates were mass multiplied on vermicompost as carrier material. Inorder to determine the compatibility between the vermicompost and the beneficial microorganisms the isolates were mass multiplied and enumerated under both sterile and unsterile vermicompost.
- The highest population in broth (6.3×10^8 cfu ml^{-1}) before mixing with vermicompost was recorded by KAU-PF. The population level didn't reduce below 10^8 cfu/g for bacteria and 10^6 in the case of fungus after mixing with vermicompost, which is the recommended standard of good quality microbial inoculant. Based on the population of the isolates in sterile and unsterile vermicompost it may be inferred that unsterile vermicompost can be used for mass multiplication of inoculants except for KAU-KSB which failed to grow in unsterile vermicompost.

- Based on the compatibility study, the consortia selected were KAU-AZO +KAU- PSB + KAU-KSB, KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF and KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV.
- These consortia were compared for their efficiency in growth promotion and disease management in ginger in comparison with treatment involving individual isolates of microbial inoculants, PGPR Mix I, PGPR Mix II, Organic adhoc package (KAU,2009), POP recommendation (KAU, 2011).
- The soil pH and nutrient status of the experimental field recorded 5.6 pH, 1.4 % organic carbon, 230.36 kg/ha available nitrogen, 50.13 kg/ha available phosphorus, available potassium 203.1 kg/ha . However, initial population of *Azospirillum,* phosphate solubilizing bacteria, potash solubilizing bacteria, fluorescent pseudomonads and *Trichoderma* in the experimental soil were absent
- Minimum days for germination (17.33) was recorded in T_6 (KAU-AZO+KAU-PSB+ KAU-KSB). Among the consortia, both T_7 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-PF) and T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the highest per cent (91.67) germination.
- Among the consortia the plant height was highest (74.86 cm) in the case of T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV). The maximum numbers of tillers were recorded in the treatment T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV).
- The maximum rhizome yield (8.93 t/ha) was in T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV).
- Based on the overall biometric and yield parameters, T_8 (AZO+KAU-PSB+ KAU-KSB +KAU-TV) performed better among the consortia. However, T_{11} (Organic adhoc package (KAU, 2009) performed better than the consortia treatments.
- With regard to disease incidence , T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum per cent rhizome rot (5.23%)

incidence among consortia while T_7 (AZO+KAU-PSB+ KAU-KSB +KAU-PF) recorded the minimum per cent incidence (5.21) of *Rhizoctonia* leaf blight

- With regard to pest incidence, T_6 (AZO+KAU-PSB+ KAU-KSB) was the least succeptible (6.25 %).to rhizome maggot whereas T_7 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF) recorded minimum per cent incidence of shoot-borer (4.17) among the consortial treatments.
- The soil pH and nutrient status of the experimental field were recorded as 5.6 pH, 1.4 % organic carbon, 230.36 Kg/ha available nitrogen, 50.13 kg/ha available phosphorus, available potassium 203.1kg/ha .
- At the time of harvest, T_7 (AZO+KAU-PSB+ KAU-KSB +KAU-FP) and T_8 (AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the lowest pH (5.30) and T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) registered highest available nitrogen (188.68 kg/ha) among the consortia. However, highest organic carbon (1.55 %) and available phosphorus (37.44 kg/ha) was recorded in T_7 (KAU-AZO+KAU-PSB+KAU-KSB+ KAU-PF). All the consortial treatments were on par with each other with respect to available potassium content in soil.
- Population of inoculated individual and consortial isolates in soil indicated a decreasing trend till the time of harvest. The population decreased from 10^8 cfu/ml to 10^4 cfu/ml in the case of bacteria and 10^6 to 10^3 cfu/ml in the case of fungus.
- The Benefit:Cost ratio was maximum (1.65) in the case of T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV).
- The present study indicated that ginger plants inoculated with microbial inoculants consortia performed better than the individual microbial inoculants.However, T_{11} (Organic POP) performed the best among all the treatments. Eventhough, consortia of microbial inoculants treated plants were on par,T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) performed better among the consortia.

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Appendices

APPENDIX I

MEDIA USED AND COMPOSITION

a) Okons Nitrogen free media

Malic acid	5.00 g
Pottasium hydroxide	4.00 g
Dipotassium hydrogen phosphate	0.50 g
Ferrous sulphate	0.05 g
Manganese sulphate	0.01 g
Magnesium sulphate	0.10 g
Sodium chloride	0.02 g
Calcium chloride	0.01 g
Sodium molybdanate	2.00 mg
Agar	20 g
Distilled water	1000 ml
Bromothymol blue	(0.50 % alcoholic solution) 5 .00 ml
pH	6.6-7

b) Pikovskayas agar media

Yeast extract	0.5 g
Dextrose	10 g
Calcium phosphate	5.0 g
Ammonium sulphate	0.5 g
Potassium chloride	0.2 g
Magnesium sulphate	0.1 g
Manganese sulphate	0.0001 g
Ferrous sulphate	0.0001 g
Agar	20 g
Distilled water	1000 ml

c) Kings B agar media

Peptone	20 g
Glycerol	10 ml
Dipotassium hydrogen phosphate	1.5 g
Magnesium sulphate	1.5 g
Distilled water	1000 ml
pH	7.2-7.4

d) Potato dextrose agar

Potato infusion	200.00 g
Glucose	20.00 g
Agar	20.00 g
Distilled water	1000 ml
pH	5.1

e) Glucose Yeast Calcium Agar media

Glucose	20.0 g
Yeast extract	3 g
Calcium carbonate	5.0 g
Agar	20 g
Distilled water	1000 ml

APPENDIX II

Organic adhoc package (KAU, 2009)

- Before planting soak the seed rhizomes in a solution containing *Pseudomonas* @ 20g/litre for 30 minutes and dry under shade.
- FYM / compost @ 25 tonnes as basal and 3t/ha each at 60DAP and 120DAP.
- Apply FYM, *Trichoderma*, neem cake mixture @ 100 g / planting pit at the time of planting.
- Apply *Azospirillum* @ 2.5 kg /ha / PGPR mix I as basal. Repeat the same dose at 120 DAP.

APPENDIX III

POP recommendation (KAU, 2011)

- $N:P_2O_5:K_2O$ 75:50:50: kg/ha/year
- Full dose of P_2O_5 and 50 per cent of K_2O may be applied as basal.
- Half the quantity of N may be applied 60 days after planting.
- The remaining quantity of N and K_2O may be applied 120 days after planting.

EVALUATION OF BIOINOCULANT CONSORTIA FOR ORGANIC CULTIVATION OF GINGER

By

HARITHA T.R.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment

of the requirement for the degree of

Master of Science in Agriculture

(Agricultural Microbiology)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Agricultural Microbiology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

2015

ABSTRACT

Ginger is one of the major spice crops of Kerala. Several constraints hinder its production and the major one is its succeptibility to various diseases. This has led to the use of high doses of chemical pesticides. Ginger is also a highly nutrient exhausting crop, which demands use of high doses of fertilizers. Although, chemical fertilizers and pesticides are highly effective, their continuous use has led to many environmental problems. Alternative approaches are therefore needed to minimize the use of chemical fertilizers and agrochemicals, since ginger is directly consumed. Emphasis should be given for the organic cultivation of ginger. The role of bioinoculants assumes special significance in this context. The magnitude of plant growth promoting activities is reported to be better in the case of consortia or mixed cultures than single strain. Therefore, bioinoculants formulation consisting of biofertilizer and biocontrol agent would be a novel technology which will provide nutrients as well as manage diseases. The literature on the use of consortia of biofertilizers and biocontrol agents are scanty. Hence, a study was undertaken on "Evaluation of bioinoculant consortia for organic cultivation of ginger'' with an objective to evaluate and find a suitable consortia of bioinoculants for ginger cultivation.

Azospirillum lipoferum, phosphate solubilizing bacteria (PSB), potash solubilizing bacteria (KSB), *Pseudomonas fluorescens* and *Trichoderma viride* cultures of KAU were used for the study. When tested for their compatibility with each other, it was found that *Azospirillum lipoferum,* PSB, KSB, *Pseudomonas fluorescens* were mutually compatible with each other. However, *Pseudomonas fluorescens* and *Trichoderma viride* were incompatible.

Based on the compatibility test, consortia consisting of biofertilizers alone and biofertilizer + biocontrol agents were selected for the field evaluation. The consortia

KAU-AZO +KAU- PSB + KAU-KSB, KAU-AZO + KAU-PSB + KAU-KSB + KAU-PF and KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV were selected. These consortia were compared with individual bioinoculants, PGPR Mix I, PGPR Mix II, Organic adhoc package (KAU, 2009) and POP recommendation (KAU, 2011).

Based on the overall biometric and yield parameters, T_{11} (Organic adhoc package, KAU, 2009) was found to be best among all the treatments evaluated.

Among the consortia, days taken for germination was minimum (17.33) in the case of T_6 (KAU-AZO+KAU-PSB+ KAU-KSB) while both T_7 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-PF) and T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the highest per cent (91.67) germination. Plant height, number of tillers, and yield were maximum in T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV).

With regard to disease and pest incidence, T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) recorded minimum per cent rhizome rot (5.23%) incidence. However, T_7 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-PF) recorded the minimum per cent incidence (5.21) of *Rhizoctonia* leaf blight and shoot-borer (4.17 %). The T_6 treatment (KAU-AZO+KAU-PSB+ KAU-KSB) was the least succeptible (6.25 %) to rhizome maggots.

At the time of harvest, T_7 (KAU-AZO+KAU-PSB+KAU-KSB +KAU-PF) and T_8 (KAU-AZO+KAU-PSB+ KAU-KSB +KAU-TV) recorded the lowest pH (5.30) and T_8 (KAU-AZO + KAU-PSB+ KAU-KSB+ KAU-TV) registered highest available nitrogen (188.68 kg/ha) among the consortia. However, highest organic carbon (1.55 %) and available phosphorus (37.44 kg/ha) was recorded in T_7 (KAU-AZO+KAU-PSB+KAU-KSB+ KAU-PF). All the consortial treatments were on par with each other with respect to available potassium content in soil.

Population of inoculated individual and consortial isolates in soil indicated a decreasing trend till the time of harvest. The population decreased from 10^8 cfu/ml to

10^4 cfu/ml in the case of bacteria and 10^6 to 10^3 cfu/ml in the case of fungus. The Benefit:Cost ratio was maximum (1.65) in the case of T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV).

The present studies clearly indicated that consortia inoculated plants performed better than the individual isolates. The consortia of bioinoculants treated plants were on par, but T_8 (KAU-AZO + KAU-PSB + KAU-KSB + KAU-TV) was the most promising treatment among the consortia. Therefore, it can be concluded that bioinoculant consortia consisting of bioagents for nutrient fixation /solubilization (N, P, K) and fungicidal effect would be a novel technology in present-day agriculture.