Eco-friendly and IPM-compatible seed treatments for some field crops against termites

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NEW DELHI–110 012
2013
Eco-friendly and IPM-compatible seed treatments for some field crops against termites

By

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A Thesis
Submitted to the Faculty of Post Graduate School,
Indian Agricultural Research Institute, New Delhi,
in partial fulfillment of the requirements
for the award of degree of

MASTER OF SCIENCE

In

ENTOMOLOGY

2013

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This is to certify that the thesis entitled “Eco-friendly and IPM-compatible Seed Treatments for some Field Crops against Termites” submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the award of MASTER OF SCIENCE IN ENTOMOLOGY, embodies the results of bona fide research work carried out by Mr. SHIVAJI HAUSRAO THUBE, Roll No: 20165 under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

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Place: New Delhi

(Doctor G. K. Mahapatro)
Chairman
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Dedicated To My Family
ACKNOWLEDGEMENT

I would like to express my deepest sense of gratitude and indebtedness to Dr. G.K. Mahapatro, National Fellow (ICAR), Indian Agricultural Research Institute, New Delhi and chairman of my Advisory Committee for his invaluable guidance, constant encouragement, cooperative attitude, immense patience and peerless criticisms during the course of investigation and preparation of the manuscript.

It is my privilege to express profound sense of gratitude to Dr. V.V. Ramamurthy, Principal scientist, Division of Entomology, Co-chairman of my Advisory Committee and Professor, Division of Entomology, for his constructive and valuable suggestions. I implore my feeling of profound gratitude to my Advisory committee members Dr. Arun Kumar, Senior Scientist, Division of Seed Science and Technology, IARI, for his help and facilities render by him.

It is my sincere thanks are to, Dr. G. T. Gujar, The Head, Division of Entomology, Indian Agricultural Research Institute for providing me the necessary facilities and encouragement throughout this work. It is my privilege to express my thanks to Dr. Pratibha Sharma, Professor, Division of Plant Pathology, IARI, for his help and facilities render by him.

My heartiest thanks are to Mr. Ganesh Rai and Mr. Sachin Kumar who assisted me throughout my research work. Their constant guidance during research work and thesis writing has reflected in the completion of this venture.

I am grateful to my friends, Rupali, Mahesh, Satish, Ashok, Vishvanath, Nakul, Manish, Rishikesh, and Rupesh and the team behind the successful completion of this manuscript.

It gives me pleasure to mention names of my seniors, Md. Sithik, Soumia, Guru, Nataraj, and Vivek, Pratap, Suresh, Rajna, my classmates Asish, Muzeer and Rajesh, My juniors, Yogesh, Sukhwinder, Veeranna, Sopan, Sugat and Namita for their timely guidance and cooperation in my need.

The endless love, affection, sacrifice and constant inspiration from my Parents and brother enabled me to reach the footstep of my long cherished aspiration. Finally, the financial assistance provided by the I.C.A.R, in the form of I.C.A.R Fellowship during the tenure is gratefully acknowledged.

Date:
Place: New Delhi

Shivaji Thube
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Introduction
INTRODUCTION

Seed treatment plays a crucial role in protecting the emerging seedlings from insect-pests and diseases. Recommendations of seed treatment for various crops are offered by Government of India under its most ambitious programme *Total Seed Treatment Campaign 2007* (www.ppqs.gov.in). Use of seed treatments on field crops in India has increased considerably over the past few years. Seed treatments protect seed from insect pests such as the shoot fly, aphids, jassids, and such other sucking pests and termites in some localities. Mostly sucking insect pests are targeted by seed treatments in these crops. In addition, seed treatments can effectively be used to tackle the termite problems as well. Mostly it is seen that seed treatment recommendations are offered based on the field trials, few cases only recommendations are based on *in vitro* (=laboratory trials). In our investigation, this point was taken care of; *in vitro* studies are carried out in the few selected major field crops *viz*; cereals (wheat, maize), pulse (chickpea) and oilseeds (groundnut, soybean)

1.1. Test crops

1.1.1. Wheat (*Triticum aestivum*) is the second most important food crop of the country, contributing nearly one-third of the total food grain production. Presently, wheat accounts for 29.9Mha of the total area contributing about 93.9 Mt of the total production with record yield of 3,150 kg/ha (Anonymous, 2013). However, the production is heavily affected by several insect pests in field. In field, wheat crop is attacked by more than a dozen of insect pests since sowing till harvesting (Bindra, 1968). Among the major insect pests of wheat in India, aphids have gained economic importance of regular pests and reported from all major wheat growing regions (Singh, 1986). Termites, Gujhiaweevil, army worms, brown wheat mite, aphids and jassids are some important pests in India.

1.1.2. Maize (*Zea mays*) It is the third most important cereal crop of the world. It is cultivated mainly for food, feed, fodder and industrial raw material. Maize is globally important crop and preferred staple food for more than one billion people in sub-Saharan Africa and Latin America, where animal source of protein is not affordable by the common people. It is cultivated on more than 160 m ha in 166 countries having wider
diversity of soil, climate, biodiversity and management practices. Among the cereal crops in India, maize with annual production of around 21 million tones covering 8.5 million hectares ranks third in production. India ranks sixth in global maize production, contributing to 2.4% of world production with almost 5% share in world harvested area. However, the country lags far behind in productivity – 24.7 quintal/ha against world average of 51.4 quintal/ha. (www.ficci.com/events).

Different biotic and abiotic factors are influencing the yield of wheat crop, and among the biotic factors insect pests play a major role in determining the yield. Normally the insect pests occurring in wheat are shoot fly, aphids, brown wheat mite, army worm, cut worms and termites (*Microtermes obesi* and *Odontotermes obesus*). Among these insect-pests attacking wheat, termites act as a major insect-pest at seedling and harvesting stage in tropical and sub-tropical areas of the world (Singh, 2001). Termite damage in wheat usually occurs at seedling and more serious at emergence of the earheads. The attacking termites eat the underground roots, resulting in yellowing of leaves and finally death of the plants in case of severe infestation. At the earhead stage, the damage is characterized by chaffy earheads with little or no grain formation (Kumawat, 2001).

1.1.3. Chickpea (*Cicer arietinum*) Chickpea remarkably predominates among other pulse crops in terms of both area and production. The year 2009-10 marked significant increase in area under chickpea (8.56 million ha) which is highest in last 10 years. Similarly, the chickpea production (7.35 million tons) also surpassed last 50 years record with highest productivity (858 kg/ha) ever recorded in the history of India. The area under chickpea has increased from 6.45 in 1992-93 to 8.56 million ha in 2009-10 (AICRP on Chickpea, 1993). Amongst the production constraints in chickpea, insect pests are noteworthy. It is infested by about 60 insect species including gram pod borer, aphids and termites. Termites attack chickpea crop at seedling stage and also near maturity.

1.1.4. Groundnut (*Arachis hypogaea*) This is grown on nearly 23.95 million ha worldwide with a total production of 36.45 million tons and an average yield of 1520 kg/ha in 2009 (FAOSTAT, 2011). India is the largest producer of groundnut in the world (32% of world production). There has been appreciable increase in the area (68.5%) and production (163%) of the crop between 1950-51 and 1998-99. Being a legume, it occupies a unique position in the farming system. It is the world’s fourth most important
source of edible oil and third most important source of vegetable protein. Aphids, jassids and thrips are of national importance, while termites are of regional importance in states like AP, Punjab, Rajasthan and Gujarat (DPPQ&S, 2001).

1.1.5. Soybean (*Glycine max* L.) This premier oilseed crop covers an estimated area of about 10.2 million ha with a production of 13.2 million tons in India (Anonymous, 2011). The productivity of soybean crop has shown gradual build up from the time of its initiation of commercial cultivation, but now it is hovering around 1 t/ha for the last one decade, mainly in view of deficit and erratic distribution of rainfall and uncertainty in onset of monsoon being experienced on account of global climatic change (Tiwari *et al.*, 2001). Bihar hairy caterpillar, girdle beetle, stem fly, gram pod borer, tobacco caterpillar, thrips, white fly, jassids and aphids are some important insect pests of soybean among them these seed treatment are recommended by directorate of soybean research, Indore for sucking complex and stem fly.

1.2. Seed treatment

Seed treatment plays crucial role in protecting the emerging seedlings from insect-pests and diseases. It deals under its purview, both products and processes. The usages of specific products and specific techniques can improve the growth environment for the seed, seedlings and young plants. Seed treatment complexity ranges from a basic dressing to coating and pelleting. Seed dressing is the most common method of seed treatment and popular amongst Indian farmers. The seed is dressed with either a dry formulation or wet treated with a slurry or liquid formulation. Recommendations of seed treatment for various crops are offered by Government of India (GOI) on cereal crops - rice, wheat, barley; vegetables (potato, tomato, chilli, okra, leguminous and cruciferous crops), pulses (gram, pigeon pea, pea) and others (sugarcane, coriander, sunflower) etc. under its most ambitious programme *Total Seed Treatment Campaign 2007* (www.ppqs.gov.in).
1.2.1. Ideal chemical seed treatment

Today, seed treatment has since evolved into a more complex science. An ideal chemical seed treatment should be highly effective against various pests and diseases must satisfy the following requirements, viz. (1) be harmless to the seed; (2) be stable for relatively longer periods before planting; (3) offer an even coating to seed, adhere well, without giving a dull or unattractive appearance, or impairing seed flow in planting equipment; (4) be relatively inexpensive; and (4) be registered for the intended use (IOWA, 2006). The pesticides used in seed treatments should not affect adversely the seedling or plant growth and development.

1.2.2. Combinatorial Approach

Insecticide seed treatments are often formulated as combinations with other seed protectant pesticides. These may be a combination of two insecticides to provide a broader spectrum of insect control, or a combination of an insecticide and a fungicide. In Good Agricultural Practices (GAP), inclusion of biofertiliser and biofungicide in the seed-treatment also add another dimension to this issue for a holistic approach study.

1.3. Target insect – termites and damage propensities

Termites are xylophagus, considered to be a serious pest as it destroys crops and households. Termites are of regular occurrence mostly in tropical and sub-tropical parts of India. About 40 species of termites are known for their injuriousness to economic plants (Roonwal and Chhotani, 1989). In Rajasthan the situation is more alarming as the termites inflict heavy damage to the crops in sandy loam soil moisture regime (Parihar, 1981). Yield losses due to termite damage ranging from 50 to 100% have been reported by Sekamatte et al. (2001) and Rao and Azad. (2009).

Termites attack seedlings, stem, leaf, cobs, tassel and harvested crop left in the field for drying. The pest damages the plants by cutting roots and stem and is capable of devouring whole plants by making earthen galleries up to tassel. In wheat, termites infest the crop stand seriously at seedling, and then at maturity (pre-harvesting) stage (Mahapatro et al., 2011). In maize, *Odototermes* and *Microtermes* species are major problem in Delhi and around (Sharma et al., 2003; and Mahapatro, 2011). In other crops
also various workers reported varied degrees of termite infestation. In groundnut, *Odontotermes* spp. cause 5-50% plant mortality; and up to 46% pod damage was reported by Nautiyal (2002) in chickpea. The initial damage to the seedlings can cause substantial seedling mortality. The chickpea roots and stems are tunneled by termites (*Odontotermes* spp.) inside which they feed remaining under the earthen galleries (Gaur *et al.*, 2010).

1.4. *In vitro* germination test

Germination testing is considered as one of the most important quality test in evaluating the planting value of a seed lot. The ability of seeds to produce normal seedling and plants later on is measured in terms of germination test. Testing of seeds under field conditions is normally unsatisfactory as the results cannot be reproduced with reliability. Laboratory methods then have been conceived wherein the external factors are controlled to give the most uniform, rapid and complete germination. Testing conditions in the laboratory have been standardized to enable the test results to be reproduced within limits nearly as possible as those determined by random sample variations. The ultimate objective of seed germination testing is to obtain information with respect to the planting value of the seed and to provide result which could be used to compare the value of different seed lots. Germination of a seed lot in a laboratory is the emergence and development of the seedling to a stage where the aspect of its essential structures indicates whether or not it is able to develop further into a satisfactory plant under favourable conditions in soil (ISTA, 2007). These essential structures are well-developed and intact root system, hypocotyl, plumule and one or two cotyledons according to the species.

Seed vigour is a highly complex subject. At biochemical level it involves energy and biosynthetic metabolism, coordination of cellular activities and transportation and utilization of reserve foods. At germination level, it involves speed and totality of germination, pushing power of seedling etc. (Agrawal, 1995). Vigour indices I and II are based on the seed germination percentage, seedling length and dry weight of the seedlings. Certainly, these indices provide better information on the seedling growth and development.
1.5. Test-insecticides

Earlier (before 1980’s) the chlorinated hydrocarbon insecticides like aldrin, dialdrin, BHC and heptachlor were effectively used to control termites in wheat due to their long residual action. But these chemicals leave harmful residues on the food stuffs and are highly hazardous to the human health and non target organisms. As a result of these consequences, the Government of India banned most of the chlorinated hydrocarbon insecticides. It was observed that most of chemical termiticides which is used for seed treatment cause harmful effects on seed germination as well as seedling development. As on today, termiticides like chlorpyriphos, imidacloriprid, and fipronil are dominating and are the recommended insecticides with label claims (www.ppq.gov.in), and very few effective management reports are available, on management of termites through seed treatment with these new chemicals further meager literature is available on compatibility of this termiticides with bio fertilizer and bio fungicide as seed treatment. So keeping these in view the following objectives were undertaken. For the last couple of years, our IARI campus is witnessing increasing termite infestation in field crops, and prompted us to undertake this research work (Mahapatro, 2011).

Realizing the negative impacts of chemical pesticides, the whole scientific community is addressing the alternative non-chemical means, and selective use of insecticides like low dose to ultra-low dose pesticides, specific pesticidal application means like seed treatments in an attempt to reduce the pesticide-load to the environment (Mahapatro, 2011).

1.5. Objectives

1.5.1. To study the effect of various dosages of insecticidal seed treatments on germination percentage, root length, shoot length and vigour index of seedlings of few selected crops - cereals – wheat, maize; pulses – gram; and oilseeds - groundnut and soybean).

1.5.2. To check the compatibility of insecticides, bio-fertilizers and bio-fungicides (fungicides) commonly used in seed treatment for selected crops, so as to verify seed treatment compatibility in IPM.
This investigation hope to generation useful data on effective insecticidal seed treatments for insect control (in particular for termites) in various crops – wheat, maize, gram, groundnut and soybean. Generation of farmers-friendly IPM-compatible seed-treatment packages (inclusive of biofungicides and biofertilisers) is the prime objective of this investigation.
Background
2. BACKGROUND

Insect pests, diseases and weeds cause colossal losses to the potential agricultural production. Anecdotal evidences also indicate rise in the losses, despite increasing use of chemical pesticides. At the same time, there is a rising public concern about the potential adverse effects of chemical pesticides on the human health, environment and biodiversity. These negative externalities, though, cannot be eliminated altogether, their intensity can well be minimized through promotion of alternative technologies such as bio-pesticides and bio-agents as well as good agronomic/pest management practices such as seed treatments that reduce the pesticide load to environment significantly. While discussing the contemporary scenario of pests and pesticides in India Gupta et al. (2009) suggested that pesticide-load to environment can substantially be reduced following zero-spray strategy like spot or local treatment and seed treatment tactics. Eco-friendly and sustainable development can be attained with right pesticides at right time and right dose following right methodology. Keeping this in mind, an investigation was carried out for developing Eco-friendly and IPM-compatible seed treatment packages for major field crops against termites. The relevant background for the seed treatments – insecticidal (in particular the insecticides recommended for termites), and other components of integrated crop management like biocontrol agent (Trichoderma spp.) and biofertilisers (Rhizobium culture), bio-efficacy of combinatorial approach in seed-treatments – all these aspects are deliberated in this chapter.

2.1. Insecticidal seed treatment

Seed may carry various microbes - fungi, bacteria, and viruses on the seed coat or within the seed, some of which cause plant diseases. Unless treated suitably, the seed propagates fungi and other organisms that attack seed and seedlings. Insects can damage seed after sowing or planting. Once planted, however, soil insects (like termites) can be extremely destructive to seeds and seedlings, particularly when soil conditions are cold, wet, or do not favour rapid germination and emergence. Besides soil insects, other foliar insect pests like sucking pests (aphids, jassids, whiteflies etc) also inflict damage to the
growing seedlings. Treating seed with pesticides can improve stand quality, increase yields, and increase return on investment.

2.1.1. Chemical insecticides

The earliest reported use of seed treatment dates back to 60 AD when wine and crushed cypress leaves were used to protect seed from storage insects. Scientists today have given credence to the practice because hydrogen cyanide evolves under these conditions (Iowa Commercial Pesticide Applicator Manual, 2006). Since 1750, when the Frenchman Tillet proved scientifically the benefits of salt and lime to control common bunt of wheat. Seed treatment has since evolved into a more complex science. The advent of the organic mercurials in the 1920s started a new era in seed treatment that has resulted in the multiple contact and systemic fungicides now available for seed treatment. Although safety concerns have led to the banning of mercurial compounds, the newer contact and systemic fungicides allowed for a more precise matching of treatment to specific needs. Insecticides are used in seed treatments mostly for sucking insect-pests like aphids, jassids (leafhoppers), thrips, whiteflies and also non-sucking pests like termites. There are two groups of termiticides applied into soil - repellent and non-repellent termiticides. The repellent termiticide is chlorpyriphos, while non-repellents are fipronil, imidacloprid and indoxacarb (Gurbel, 2008).

**Chlorpyriphos** It is less persistent in the environment and widely accepted, although it is more toxic to vertebrates than chlorinated hydrocarbons (Perrott, 2003). The mode action of chlorpyriphos is attack on the nervous system by binding with acetyl cholinesterase that inhibits its function, causing accumulation of acetylcholine at the all available receptor sites. This produces repetitive firing of impulses at the next neural unit (Lee *et al.*, 2003).

**Fipronil** The mode of action involves blocking the γ-aminobutyric acid (GABA)-gated chloride channel (Hainzl and Casida, 1996). Mode action of fipronil is interference with the passage of chloride ions in the nervous system, eventually causing death. According to Henderson (2003), fipronil and imidacloprid are more toxic to insects than to mammals because they kill insects through hyper-excitation of the central nervous system.
**Imidacloprid** The mode of action of imidacloprid is on the nervous system of the termites by binds to a postsynaptic nicotinic receptor thus blocking neural transmission. When the Imidacloprid action prevents the transmission of the information of the binding sites, resulting a lasting impairment of the nervous system and eventually, death of the insect (Gurbel, 2008). Imidacloprid is a new termiticide which is a slow–acting toxicant even in low concentration. Imidacloprid treatment caused the termites to become sluggish, inhibits grooming and tunneling and eventually caused death (Boucias *et al.*, 1996). One of the important factors effecting on imidacloprid bioavailability for control termite is the type of soil. Ramakrishna *et al.* (2000) indicated that organic matter, silt, clay, pH, and cation exchanges capacity affect the bioavailability of imidacloprid effects to termites.

The active ingredients of insecticides are poisonous to insects, and in some circumstances, may be poisonous to seed. The phytotoxic effects can be seen at germination with abnormal growth of seedlings. Typical symptoms in cereals are short, thickened roots and plumules. It is very important to apply enough insecticide(s) to protect seed from insect attack without impairing germination. In some cases, the effective dosage is substantially below the phytotoxic dose, but in other cases it may be very close with very little margin for error.

**2.1.2. Seed treatment for fertilization and disease management**

**Biofertilizer**

Biofertilizers are environmentally and farmer friendly renewable source of non-bulky low cost organic farm input, while rhizobium, Cyanobacteria and *Azolla* are crop-specific, *Azotobacter*, *Azospirillum*, phosphorus-solubilizing bacteria and vesicular arbuscular mycorrhizas (VAMs) are broad spectrum biofertilizers. Their significance and economic feasibility of their application both by seed treatment and to soil, would promote their adoption as an effective supplement to chemical fertilizers in meeting crop requirements (Marwaha, 1995; Gupta and Parihar, 1996).

**Azospirillum as nitrogen fixing biofertilizer**

*Azospirillum* is one of the most important associative micro-aerophillic nitrogen fixer commonly found in loose association with the roots of cereals and grasses. It is of great interest as it has high nitrogen fixation capacity, low energy requirements and
abundant establishment in rhizosphere of cereals and increased tolerance to high temperature (30-40°C) which are responsible for its suitability under tropical condition (Yadav and Raychaudhuri, 1999). Positive effects of *Azospirillum* inoculation on growth and yield of several crop plants (mainly cereals) have been reported (Wani, 1990; Saxena and Tilak, 1998).

Chunchun *et al.*, (1998) reported that the *Azospirillum* is second micro aerophilic N fixer, after blue green algae. Results of Indian experiments on wide range of field crops (Pearlmillet, sorghum, maize, wheat, jute and mustard) showed that *Azospirillum* could successfully be used to replace some of N fertilizer requirement.

Patel *et al.* (1993) recorded significant increase in yield with the application of sub-optimum level of N fertilizer along with *Azospirillum* inoculation.

**Azotobacter as nitrogen fixing biofertilizer**

These are free living bacteria which grow well on a nitrogen free medium. These bacteria utilize atmospheric nitrogen gas for their cell protein synthesis. This cell protein is then mineralized in soil after the death of *Azotobacter* cells thereby contributing towards the nitrogen availability of the crop plants. Treatment of seeds with *Azotobacter* and *Azospirillum* can help to control disease incidence and severity (O’Sullivan and Gora, 1992), improve nutrient uptake efficiency (Bashan *et al.*, 1990), produce thiamin riboflavin, indole acetic acid and gibberellins and promote growth leading to enhanced yield (De Freitas, and Germida, 1990).

Elshanshoury (1995); Patil *et al.* (1995); and Jarak *et al.* (2004) reported that among the free-living nitrogen-fixing bacteria, those from genus *Azotobacter* have an important role, being broadly dispersed in many environments such as soil, water and sediments. Many authors have shown the positive effect of inoculation of wheat with these bacteria. Jagnow (1987) claimed, inoculation of wheat and maize with *Azotobacter* increases both the mass of the above ground part of the plant (26-50%) and the yield (19-30%). According to Zahir *et al.* (1996) and Kumar *et al.* (2001), wheat which has been inoculated with free nitrogen fixators grows more evenly resulting in higher yield. Kumar *et al.* (2001) reported that *Azotobacter chroococcum* has been widely used to inoculate
crops of non-legumes and increases the yield of field crops by about 10% and of cereals by about 15-20%.

**Rhizobium as nitrogen fixing biofertilizer**

*Rhizobium* is the most well-known bacterial species that acts as the primary symbiotic fixer of nitrogen. These bacteria can infect the roots leading to formation of lumps or nodules where the nitrogen fixation takes place. The bacterial enzyme system supplies a constant source of reduced nitrogen to the host plant and the plant furnishes nutrients and energy for the activities of the bacterium. About 90% of legumes can become nodulated (Chenn, 1999).

The initial interaction between the host plant and free-living rhizobia is the release of a variety of chemicals by the root cells into the soil. Some of these encourage the growth of the bacterial population in the area around the roots (the rhizosphere). Reactions between certain compounds in the bacterial cell wall and the root surface are responsible for the rhizobia recognizing their correct host plant and attaching to the root hairs. Flavonoids secreted by the root cells activate the *nod* genes in the bacteria which then induce nodule formation. The whole nodulation process is regulated by highly complex chemical communications between the plant and the bacteria (Chenn, 1999).

**Fungicidal seed treatment**

Historically, fungicides were developed from sulphur, copper, and mercury compounds. The toxicity of these materials to seed and the development of newer and more specific materials contributed to the decline in their use. Toxicity to warm-blooded animals and the accumulation of mercury in the environment caused them to be banned. The newer organic fungicides largely replaced inorganic compounds. The organic fungicides are extremely efficient; thus less quantity is required in treatment. They also are less risky for crops, animals, and the environment. In India, few chemicals like captan, thiram are most popular in common marketplace. However, latest for eco-friendly approach, biofungicides like *Trichoderma viridae* and *harzianum* are gaining popularity (Hadar *et al*. (1979).
*Trichoderma* as biocontrol agent

This is a very effective biological mean for plant disease management especially the soil borne ones. It is a free-living fungus which is common in soil and root ecosystems. It is highly interactive in root, soil and foliar environments. It reduces growth, survival or infections caused by pathogens by different mechanisms like competition, antibiosis, mycoparasitism, hyphal interactions, and enzyme secretion. Biological control of soil borne plant pathogens by the addition of antagonistic microorganisms to the soil is a potential nonchemical means for plant disease control. *Trichoderma* species capable of hyperparasitizing pathogenic fungi, are highly efficient antagonists (Dennis and Webster, 1971). Weindling, (1934) reported parasitism of *Trichoderma lignorum* on *Sclerotium rolfsii* and *Rhizoctonia solani*. This effect was also shown under field conditions by Wells *et al.* (1972) using *T. harzianum* grown on ryegrass. Similarly, Backman and Rodriguez (1975) controlled *S. rolfsii* in peanuts using molasses enriched clay granules as a food base for *T. harzianum*. Recently Hadar *et al.* (1979) found that *T. harzianum* directly attacked *R. solani.*

2.2. Seed treatment experimentation in lab (*in vitro*) and field

Effect of seed treatments on various crops are investigated by few scientists only. Differential seed treatment reaction and resultant varietal sensitivity were recorded in crops like wheat (Chaudhary *et al.*, 2001, Shukla, 2010), groundnut (Narasimhulu and Kameswara Rao, 1989), chickpea (Chaudhary and Dashad, 2002), green gram (Dhillon *et al.*, 2001), sesame (Charjan and Tarar, 1993), and okra (Gaikwad and Pawar, 1979).

Few laboratory investigation were taken on seed treatments of insecticides than the field trials. Relevant literature in the test-crops is discussed below.

2.2.1. Wheat

**Lab condition**

Kashyap *et al.* (1994) reported effect of four insecticidal (aldrin 30EC, endosulfan 35EC, formothion 20EC and chloryphosph 20EC @ 4.0, 3.5, 2.5 and 1.5 ml/kg seed respectively) seed treatments on seed viability and vigour in eight wheat cultivars (WH 147, WH 157, WH 291, WH 416, HD 2329, HD 2285, Sonalika and C-306) under lab conditions. He observed significant differences among different cultivars, insecticides,
period of storage of treated seed for the parameters of germinability, viability and vigour. ‘Sonalika’ cultivar was most sensitive while ‘HD 2329’ was least sensitive to insecticidal seed treatment. Among the four insecticides formothion 20EC affected seed viability and vigour in most of the cultivars, especially in cv. ‘Sonalika’.

Chaudhary et al. (2001) reported the effect of three insecticidal (formothion 20EC, endosulfan 35EC and chlorpyriphos 20EC @ 2.5, 3.5 and 1.5 ml/kg) seed treatments on germination, leachate conductivity, respiration rate, intensity of dehydrogenase activity and α-amylase activity in three cultivars (Sonalika, WH 147 and HD 2329) under lab conditions. He found that inhibition of seed germination in ‘Sonalika’ as compared to ‘HD 2329’ and ‘WH 147’ with insecticide seed treatment seems to be due to imbibition damage caused by rapid imbibition rate and higher amount of seed leachate conductivity. Respiration rate, intensity of dehydrogenase activity, which reflects the vigour of seeds, and also specific activity of α-amylase were affected more in seed treatment with formothion 20EC in ‘Sonalika’ than ‘HD 2329’ or ‘WH 147’. It was inferred that, varietal sensitivity depends upon the genetic variability that governs the effect of seed treatment chemicals, particularly systemic insecticides belonging to the organophosphorus group.

In an insecticidal seed treatment trial both in laboratory and field, Shukla (2010) evaluated chlorpyriphos 20EC, imidacloprid 200SL and fipronil 5FS @ 4, 5 and 6 ml/kg of seed, and observed fipronil 5 ml/kg as the best treatment based on germination percentage, yield and cost: benefit ratio. Latest, our laboratory reported the effective seed treatments with chlorpyriphos, imidacloprid, fipronil, garlic-based products for wheat for six varieties (Sithik and Mahapatro, 2012).

Field condition

The earlier recommendations to control termites in wheat crop include seed treatment with aldrin 30EC (@ 4 ml/kg seed) which remained effective for the crop season and enhanced the wheat yield (Verma et al., 1978) and alternatively soil mixing with 10% BHC dust or 5% heptachlor @ 20-25 kg/ha was recommended (Atwal, 1976). Verma et al. (1980) reported effect of different dates of sowing of aldrin treated and untreated wheat seeds on germination, termite damage and yield. He observed that there
were no differences in the germination counts of the two types of seeds sown on five different dates. Termite damage was more in the crop sown in the first week of November than during the mid-October or end-November.

Bhanot et al. (1991) reported the effect of seed treatment with different insecticides on germination and damage by termite (Microtermes obesi Holmgren) and grain yields in wheat. In a series of experiments, they took various insecticides – chlorpyriphos, aldrin, endosulfan and formothion, carbaryl, formothion and monocrotophos as seed treatment chemicals. Considering efficacy and economics, chlorpyriphos 20 EC (1.5 ml/kg), aldrin 30EC (4.0 ml/kg), formothion 25EC (2.5 ml/kg), carbaryl 50WP (2.5 g/kg), endosulfan 35EC (3.5 ml/kg) and monocrotophos 36 WSC (3 ml/kg) - were recommended for termite control.

Thakar et al. (1991) compared different modes of application of aldrin, viz., seed treatment, soil treatment (aldrin 5% dust @ 5, 6, and 7 kg/100 kg seed; aldrin 30EC @ 300, 400 and 500 ml/100 kg seed; and soil application of dust of aldrin 5% and BHC 10% @ 25 kg/ha) and their combination for termite control in wheat. The result had shown that seed treatment with aldrin @ 400 ml/100 kg seed was most effective, whereas aldrin 5% dust @ 5kg/100 kg seed was least effective.

Rana and Dahiya (2001) conducted an experiment to study the effect of various seed treatment insecticides (cypermethrin, imidacloprid, carbosulfan, triazophos, chlorpyriphos, and endosulfan) for the management of the M. obesi pest under field conditions. He advocated seed treatment with chlorpyriphos and endosulfan @ 0.9 and 2.4 g a.i./kg respectively.

Out of 15 insecticides tested to control Odontotermes obesus and Microtermes obesi, minimum infestation was observed in the seed treatment of chlorpyriphos 20EC at 4.5 ml/kg, followed by endosulfan 35 EC at 7.3 ml/kg, lindane 20EC at 7.5 ml/kg (Kumawat, 2001).

A study was conducted to evaluate the effect of insecticidal (endosulfan, monocrotophos, chlorpyriphos, imidacloprid, carbaryl, quinalphos and methyl parathion at 2.5, 2.5, 5.0, 2.0, 4.0, 2.5 and 2.5 ml/kg) seed treatments for the control of O. obesus and M. obesi. Maximum plant-stand (77.7 plant/m²), maximum damaged tillers(5
tillers/plot) and maximum grain yield (42.2 q/ha) were obtained with imidacloprid @ 2 ml/kg, followed by chlorpyriphos at 5 ml/kg of seed. Carbaryl showed least efficacy (Mishra and Singh, 1994).

The nine insecticidal seed treatments, viz., chlorpyriphos 20EC, imidacloprid 200SL and fipronil 5FS ( @ 4, 5 and 6 ml/kg of seed) were evaluated against termites. Fipronil 5FS (5 ml/kg) was found most effective in protecting wheat crop from termite infestation and imidacloprid 200SL @ 6 ml/kg, the least effective seed treatment (Shukla, 2010).

A field experiment was conducted to study the effect of various seed treatment insecticides (cypermethrin, imidacloprid, carbosulfan, triazophos, chlorpyriphos, and endosulfan) for the management of the Microtermes obesi. The plots, where the seeds treated with chlorpyriphos and endosulfan @ 0.9 and 2.4 g a.i./kg of seed respectively were shown least infestation by termites (Rana and Dahiya, 2001).

In a field trial by Kumawat (2001) with benefit:cost ratio (BCR) analysis, it was found that out of 15 test-insecticides against Odontotermes obesus and Microtermes obesi; minimum infestation was observed in chlorpyriphos 20EC treatment (@ 4.5 ml/kg, BCR 33.5) followed by endosulfan 35EC (@ 7.3 ml/kg, BCR 32.7), and lindane 20EC (@ 7.5 ml/kg seed, BCR 26.5).

Deol and Singh (2002) evaluated cypermethrin, silafluofen, carbofuran, lindane, imidacloprid, chlorpyriphos, endosulfan @ 0.8, 2.0, 1.0, 0.7, 0.6, 0.9 and 2.4 g ai/kg seed, and recorded the seed treatment efficacies in field for four consecutive years (1996-2000) with economic (cost: benefit ratio) analysis. Silafluofen exhibited highest plant population /meter row then those in rest of the treatments. None of the insecticides affected the seed germination.

2. Maize: Sharma et al. (2003) worked on theseed treatment, spray and soil-treatment of termiticides against termites in maize, and reported the effectiveness of seed treatment. Chlorpyriphos (@ 0.9 g ai/kg seed), endosulfan (@ 3.0g ai/kg) and imidacloprid (0.5, 0.1 and 10 g ai/kg seed) were evaluated by them in field trials.

2.2.3. Groundnut: Narasimhulu and Kameswara Rao (1989) recorded the germination percentage, plumule and radical measurements of ten days old seedling in seed treatment
laboratory experimentation. Three fungicides viz., carbendazim, captan and captafol; and eight insecticides viz., monocrotophos, phosphamidon, carbofuran, oxydemeton, thiometon, dimethoate, formothion and chlorpyriphos were tested in this study. None of the chemicals alone or in combinations had adverse effect on germination of peanut seed. Evaluating the chlorpyriphos performance as soil treatment and seed treatment, Mishra (1994) recorded that seed dressing @ 12.5ml/kg seed is an effective method for termite control.

2.2.4. Chickpea: Chaudhary and Dashad (2002) evaluated three cultivars of chickpea – ‘C-235’, ‘HC-1’ and ‘Gora Hisari’ for their reaction to different insecticides as seed treatment to control termite. Four insecticides viz., endosulfan 35EC, monocrotophos 36 EC, chlorpyriphos 20EC and cypermethrin 25 EC were taken @ 8.5, 15, 7 and 5 ml per kg of chickpea seed) respectively, and they found that all test- insecticides deterred the seed germination, the intensity being maximum in monocrotophos with 19.5% reduction from control value (98.5%). It was followed by endosulfan (15.7% reduction) and chlorpyriphos (13.0%) in germination reduction.

Panigrahi (2010) conducted research work in the field with different insecticides viz., endosulphan 35EC, chlorpyriphos 20EC, monocrotophos 36EC and imidacloprid 70WS each at 7 and 10 ml/kg of chickpea seeds against termites. He observed that percentage infestation were within the range of 0.8 to 2.5% in various treatments as compared to that of 16.9% in control.

2.2.5. Soybean: Seed treatment recommendation by Directorate of Soybean, Indore (http://www.nrcsoya.nic.in/zonewiseprodtech.htm) is as follows. (i) fungicidal/bio-agent: thiram 75 WP + cabendazim 50 WP (2:1) @ 3 g/kg seed or Trichoderma viride @ 4-5 g/kg seed. (ii) Microbial: About 500 g/75 kg seed Bradyrhizobium japonicum culture + PSB 500 g/ 75kg. There is no recommendation for termiticidal seed-treatments in soybean. Termite damage is rare in soybean. However, in IARI farmlands termite damage was observed in soybean during 2010-12 (Mahapatro, unpublished). Seed treatment for the management of leaf folder and stem fly in soybean was reported by Rao and Azad (2009), with reported use of insecticides like imidacloprid 200SL @ 5ml/kg seed and carbofuran 3G @ 250 g/kg seed.
In an field investigation for white grub control it was revealed that chlorpyriphos 20EC@ 25ml/kg seed had no adverse effect on germination (Mishra and Singh, 1994).

2.3. Combinatorial seed treatment

Imidacloprid applied as a seed treatment, alone or in combination with fungicides (carboxin - thiram, triadimenol - captan, and tebuconazole - thiram), could protect wheat and barley plants from developing infestation of Russian wheat aphid *Diuraphis noxia* for 27-85 days (greenhouse and field trials). There were no compatibility problems in insecticides performance by combining imidacloprid with fungicides (Pike *et al*., 1993).

Compatibility of insecticide-fungicide on wheat seed treatments with respect to germination, seedling emergence in greenbug control was evaluated by Pike and Glezaer (1980). Disulfoton and carbofuran seed-treatments protected seedlings from *Schizaphis graminum*. These insecticides were assayed for compatibility with 7 fungicides (hexachlorobenzene, thiabendazole, pentachloronitrobenzene, carboxin, carboxin: thiram, and triadimenol) to determine the effect on germination, seedling emergence, and control of greenbug. All combination treatments affected germination adversely, and in some cases (disulfoton-thiabendazole, carbofuron-thiabendazole, carbofuran-pentachloronitrobenzene) there was significant reduced seedling stand as compared to the untreated check (Pike and Glezer, 1980).

Efficacy and compatibility of insecticides, fungicides and rhizobium inoculant combination for seed treatment in chickpea was tested by Cheema *et al*. (2009). In their field experiments (2005-08), endosulfan and chlorpyriphos were applied with recommended fungicide captan and rhizobium inoculant. Endosulfan @ 15 ml/kg and chlorpyriphos @ 10 ml/kg seed had no adverse effect on germination, nodulation, yield-attributing characters and grain yield when applied alone or in combination with captan and *Rhizobium* inoculant, thus indicating the compatibility.
Materials and Methods
3. MATERIALS AND METHODS

The present investigation entitled “Eco-friendly and IPM-compatible Seed Treatments for some Field Crops against Termites” was undertaken in the Division of Entomology and Seed Science and Technology at Indian Agricultural Research Institute, New Delhi during 2012-2013. Experimental materials were availed from the Divisions of Entomology and Seed Science and Technology. The treatment details and methodology for execution is presented in this chapter.

3.1. Materials

3.1.1. Test-pesticides (Table 3.1)

1. Test chemicals like synthetics: chlorpyrifos 20%EC (Dursban®), imidacloprid 48%FS (Gaucho®) 600FS, fipronil 5%SC (Regent®) SC).

2. Test-biofertilizers – Rhizobium (Bradyrhizobium, Mesorhizobium and Rhizobium japonicum), Azospirillum and Azotobacter

3. Test-biofungicide - Trichodermaharzianum

3.1.2. Test crops and varieties

Varieties of Wheat, Soybean and Chickpea crops were obtained from Division of Genetics, IARI, New Delhi, variety of Maize from Directorate of Maize Research, New Delhi and variety of Groundnut brought from National Research Centre on Groundnut, Junagadh for seed treatment trial in vitro. The variety profile is detailed as follows (Pusa Krishi Vigyan Mela, 2012).

Wheat (HD-2967)

A new wheat variety ‘HD 2967’ was released for North-Western Plains Zone to replace the dominant ‘PBW 343’, which has become highly susceptible to yellow and stem rusts. ‘HD 2967’ has an average yield of 5.5 t/ha with excellent chappati making quality and high iron and zinc content. During the crop season 2010-11, thousands of farmers of Punjab and Haryana, who had grown ‘HD 2967’, reported resistance of this
variety against yellow rust while other wheat varieties suffered heavy losses. This variety has become a boon to the farmers in terms of its resistance to yellow rust, and

Table 3.1.

Details of insecticides, bioagents and their source of supply

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Trade Name</th>
<th>Source of supply</th>
<th>Cost (Rs/L or kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorpyriphos 20EC</td>
<td>Dursban®</td>
<td>Dow Agroscience of India Pvt. Ltd. Mumbai-400 071</td>
<td>240/L</td>
</tr>
<tr>
<td>Imidacloprid 48% FS</td>
<td>Gaucho® 600FS</td>
<td>Bayer CropScience Ltd. Mumbai-400 076</td>
<td>2580/L</td>
</tr>
<tr>
<td>Fipronil 5SC</td>
<td>Regent®</td>
<td>-do-</td>
<td>1072/L</td>
</tr>
<tr>
<td><em>Trichoderma harzianum</em></td>
<td>Lab culture</td>
<td>Division of Plant Pathology IARI, New Delhi</td>
<td>-</td>
</tr>
<tr>
<td><em>Rhizobium japonicum</em></td>
<td>Lab culture</td>
<td>Division of Microbiology IARI, New Delhi</td>
<td>-</td>
</tr>
<tr>
<td><em>Mesorhizobium ciceri.</em></td>
<td>-do-</td>
<td>-do-</td>
<td>-</td>
</tr>
<tr>
<td><em>Azotobacter</em></td>
<td>-do-</td>
<td>-do-</td>
<td>-</td>
</tr>
<tr>
<td><em>Azospirillum</em></td>
<td>-do-</td>
<td>-do-</td>
<td>-</td>
</tr>
<tr>
<td><em>Bradyrhizobium japonicum.</em></td>
<td>-do-</td>
<td>NRC for Groundnut, Junagadh</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 3.2.
Crop-specific requirements (temperature, experimental period, and minimum recommended germination percentage), as recommended by ISTA

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Name of crop</th>
<th>Temperature for germination test (°C)</th>
<th>Days require to take final count (days)</th>
<th>Minimum germination recommended (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wheat</td>
<td>20</td>
<td>8</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>Maize</td>
<td>25</td>
<td>7</td>
<td>80 (composites)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90 (hybrids)</td>
</tr>
<tr>
<td>3</td>
<td>Groundnut</td>
<td>25</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>Chickpea</td>
<td>20</td>
<td>8</td>
<td>85</td>
</tr>
<tr>
<td>5</td>
<td>Soybean</td>
<td>25</td>
<td>8</td>
<td>75</td>
</tr>
</tbody>
</table>

confirmed field resistance to Ug99 from Kenyan and Ethiopian data over the last three years. Our Institute (IARI) supplied a large quantity of seed of this variety by focusing on Punjab through extension system and has already taken up a programme to produce 20,000 q seed of ‘HD 2967‘ for distribution to farmers during Rabi 2012-13.

Maize (HQPM-1)

This hybrid is identified for cultivation across the country. The hybrid variety identified for full season maturity with mean average yield of 6.2 t/ha having quality protein, was developed by Haryana Agricultural University in 2005. It is resistant to major diseases like Maydis leaf blight (MLB) and Turcicum leaf blight (TLB).

Soybean (DS- 9712)

It is recommended for sole cropping and irrigated conditions having plant height 52-83 cm and growth habit is determinate type (flower initiation, 33-42; 50% flowering, 39-62 DAS). Its average seed yield is 20.5 q/ha. It is resistant to yellow mosaic virus, soybean mosaic virus, bacterial pustule, charcoal rot, Myrothecium leaf spot and stem fly. Early in maturity (116 days).
Chickpea (PUSA-1003)

It is Kabuli type of chickpea; and mainly recommended for Eastern Uttar Pradesh, Bihar, West Bengal, and Assam. Yield potential is 2.0 t/ha. Important characteristics of this variety are tolerance to wilt, and boldseeds.

Groundnut (TAG-24)

‘TAG 24’ is Spanish bunch variety released for cultivation during 1992 for Maharashtra region and now popular in all major groundnut growing areas. It was developed at BARC Mumbai by crossing TGS 2 and TGE 1. It has some good characters like early maturity, suitable for summer cultivation and possesses tolerance to bud necrosis. It is a semi dwarf, early maturing and high yielding variety (Patil et al., 1995).

3.1.3. Apparatus for seed germination

Seed Germinator: The seed germination test was conducted in Seed Germinator chamber in the Division of Seed Science and Technology, IARI, New Delhi. The chamber is a modification of the germination cabinet, but is large enough to permit workers to enter it and place the tests along the either side of the way. It consists of double walled structure suitably insulated against temperature changes by an air jacket or layers of insulating material.

Germination paper: Seed germination papers are ideal for ensuring an optimal moisture content for the most diverse types of seeds and germination forms. They feature excellent wet strength and their special structure prevents fine seed roots from growing through. The seed germination papers can be supplied in different formats and in customized shapes and sizes for testing seeds according to ISTA (International Seed Test Association).

Hot air oven: Double walled thermostatically controlled: Inner chamber made of Alluminium/stainless steel. Outer body is made of mild steel. Beaded heating Elements are placed under the ribs at the bottom and sides. Temperature Controlled by Hydraulic Thermostat from 10º C above ambient to 240º C. Dial setting approximate basis. Correct reading as per L- shape thermometer fitted on the front panel at the top. Suitable to work on 220 volt A.C. supply.
3.2. Methods

Seed germination test

Objective 1: To study the effect of various dosages of insecticidal seed treatments on germination percentage, root length, shoot length and vigour indices of seedlings of few selected crops *viz.*., cereals – wheat, maize; pulses – gram (chickpea) and oilseeds - groundnut and soybean.

3.2.1. Standardization of water for seed treatment

    One kilogram seed was taken in the plastic tray and 50 ml of water was poured in the tray containing seed that is sufficient to soak one kg of seed and mixed thoroughly with hand.

3.2.2. Seed treatment

    The seeds were treated with chlorpyriphos 20%EC (Dursban®), imidacloprid 48%FS (Gaucho® 600FS) and fipronil 5%SC (Regent® SC) each at three doses including
### Table 3.3.
Treatment details for various test-crops – screening for termiticidal doses

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Ti: Seed Treatment</th>
<th>Test-dose levels</th>
<th>Wheat</th>
<th>Maize</th>
<th>Ground nut</th>
<th>Chick Pea</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$T_1$, Imidacloprid 600FS</td>
<td>1</td>
<td>2</td>
<td>1.5</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>$T_2$, Imidacloprid 600FS</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>$T_3$, Imidacloprid 600FS</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>$T_4$, Fipronil 5FS</td>
<td>1</td>
<td>4</td>
<td>5</td>
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<td>5</td>
<td>3</td>
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<tr>
<td>5</td>
<td>$T_5$, Fipronil 5FS</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>$T_6$, Fipronil 5FS</td>
<td>3</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>$T_7$, Chlorpyriphos 20EC</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>$T_8$, Chlorpyriphos 20EC</td>
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<td>4</td>
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<td>12.5</td>
<td>10</td>
<td>6</td>
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<tr>
<td>9</td>
<td>$T_9$, Chlorpyriphos 20EC</td>
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<td>6</td>
<td>10</td>
<td>25</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>$T_{10}$, Control (water)</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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</tbody>
</table>

control with water. The seeds were first spread on plastic tray. The desired quantity of the insecticide emulsion was then sprinkled on the seeds which were turned properly to ensure uniform seed coating. Treated seeds were then subjected to germination test after 24 hours.

3.2.3. **Standard germination test** (Between Paper Method: Agarwal, 1995) (Table 3.2).

The seeds were germinated between two layers of germination paper by placing the seeds in to folded envelops which were placed in upright position in the germination
chamber. The temperature of the chamber was maintained at 20±1°C for Wheat and Chickpea and 25±1°C for Groundnut, Maize and Soybean throughout the germination period. Four replicates of 50 seeds from each treatment were sown in the paper towel. Normal seedlings, abnormal seedlings and in germinated seeds were counted 7-10 days after sowing as per the crop (Table 3.2). Ten seedlings were randomly selected for measuring plumules, radicles and total length of seedlings.

**Vigour Indices (VI):** Observations taken were,

- Mean values of radicles and plumules length of 10 seedlings in each replication
- Mean values of dry weight of 10 seedlings in each replication (dry weight taken after 24 h in hot air oven at 80°C).

**Formulae for VI**

\[
\text{Vigour Index (I)} = \text{Germination} \% \times \text{Mean of root and shoot length (cm)}
\]

\[
\text{Vigour Index (II)} = \text{Germination} \% \times \text{Mean dry weight (g)}
\]

**3.2.4. Method to calculate Effect of seed treatment on germination and other seedling parameters**

**Description:**

1. Three different dosages (levels 1-3) of each insecticide have been taken.
2. Test-seeds (350nos, manually screened healthy ones) of each crop have been treated with selected doses/levels of test-insecticides and the procedure for seed dressing have been followed as per the recommendation of plant protection schedule.
3. Three replication of each dose is taken with 100 seeds/replication.
4. Treated seeds of test-insecticides with three different dosage (treatments) with three replication of each dose (treatment) was kept for germination by using towel paper (In-between Paper Method, Agarwal, 1995) in controlled conditions (temp. 25°C, RH 70%, depending the test-crop).
5. Germination count was taken after seven days, in this mean germination percentage for each dose was calculated by counting number of normal seedlings and abnormal seedlings from each replication.

6. Seed vigour index was calculated by measuring shoot length and root length of ten seedling from each replication by using abovementioned formulae.

7. Result of germination percentage and vigour index were compared with untreated (control).

3.2.5. Statistical analysis

The data were subjected to one factorial ANOVA following standard statistical package (OPSTAT online, www.hau.ernet.in/opstat.html).

Tabular presentation: For each single crop

<table>
<thead>
<tr>
<th>Method</th>
<th>Between Paper Method (Agarwal, 1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Seeds are germinated between two layers of germination paper at 25°C</em></td>
</tr>
<tr>
<td>Number of treatments</td>
<td>10</td>
</tr>
<tr>
<td>Number of replications</td>
<td>3 (100 seeds in each replication)</td>
</tr>
<tr>
<td>Test-concentrations</td>
<td>Field recommendation is included,</td>
</tr>
<tr>
<td></td>
<td>Total three dosage/levels: lower dose (level-1), intermediate dose (2) and higher dose (3) (may vary from crop to crop)</td>
</tr>
</tbody>
</table>

In this study we have also detected whether chemicals cause any harmful effect on seed viability or makes the seed dead by the Rapid Tetrazolium Test (ISTA, 2007).

Principle(s) -

The tetrazolium test relies on the premise that only living cells have ther respiratory enzymes (dehydrogenases) capable of converting the colourless, soluble compound (2,3,5triphynyl tetrazoliumchloride) into an insoluble red product (2,3,5triphynylformazan) (Lakon, 1942). Seeds are therefore soaked in a colourless solution of TZ which enters both living and dead cells, but only the living cells catalys the formation of the red, formazan precipitate. There then follow several stages of
interpretation. Stained and unstained areas are first used to differentiate between living and dead tissues. The size and position of the stained areas is then interpreted as an indication of live versus dead seeds. Finally, there are some seed testers who claim to make an additional level of interpretation and relate certain staining patterns to normal seedlings.

**Procedure for Tetrazolium (TZ test) Test**

For most crops a 1% TZ solution is to be used (1 g TZ salt in 1 litre of water/ buffer).

The practical steps of the TZ test are as follows:

- Preparation of hard seeds for imbibitions by scarification, puncturing or extraction.
- Pre-moistening of seeds by soaking, or between or on moist paper at approx. 20°C for 3-48 hours (depending on species, cf. ISTA prescriptions); and then drain off water.
- Immersing seeds in the TZ solution (seeds should be completely covered).
- Incubating seeds in the TZ solution in darkness at 30-35°C for 1-24 hours (depending on species, cf. ISTA prescriptions).
- Washing seeds in distilled water and placing them on moist filter paper until evaluation, finally the evaluation.

On the basis of above explained procedure (TZ test) we have detected whether there is any effect of test-chemical (insecticides) on viability of seeds which are not germinated at the end of standard germination test.

**Objective 2:** To check the compatibility of insecticides, bio-fertilizers and bio-fungicides (fungicides) commonly used in seed treatment for selected crops, so as to verify seed treatment compatibility in IPM.

**3.2.6. Compatibility test (Table 3.4)**

1. Tested dose (amongst 1-3 levels) of each insecticide that proves least adverse effect on germination and other seedling parameters is selected by above experiment (Objective -1) and this dose has been selected in compatibility test.

2. In this test also 350 have been taken and treat with sequence of insecticide – biofertilizer – biofungicide/ fungicides with above selected dose/level of insecticide and field recommended dose(s) of bio fertilizer and biofungicide.
3. Test-seeds (300nos) in triplication (100 seeds/replication) has been kept for germination by ‘Between Paper Method’ in controlled condition of temperature and humidity.

4. Germination count has been taken after 7-days; and germination percentage and vigour index is calculated by measuring following parameters – numbers of normal and abnormal seedlings and shoot and root length of ten seedlings from each replication.

5. Results of treated and control seedlings of test-crops is compared based on the appropriate and standard statistical analysis.
Research Paper-I
In vitro Evaluation of insecticidal seed treatments on major field crops - cereals (wheat, maize), pulse (chickpea) and oilseeds (groundnut, soybean)

4.1. Abstract

Seed treatment plays crucial role in protecting the emerging seedlings from insect-pests and diseases. Recommendations of seed treatment for various crops are offered by Government of India under its most ambitious programme Total Seed Treatment Campaign 2007. Use of seed treatments in crops like wheat, maize, chickpea, groundnut and soybean has increased considerably over the past few years. But mostly the field recommendations are not based/supported by in vitro tests. Laboratory evaluations were made with three insecticides – imidacloprid (600FS), fipronil (5FS) and chlorpyriphos (20EC) (each at three doses) to verify deleterious effects of test-doses for the test-crops, following in between paper method. In chickpea and maize, supporting rapid tetrazolium tests were conducted to verify the hard and dead seeds in ungerminated seeds.

The experiment resulted in following seed-treatment-recommendations, i.e.

Wheat – imidacloprid@ 3-5; fipronil@ 4 and chlorpyriphos @2 ml/kg seeds.

Maize - imidacloprid@ 1.5-5; fipronil @ 5 ml/kg seeds. Chlorpyriphos is not recommended.

Chickpea – imidacloprid@ 5-10; fipronil @ 5-7 and chlorpyriphos @7 ml/kg seeds.

Groundnut – imidacloprid@ 3-7; fipronil @ 5 and chlorpyriphos @6 ml/kg seeds.

Soybean – imidacloprid@ 4-6; fipronil @ 3-5 and chlorpyriphos @4 ml/kg seeds.

These seed-treatment rates may be tried-and-tested for further field validation for concerned insect-pests to be controlled.

Keywords: Chlorpyriphos, fipronil, imidacloprid and Seed treatment
4.2. Introduction

Seed treatment is an eco-friendly disease and pest-management tactics and gaining much importance as an IPM-compatible measure. Recommendations of seed treatment for various field crops are offered by Government of India under its most ambitious programme Total Seed Treatment Campaign 2007(www.ppqs.gov.in). Use of seed treatments on cereals, pulses and oilseed crops has increased considerably over the past few years in India. Seed treatments protect seed from insect pests such as the jassids, aphids, shoot fly and termites in some localities. In order to study the effect of insecticidal seed treatments on seedling growth, i.e., germination percentage, root length, shoot length and vigour indices, a series of in vitro experimentations were carried out; and crop-specific recommendations for seed treatments are offered. The target crops are as follows:

**Wheat:** Major problem in dry areas of the wheat growing zones (north western plain zone, north eastern plain zone, and central zone are termites. Aphids are major insect-pests in most wheat tracts, and are a newly emerging problem (in particular root aphids, *Rhopalosiphum rufiabdominalis*). IPM packages of Government of India, Ministry of Agriculture (Directorate of Plant Protection, Quarantine & Storage ‘DPPQ&S’, 2001) recommends chlorpyriphos 20EC@4 ml/kg seed. The recommendation of endosulfan is now obsolete in the light of recent ban by Supreme Court (Mahapatro and Panigrahi, 2013).

**Maize:** In maize shoot fly is a major pest of national significance and aphid, *Pyrilla*, thrips and termites are pests of regional significance. These insect-pests (sucking or non-sucking type) can well be managed by seed treatment. IPM package as advocated by Government of India includes seed treatment with *Trichoderma viridae* and *T. harzianum* @ 4g/kg (DPPQR&S, 2001). No insecticidal seed treatment is offered in this package. However, Directorate of Maize Research, New Delhi recommends imidacloprid seed treatment @ 4ml/kg seed for termite and shoot fly (DMR, 2009).

**Chickpea:** Termites are insect pests of regional importance in particular in Rajasthan and Haryana (DPPQ&S, 2001). Economic threshold level suggested is 5 damaged plants/meter$^2$ for *Odontotermes* species. The IPM package advocates seed treatment with
T. viridaeor T. harzianum @4 g/kg for diseases and chlorpyriphos 20EC @15-20 ml/kg of seed for termites. Seed treatment with carbosulfan 25EC and carbendazim 20%DS were also advocated for other insects and diseases. Biofertiliser like Rhizobium culture is also mentioned in the package. But these recommendations are in isolation, and nothing is mentioned regarding combination of these pesticides.

**Soybean:** IPM package (DPPQ&S, 2001) does not recognise termites or other sucking insect-pests as of national or even regional importance. Previous 2-3 years’ experience at IARI farmlands implies termite problem in the seedling stage. Thus three termiticides chlorpyriphos, imidacloprid and fipronil were tested for insecticidal seed treatment efficacy in vitro.

**Groundnut:** Groundnut crop is prone to attack by several insect-pests and diseases. Aphids, jassids and thrips are of national importance, while termites are of regional importance in states like AP, Punjab, Rajasthan and Gujarat (DPPQ&S, 2001). Seed treatment with chlorpyriphos 20 EC @ 2.5-12.5 ml/kg for termite control and with biofungicide T. viride or T. harzianum @ 4g/kg seed for control of seed/seedling rot disease are also suggested by DPPQ&S (2001).

**4.3. Materials and Methods**

**4.3.1.** Seeds of test crops - wheat (HD-2967), maize (HQPM-1), chickpea (PUSA-1003, and soybean (DS-9712) were obtained from Seed Unit, Division of Genetics, Indian Agricultural Research Institute, New Delhi and groundnut seeds (var. TAG-21) was obtained from NRC for Groundnut, Junagadh (Gujarat). The seeds are treated with imidacloprid 48% FS (Gaucho® 600FS), fipronil 5SC (Regent®) and chlorpyriphos 20EC (Dursban®) each at three different doses as mentioned in the previous chapter (Table 3.3). An untreated control (water) was also included in the test. The insecticides were first added to water so as to make the final required volume of 50-100 ml according to different crop seeds, which was sufficient to soak one kg of seed. The seeds were first spread on plastic trays, desired quantity of the insecticide emulsion was then sprinkled on the seeds which were turned regularly to ensure uniform seed coating. Treated seeds were then subjected to germination test after 24 hours.
4.3.2. **In vitro germination test** (Between Paper Method: Agarwal, 1995)

The seeds were germinated between two layers of germination paper by placing the seeds in to folded envelops which were placed in upright position in the germination chamber. The temperature of the chamber was maintained at 20±1 to 25±1°C according to crop as mentioned in Table 3.2 throughout the germination period. Three replicates of 100 seeds from each treatment were sown in the paper towel. Normal seedlings, abnormal seedlings and ungerminated seeds were counted 7-10 days after sowing according to test crops as days required for final count mentioned in Table 3.2 according to ISTA (2008). Ten seedlings were randomly selected for measuring plumules, radicles and total length of seedlings.

**Vigour Index (VI):** Observationson mean values of (a) radicles and plumules length of 10 seedlings in each replication; and (b) dry weights of 10 seedlings in each replication (dry weight taken after 24 h in oven)were recorded. VIs are calculated as follows:

\[
\text{Vigour Index (I)} = \text{Germination} \% \times \text{Mean of root and shoot length (cm)}
\]

\[
\text{Vigour Index (II)} = \text{Germination} \% \times \text{Mean dry weight (g)}
\]

4.3.3. **Rapid tetrazolium test (TZ) for seed viability**

Amongst the test crops, maize from cereals and chickpea from pulses, single representative crops in each group i. are chosen for tetrazolium test, to substantiate the reasons of germination failure in various insecticidal seed treatments or to detect the effect of insecticides on viability of seeds. Ungerminated seeds of above mentioned two crops were taken at the end of standard germination test and subjected to Rapid Tetrazolium Test (TZ).

Ungerminated maize seeds from standard germination test were taken and soaked in water for 1 hour. Seeds were then bisected longitudinally. One-half of each seed were transferred to flask containing 2,3,5 triphenyl tetrazolium chloride salt solution; then kept in dark at 30°C for 24-hr. Finally staining pattern was observed and on the basis of position and size of necrotic areas in the embryo; the seeds were classified as viable or non-viable/dead seeds. Dormant and hard seeds are also considered as viable seeds (Agrawal, 1995).
For chickpea ungerminated seeds were selected at the end of in-between paper method. Then conditioning of seeds by soaking (1-hr) in water was carried out. Seed-coats were removed with forceps. Uncoated-seeds were transferred to flask containing TZ solution (2,3,5 triphenyl tetrazolium chloride salt); and the flask was then kept at 30°C for 24-hr under darkness. Finally staining pattern was observed and on basis position and size of necrotic areas in the embryo seeds are classified as viable and non-viable seeds dead seed), dormant and hard seeds are also considered as viable seed (Agrawal, 2010).

4.3.4. Statistical analysis

The data were subjected to one factorial ANOVA following standard statistical package (OPSTAT online, www.hau.ernet.in/opstat.html).

4.4. Results and Discussion

The effect of various seed treatment chemicals (imidacloprid, fipronil and chlorpyriphos each at three doses) on germination percentage, seedling length and vigour indices on seed germination of test crops viz., wheat, maize, chickpea, groundnut and soybean are presented in Tables 4.1, 4.2, 4.3, 4.4 and 4.5 respectively.

Wheat (Table 4.1, Plate 4.1 &5.1 and Fig. 4.1)

In untreated seedlings (control) the germination was 96.5 percent. In insecticidal treatments of imidacloprid (all three test doses), fipronil (two doses i.e. 4 and 6 ml/kg seed) chlorpyriphos only one dose (2ml/kg seed); the germination were above 85 per cent which is international standard for germination as per ISTA (2008).

Chlorpyriphos both @4 and 6 ml/kg seed affected germination (i.e. <85%). However, almost all research papers recommends 4-5ml chlorpyriphos/kg seed and most of these studies are field studies (Verma et al., 1980, Bhanot et al., 1991, Thakar et al., 1991, Rana and Dahiya, 2001). But this *in-vitro* investigation suggests 2ml/kg is safest dose for wheat variety ‘HD-2967’. Varietal sensitivity of chlorpyriphos was reported by few previous workers (Sithik and Mahapatro, 2012). Our finding is in accordance with those of previous works.

In control the total seedling length was 26.52cm whereas in various treatments the range is 22.25-28.43 cm. chlorpyriphos 4ml and 6ml/kg exhibited reduced seedling length with
statistically significance. In all treatments of imidacloprid, there was increase in seedling length but statistically at par with control. A close look into Vigour Index-I suggests higher seedling vigour for imidacloprid (all three doses) and fipronil (4ml/kg) \((p\leq0.05)\). Recorded Vigour Index-II which is based on dry weight gain of seedling does not exhibit substantial vigour increase but of course there is slight increase in imidacloprid. In
<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T&lt;sub&gt;1&lt;/sub&gt;: Imidacloprid</strong> (2ml/kg seed)</td>
<td>95.5&lt;sub&gt;a&lt;/sub&gt; [77.86]</td>
<td>18.51&lt;sub&gt;a&lt;/sub&gt; (4.42)</td>
<td>9.8&lt;sub&gt;a&lt;/sub&gt; (3.29)</td>
<td>28.31&lt;sub&gt;ab&lt;/sub&gt; (5.41)</td>
<td>2706.12&lt;sub&gt;a&lt;/sub&gt; (52.02)</td>
<td>17.28&lt;sub&gt;bc&lt;/sub&gt; (4.28)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;2&lt;/sub&gt;: Imidacloprid</strong> (3ml/kg seed)</td>
<td>96&lt;sub&gt;a&lt;/sub&gt; [78.45]</td>
<td>18.15&lt;sub&gt;a&lt;/sub&gt; (4.38)</td>
<td>10.28&lt;sub&gt;a&lt;/sub&gt; (3.36)</td>
<td>28.43&lt;sub&gt;a&lt;/sub&gt; (5.43)</td>
<td>2729.56&lt;sub&gt;a&lt;/sub&gt; (52.25)</td>
<td>17.50&lt;sub&gt;ab&lt;/sub&gt; (4.30)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;3&lt;/sub&gt;: Imidacloprid</strong> (5ml/kg seed)</td>
<td>95&lt;sub&gt;a&lt;/sub&gt; [77.27]</td>
<td>17.96&lt;sub&gt;a&lt;/sub&gt; (4.36)</td>
<td>10.36&lt;sub&gt;a&lt;/sub&gt; (3.37)</td>
<td>28.33&lt;sub&gt;a&lt;/sub&gt; (5.42)</td>
<td>2696.45&lt;sub&gt;a&lt;/sub&gt; (51.94)</td>
<td>17.76&lt;sub&gt;a&lt;/sub&gt; (4.33)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;4&lt;/sub&gt;: Fipronil</strong> (4ml/kg seed)</td>
<td>93&lt;sub&gt;b&lt;/sub&gt; [75.02]</td>
<td>17.53&lt;sub&gt;ab&lt;/sub&gt; (4.31)</td>
<td>10.38&lt;sub&gt;a&lt;/sub&gt; (3.37)</td>
<td>27.91&lt;sub&gt;ab&lt;/sub&gt; (5.38)</td>
<td>2605.41&lt;sub&gt;a&lt;/sub&gt; (51.05)</td>
<td>16.30&lt;sub&gt;d&lt;/sub&gt; (4.16)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;5&lt;/sub&gt;: Fipronil</strong> (6ml/kg seed)</td>
<td>89.5&lt;sub&gt;c&lt;/sub&gt; [71.23]</td>
<td>16.0&lt;sub&gt;d&lt;/sub&gt; (4.12)</td>
<td>10.25&lt;sub&gt;a&lt;/sub&gt; (3.35)</td>
<td>26.25&lt;sub&gt;bc&lt;/sub&gt; (5.22)</td>
<td>2353.73&lt;sub&gt;b&lt;/sub&gt; (48.53)</td>
<td>15.93&lt;sub&gt;e&lt;/sub&gt; (4.12)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;6&lt;/sub&gt;: Fipronil</strong> (8ml/kg seed)</td>
<td>84.5&lt;sub&gt;d&lt;/sub&gt; [62.72]</td>
<td>15.0&lt;sub&gt;d&lt;/sub&gt; (4.0)</td>
<td>10.18&lt;sub&gt;a&lt;/sub&gt; (3.34)</td>
<td>25.21&lt;sub&gt;cd&lt;/sub&gt; (5.12)</td>
<td>2130.74&lt;sub&gt;c&lt;/sub&gt; (46.17)</td>
<td>14.39&lt;sub&gt;f&lt;/sub&gt; (3.92)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;7&lt;/sub&gt;: Chlorpyriphos</strong> (2ml/kg seed)</td>
<td>87&lt;sub&gt;c&lt;/sub&gt; [69.13]</td>
<td>17.13&lt;sub&gt;abc&lt;/sub&gt; (4.26)</td>
<td>8.53&lt;sub&gt;b&lt;/sub&gt; (3.09)</td>
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<td>14.99&lt;sub&gt;f&lt;/sub&gt; (4.0)</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;8&lt;/sub&gt;: Chlorpyriphos</strong> (4ml/kg seed)</td>
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<td>7.43&lt;sub&gt;c&lt;/sub&gt; (2.90)</td>
<td>23.76&lt;sub&gt;d&lt;/sub&gt; (4.98)</td>
<td>1881.57&lt;sub&gt;d&lt;/sub&gt; (43.39)</td>
<td>13.53&lt;sub&gt;b&lt;/sub&gt; (3.81)</td>
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<tr>
<td><strong>T&lt;sub&gt;9&lt;/sub&gt;: Chlorpyriphos</strong> (6ml/kg seed)</td>
<td>74&lt;sub&gt;c&lt;/sub&gt; [59.41]</td>
<td>15.46&lt;sub&gt;d&lt;/sub&gt; (4.06)</td>
<td>6.78&lt;sub&gt;c&lt;/sub&gt; (2.79)</td>
<td>22.25&lt;sub&gt;e&lt;/sub&gt; (4.82)</td>
<td>1650.47&lt;sub&gt;c&lt;/sub&gt; (40.61)</td>
<td>12.00&lt;sub&gt;f&lt;/sub&gt; (3.61)</td>
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<tr>
<td><strong>T&lt;sub&gt;10&lt;/sub&gt;: Control (Water)</strong></td>
<td>96.5&lt;sub&gt;a&lt;/sub&gt; [79.31]</td>
<td>17.1&lt;sub&gt;abc&lt;/sub&gt; (4.25)</td>
<td>9.42&lt;sub&gt;ab&lt;/sub&gt; (3.23)</td>
<td>26.52&lt;sub&gt;abc&lt;/sub&gt; (5.24)</td>
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<td>17.05&lt;sub&gt;e&lt;/sub&gt; (4.25)</td>
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<td>SE(d)</td>
<td>0.68</td>
<td>0.08</td>
<td>0.06</td>
<td>0.09</td>
<td>0.87</td>
<td>0.013</td>
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<tr>
<td>CD (P=0.05)</td>
<td>[1.43]</td>
<td>(0.17)</td>
<td>(0.14)</td>
<td>(0.19)</td>
<td>(1.82)</td>
<td>(0.027)</td>
</tr>
</tbody>
</table>

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
**Fig 4.1**

*Effect of insecticidal seed treatments on Vigour Index-I for Wheat (HD-2967)*

**Fig 4.2**

*Effect of insecticidal treatments on the total seedling length for Maize (HQPM-1)*
chlorpyriphos at higher doses i.e. 4 and 6 ml/kg; both vigour indices I and II were substantially reduced.

**Maize** (Table 4.2, Plate 4.1 & 5.1 and Fig. 4.2)

The effect of various insecticidal seed treatments on germination percentage, seedling length and vigour indices is presented in Table 4.2. In untreated (control) the germination recorded is 96.88 percent. In imidacloprid (all three test-doses), fipronil (two doses i.e. 5 ml and 7 ml/kg seed) germination was above 90 per cent which is recommended for maize hybrid as minimum seed germination standard by ISTA (2008). But in case of chlorpyriphos all three test-doses showed germination <90% and also other seedling parameters were adversely affected; hence this study concludes chlorpyriphos is not recommendable as seed treatment in maize.

In control, total seedling length (average value) was 39.88 cm whereas in various insecticidal seed treatments the range is 26.85-43.81 cm. Chlorpyriphos treatment exhibited reduced seedling lengths statistically \((P < 0.05)\). In case of imidaclorpid, all the three test-doses (1.5ml, 3ml and 5 ml per kg seed) resulted in increase in total length but statistically at par with that for control. In case of fipronil test-dose (7 ml/kg seed) resulted in increase of total seedling length was observed which is significantly different from all other treatments. All doses of chlorpyriphos showed drastic decrease in seedling length implying its detrimental impact on seedlings.

Corresponding VI values suggest that in case of imidacloprid all doses resulted in increase in both VI-I and VI-II which are significantly different from those of control; hence showing possible phytotonic effect on growth parameters. In case of fipronil test-dose (5ml/kg seed), both the vigour indices are at par with control and for test-dose (7ml/kg seed) VI-I increased but VI-II decreased significantly than that of control. In case of chlorpyriphos treatments, as other parameters of seedlings, both vigour indices decreased drastically. Recorded VIs for three test-doses of imidacloprid seed-treatments, shows a dose-dependent increase in the observed seedling parameters (eg. seedling lengths, and vigour indices) implying the possible phytotonic effect. The higher seed quality parameters observed with imidacloprid treated seeds were due to its phytotonic effect as reported by Jarande and Dethe (1994) in cotton.
Table 4.2.

Germination percentage, seedling length and vigour indices for various seed-treatments (insecticides/termiticides only) in maize var. ‘HQPM-1’

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;: Imidacloprid (1.5ml/kg seed)</td>
<td>97.38&lt;sub&gt;a&lt;/sub&gt; [80.68]</td>
<td>21.70&lt;sub&gt;a&lt;/sub&gt; (4.76)</td>
<td>19&lt;sub&gt;cd&lt;/sub&gt; (4.47)</td>
<td>40.43&lt;sub&gt;bc&lt;/sub&gt; (6.44)</td>
<td>3937.58&lt;sub&gt;ab&lt;/sub&gt; (62.76)</td>
<td>76.05&lt;sub&gt;c&lt;/sub&gt; (8.79)</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;: Imidacloprid (3ml/kg seed)</td>
<td>96.93&lt;sub&gt;a&lt;/sub&gt; [79.88]</td>
<td>19.26&lt;sub&gt;cd&lt;/sub&gt; (4.5)</td>
<td>20.16&lt;sub&gt;bc&lt;/sub&gt; (4.60)</td>
<td>39.68&lt;sub&gt;bcd&lt;/sub&gt; (6.38)</td>
<td>3846.60&lt;sub&gt;b&lt;/sub&gt; (62.03)</td>
<td>77.74&lt;sub&gt;b&lt;/sub&gt; (8.87)</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;: Imidacloprid (5ml/kg seed)</td>
<td>95.13&lt;sub&gt;b&lt;/sub&gt; [77.23]</td>
<td>19.3&lt;sub&gt;cd&lt;/sub&gt; (4.15)</td>
<td>22&lt;sub&gt;a&lt;/sub&gt; (4.80)</td>
<td>41.13&lt;sub&gt;bc&lt;/sub&gt; (6.49)</td>
<td>3913.18&lt;sub&gt;ab&lt;/sub&gt; (62.56)</td>
<td>80.35&lt;sub&gt;a&lt;/sub&gt; (9.02)</td>
</tr>
<tr>
<td>T&lt;sub&gt;4&lt;/sub&gt;: Fipronil (5ml/kg seed)</td>
<td>95.11&lt;sub&gt;b&lt;/sub&gt; [77.22]</td>
<td>21.21&lt;sub&gt;abc&lt;/sub&gt; (4.71)</td>
<td>18.31&lt;sub&gt;de&lt;/sub&gt; (4.4)</td>
<td>39.83&lt;sub&gt;bcd&lt;/sub&gt; (6.39)</td>
<td>3789.11&lt;sub&gt;b&lt;/sub&gt; (61.56)</td>
<td>71.52&lt;sub&gt;d&lt;/sub&gt; (8.52)</td>
</tr>
<tr>
<td>T&lt;sub&gt;5&lt;/sub&gt;: Fipronil (7 ml/kg seed)</td>
<td>93.11&lt;sub&gt;c&lt;/sub&gt; [74.77]</td>
<td>21.61&lt;sub&gt;ab&lt;/sub&gt; (4.75)</td>
<td>21.2&lt;sub&gt;ab&lt;/sub&gt; (4.71)</td>
<td>43.81&lt;sub&gt;a&lt;/sub&gt; (6.69)</td>
<td>4079.59&lt;sub&gt;a&lt;/sub&gt; (63.87)</td>
<td>63.96&lt;sub&gt;e&lt;/sub&gt; (8.02)</td>
</tr>
<tr>
<td>T&lt;sub&gt;6&lt;/sub&gt;: Fipronil (10ml/kg seed)</td>
<td>89.66&lt;sub&gt;d&lt;/sub&gt; [71.24]</td>
<td>19.45&lt;sub&gt;bcd&lt;/sub&gt; (4.52)</td>
<td>19.1&lt;sub&gt;cd&lt;/sub&gt; (4.48)</td>
<td>38.43&lt;sub&gt;d&lt;/sub&gt; (6.28)</td>
<td>3445.8&lt;sub&gt;c&lt;/sub&gt; (58.71)</td>
<td>53.68&lt;sub&gt;e&lt;/sub&gt; (7.40)</td>
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<tr>
<td>T&lt;sub&gt;7&lt;/sub&gt;: Chlorpyriphos (5ml/kg seed)</td>
<td>89.11&lt;sub&gt;d&lt;/sub&gt; [70.73]</td>
<td>21.53&lt;sub&gt;ab&lt;/sub&gt; (4.75)</td>
<td>17.23&lt;sub&gt;e&lt;/sub&gt; (4.27)</td>
<td>38.76&lt;sub&gt;cd&lt;/sub&gt; (6.31)</td>
<td>3453.57&lt;sub&gt;c&lt;/sub&gt; (58.78)</td>
<td>57.03&lt;sub&gt;f&lt;/sub&gt; (7.62)</td>
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<tr>
<td>T&lt;sub&gt;8&lt;/sub&gt;: Chlorpyriphos (7ml/kg seed)</td>
<td>83&lt;sub&gt;e&lt;/sub&gt; [67.16]</td>
<td>18.83&lt;sub&gt;d&lt;/sub&gt; (4.6)</td>
<td>14.76&lt;sub&gt;f&lt;/sub&gt; (3.97)</td>
<td>32.1&lt;sub&gt;e&lt;/sub&gt; (5.75)</td>
<td>2663.95&lt;sub&gt;d&lt;/sub&gt; (51.62)</td>
<td>37.90&lt;sub&gt;h&lt;/sub&gt; (6.24)</td>
</tr>
<tr>
<td>T&lt;sub&gt;9&lt;/sub&gt;: Chlorpyriphos (10ml/kg seed)</td>
<td>77.33&lt;sub&gt;f&lt;/sub&gt; [63.48]</td>
<td>16.16&lt;sub&gt;e&lt;/sub&gt; (4.57)</td>
<td>10.85&lt;sub&gt;g&lt;/sub&gt; (3.44)</td>
<td>26.85&lt;sub&gt;f&lt;/sub&gt; (5.23)</td>
<td>2077.23&lt;sub&gt;e&lt;/sub&gt; (45.58)</td>
<td>25.00&lt;sub&gt;i&lt;/sub&gt; (5.10)</td>
</tr>
<tr>
<td>T&lt;sub&gt;10&lt;/sub&gt;: Control (Water)</td>
<td>96.88&lt;sub&gt;a&lt;/sub&gt; [79.85]</td>
<td>21.61&lt;sub&gt;ab&lt;/sub&gt; (4.75)</td>
<td>18.75&lt;sub&gt;de&lt;/sub&gt;(4.3 8)</td>
<td>39.88&lt;sub&gt;bcd&lt;/sub&gt; (6.39)</td>
<td>3864.64&lt;sub&gt;b&lt;/sub&gt; (62.16)</td>
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<td>0.06</td>
<td>0.68</td>
<td>0.03</td>
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<tr>
<td>CD (P=0.05)</td>
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<td>(0.23)</td>
<td>(0.14)</td>
<td>(0.13)</td>
<td>(1.42)</td>
<td>(0.06)</td>
</tr>
</tbody>
</table>

Figures in parentheses [  ] are arcsine-transformed values and in parentheses (  ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
**Chickpea** (Table 4.3, Plate 4.1 & 5.1)

Minimum seed germination percentage in chickpea according to ISTA is 85%. Here seed treated with imidacloprid (all three test-doses 5, 7 and 10 ml/kg), fipronil two doses (5 and 7ml/kg) and chlorpyriphos (only one dose 6ml/kg) showed the germination above 85% which is acceptable according to ISTA recommendation. In this experiment, it was found that in case of chlorpyriphos treated seeds with two doses 10ml and 12ml/kg seed; there was drastic reduction in germination which were 72.3 and 65 per cent respectively; whereas in case of control it was 96.5 per cent.

It was recorded that total length of seedling which was 27.6cm in control and it increased in seedlings treated with all test-doses of imidacloprid and two doses of fipronil i.e. 5 and 7ml/kg seed which was in the range of 30.42-32.78cm, and are statistically significant from that of control. Chlorpyriphos at higher doses resulted in significant reduction in growth rate and total length (Table 4.3).

Vigour indices (both I & II) were observed to increase substantially in all test-doses of imidacloprid showing phytotonic effect on seedling growth. Whereas, fipronil treatments at two doses i.e. 5 and 7ml/kg seeds showed increase in Vigour Index I only; but all three doses resulted in reduced Vigour Index II. Seed-treatment with chlorpyriphos (all three doses) resulted in substantial reduction in vigour indices.

**Groundnut** (Table 4.4 & Plate 4.1 & 5.1)

According to ISTA, minimum seed germination for groundnut is 70 per cent. In our research all doses of all test-insecticides showed germination percentage >70% (range between 74.13% in chlorpyriphos @25ml/kg to 96% in imidacloprid@5 ml/kg). However, other seedling parameters (total seedling length and vigour indices) were affected at higher doses of chlorpyriphos and fipronil (P<0.05). Imidacloprid at all three test-doses did not cause any deleterious effect on seedling growth, rather indicates possible phytotonic effect.

Total length of seedling in control was 25.07cm but in imidacloprid treated seedling length is still increased in all three doses with relative increase in doses which was in the range of 26.1cm in lower dose and 29.3cm in higher dose. But all doses of fipronil and chlorpyriphos resulted in significant reduction in seedling length.
Table 4.3.

Germination percentage, seedling length and vigour indices for various seed-treatments (insecticides/termicides only)
in chickpea var. ‘PUSA-1003

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$: Imidacloprid (5ml/kg seed)</td>
<td>95.57&lt;sub&gt;a&lt;/sub&gt; [77.86]</td>
<td>18.13&lt;sub&gt;ab&lt;/sub&gt; (4.37)</td>
<td>12.68&lt;sub&gt;a&lt;/sub&gt; (3.7)</td>
<td>30.82&lt;sub&gt;ab&lt;/sub&gt; (5.64)</td>
<td>2945.25&lt;sub&gt;ab&lt;/sub&gt; (54.27)</td>
<td>39.18&lt;sub&gt;c&lt;/sub&gt; (6.34)</td>
</tr>
<tr>
<td>$T_2$: Imidacloprid (7ml/kg seed)</td>
<td>96&lt;sub&gt;a&lt;/sub&gt; [78.45]</td>
<td>18.33&lt;sub&gt;ab&lt;/sub&gt; (4.4)</td>
<td>12.08&lt;sub&gt;a&lt;/sub&gt; (3.62)</td>
<td>30.42&lt;sub&gt;abc&lt;/sub&gt; (5.6)</td>
<td>2920.33&lt;sub&gt;b&lt;/sub&gt; (54.04)</td>
<td>50.56&lt;sub&gt;b&lt;/sub&gt; (7.18)</td>
</tr>
<tr>
<td>$T_3$: Imidacloprid (10ml/kg seed)</td>
<td>94.8&lt;sub&gt;b&lt;/sub&gt; [76.85]</td>
<td>18.5&lt;sub&gt;b&lt;/sub&gt; (4.77)</td>
<td>12.3&lt;sub&gt;a&lt;/sub&gt; (3.65)</td>
<td>30.8&lt;sub&gt;b&lt;/sub&gt; (5.64)</td>
<td>2920.97&lt;sub&gt;b&lt;/sub&gt; (54.05)</td>
<td>59.75&lt;sub&gt;a&lt;/sub&gt; (7.79)</td>
</tr>
<tr>
<td>$T_4$: Fipronil (5ml/kg seed)</td>
<td>92.6&lt;sub&gt;c&lt;/sub&gt; [74.34]</td>
<td>20.76&lt;sub&gt;a&lt;/sub&gt; (4.65)</td>
<td>12.02&lt;sub&gt;a&lt;/sub&gt; (3.61)</td>
<td>32.78&lt;sub&gt;a&lt;/sub&gt; (5.64)</td>
<td>3041.25&lt;sub&gt;a&lt;/sub&gt; (55.11)</td>
<td>29.98&lt;sub&gt;e&lt;/sub&gt; (5.57)</td>
</tr>
<tr>
<td>$T_5$: Fipronil (7 ml/kg seed)</td>
<td>86.76&lt;sub&gt;c&lt;/sub&gt; [68.65]</td>
<td>18.88&lt;sub&gt;ab&lt;/sub&gt; (4.46)</td>
<td>12.65&lt;sub&gt;a&lt;/sub&gt; (3.69)</td>
<td>31.53&lt;sub&gt;a&lt;/sub&gt; (5.70)</td>
<td>2736.17&lt;sub&gt;b&lt;/sub&gt; (52.32)</td>
<td>26.69&lt;sub&gt;f&lt;/sub&gt; (5.26)</td>
</tr>
<tr>
<td>$T_6$: Fipronil (10ml/kg seed)</td>
<td>84.5&lt;sub&gt;c&lt;/sub&gt; [66.80]</td>
<td>17.5&lt;sub&gt;b&lt;/sub&gt; (4.29)</td>
<td>9.95&lt;sub&gt;b&lt;/sub&gt; (3.31)</td>
<td>27.45&lt;sub&gt;c&lt;/sub&gt; (5.33)</td>
<td>2317.49&lt;sub&gt;c&lt;/sub&gt; (48.1)</td>
<td>25.91&lt;sub&gt;g&lt;/sub&gt; (5.19)</td>
</tr>
<tr>
<td>$T_7$: Chlorpyriphos (7ml/kg seed)</td>
<td>85.6&lt;sub&gt;d&lt;/sub&gt; [67.33]</td>
<td>17.38&lt;sub&gt;b&lt;/sub&gt; (4.29)</td>
<td>10.08&lt;sub&gt;b&lt;/sub&gt; (3.33)</td>
<td>27.46&lt;sub&gt;c&lt;/sub&gt; (5.34)</td>
<td>2338.95&lt;sub&gt;d&lt;/sub&gt; (48.37)</td>
<td>24.69&lt;sub&gt;h&lt;/sub&gt; (5.07)</td>
</tr>
<tr>
<td>$T_8$: Chlorpyriphos (10ml/kg seed)</td>
<td>72.3&lt;sub&gt;f&lt;/sub&gt; [58.26]</td>
<td>16.46&lt;sub&gt;b&lt;/sub&gt; (4.18)</td>
<td>6.65&lt;sub&gt;b&lt;/sub&gt; (2.76)</td>
<td>23.11&lt;sub&gt;d&lt;/sub&gt; (4.91)</td>
<td>1672.42&lt;sub&gt;d&lt;/sub&gt; (40.89)</td>
<td>10.12&lt;sub&gt;i&lt;/sub&gt; (3.34)</td>
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<tr>
<td>$T_9$: Chlorpyriphos (12ml/kg seed)</td>
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<td>5.40&lt;sub&gt;c&lt;/sub&gt; (2.53)</td>
<td>19.65&lt;sub&gt;e&lt;/sub&gt; (4.54)</td>
<td>1278.85&lt;sub&gt;c&lt;/sub&gt; (35.76)</td>
<td>6.94&lt;sub&gt;j&lt;/sub&gt; (2.82)</td>
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<tr>
<td>$T_{10}$: Control (Water)</td>
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<td>17.1&lt;sub&gt;b&lt;/sub&gt; (4.25)</td>
<td>10.51&lt;sub&gt;b&lt;/sub&gt; (3.39)</td>
<td>27.60&lt;sub&gt;b&lt;/sub&gt; (5.35)</td>
<td>2664.24&lt;sub&gt;b&lt;/sub&gt; (5.61)</td>
<td>30.56&lt;sub&gt;d&lt;/sub&gt; (5.62)</td>
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SE(d) 0.858 0.15 0.09 0.14 1.33 0.025

CD (P=0.05) [1.80] (0.31) (0.19) (0.29) (2.78) (0.05)

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
Table 4.4.
Germination percentage, seedling length and vigour indices for various seed-treatments (insecticides/termiticides only) in groundnut var. ‘TAG-21’

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<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
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<tr>
<td><strong>T₁</strong>: Imidacloprid (3ml/kg seed)</td>
<td>95.57&lt;sub&gt;ab&lt;/sub&gt; [77.86]</td>
<td>11.80&lt;sub&gt;b&lt;/sub&gt; (3.58)</td>
<td>14.30&lt;sub&gt;b&lt;/sub&gt; (3.91)</td>
<td>26.10&lt;sub&gt;b&lt;/sub&gt; (5.21)</td>
<td>2494.08&lt;sub&gt;b&lt;/sub&gt; (49.95)</td>
<td>71.04&lt;sub&gt;d&lt;/sub&gt; (8.49)</td>
</tr>
<tr>
<td><strong>T₂</strong>: Imidacloprid (5ml/kg seed)</td>
<td>96.00&lt;sub&gt;ab&lt;/sub&gt; [78.45]</td>
<td>13.20&lt;sub&gt;b&lt;/sub&gt; (3.77)</td>
<td>14.90&lt;sub&gt;b&lt;/sub&gt; (3.99)</td>
<td>28.10&lt;sub&gt;a&lt;/sub&gt; (5.39)</td>
<td>2697.47&lt;sub&gt;a&lt;/sub&gt; (51.93)</td>
<td>77.76&lt;sub&gt;b&lt;/sub&gt; (8.88)</td>
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<tr>
<td><strong>T₃</strong>: Imidacloprid (7ml/kg seed)</td>
<td>95.17&lt;sub&gt;b&lt;/sub&gt; [77.27]</td>
<td>13.47&lt;sub&gt;a&lt;/sub&gt; (3.80)</td>
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<td>2788.33&lt;sub&gt;a&lt;/sub&gt; (52.81)</td>
<td>85.33&lt;sub&gt;b&lt;/sub&gt; (9.29)</td>
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<td>2149.53&lt;sub&gt;c&lt;/sub&gt; (46.37)</td>
<td>69.38&lt;sub&gt;c&lt;/sub&gt; (8.39)</td>
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<td>56.98&lt;sub&gt;f&lt;/sub&gt; (7.61)</td>
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<td>8.63&lt;sub&gt;e&lt;/sub&gt; (3.10)</td>
<td>8.70&lt;sub&gt;f&lt;/sub&gt; (3.11)</td>
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<td>1464.87&lt;sub&gt;e&lt;/sub&gt; (38.28)</td>
<td>51.83&lt;sub&gt;g&lt;/sub&gt; (7.27)</td>
</tr>
<tr>
<td><strong>T₇</strong>: Chlorpyriphos (6ml/kg seed)</td>
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<td>9.83&lt;sub&gt;cd&lt;/sub&gt; (3.29)</td>
<td>12.33&lt;sub&gt;d&lt;/sub&gt; (3.65)</td>
<td>22.17&lt;sub&gt;c&lt;/sub&gt; (4.81)</td>
<td>1924.75&lt;sub&gt;d&lt;/sub&gt; (43.88)</td>
<td>54.42&lt;sub&gt;g&lt;/sub&gt; (7.44)</td>
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<tr>
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<td>7.10&lt;sub&gt;e&lt;/sub&gt; (2.85)</td>
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<td>35.63&lt;sub&gt;f&lt;/sub&gt; (6.05)</td>
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<tr>
<td><strong>T₉</strong>: Chlorpyriphos (25ml/kg seed)</td>
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<td>5.20&lt;sub&gt;e&lt;/sub&gt; (2.49)</td>
<td>10.70&lt;sub&gt;e&lt;/sub&gt; (3.42)</td>
<td>793.02&lt;sub&gt;f&lt;/sub&gt; (28.17)</td>
<td>28.66&lt;sub&gt;i&lt;/sub&gt; (5.45)</td>
</tr>
<tr>
<td><strong>T₁₀</strong>: Control (Water)</td>
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<td>11.57&lt;sub&gt;c&lt;/sub&gt; (3.54)</td>
<td>13.50&lt;sub&gt;c&lt;/sub&gt; (3.81)</td>
<td>25.07&lt;sub&gt;b&lt;/sub&gt; (5.11)</td>
<td>2420.40&lt;sub&gt;b&lt;/sub&gt; (49.2)</td>
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<td>SE(d)</td>
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<td>0.026</td>
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<td>CD (P=0.05)</td>
<td>[1.42]</td>
<td>(0.12)</td>
<td>(0.09)</td>
<td>(0.13)</td>
<td>(1.29)</td>
<td>(0.054)</td>
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</table>

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05).
Table 4.5.

Germination percentage, seedling length and vigour indices for various seed-treatments (insecticides/termiticides only) in soybean var. ‘DS 9712’.

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: Imidacloprid  (4ml/kg seed)</td>
<td>84.00&lt;sub&gt;ab&lt;/sub&gt; [77.86]</td>
<td>19.01&lt;sub&gt;abc&lt;/sub&gt; (4.47)</td>
<td>18.33&lt;sub&gt;bc&lt;/sub&gt; (4.4)</td>
<td>37.38&lt;sub&gt;bc&lt;/sub&gt; (6.2)</td>
<td>3,140.34&lt;sub&gt;b&lt;/sub&gt; (56.05)</td>
<td>63.84&lt;sub&gt;c&lt;/sub&gt; (6.34)</td>
</tr>
<tr>
<td>T2: Imidacloprid  (6ml/kg seed)</td>
<td>81.66&lt;sub&gt;ab&lt;/sub&gt; [78.45]</td>
<td>19.26&lt;sub&gt;abc&lt;/sub&gt; (4.5)</td>
<td>18.7&lt;sub&gt;bc&lt;/sub&gt; (4.44)</td>
<td>38.21&lt;sub&gt;bc&lt;/sub&gt; (6.26)</td>
<td>3,120.86&lt;sub&gt;b&lt;/sub&gt; (55.87)</td>
<td>56.35&lt;sub&gt;b&lt;/sub&gt; (7.20)</td>
</tr>
<tr>
<td>T3: Imidacloprid  (8ml/kg seed)</td>
<td>81.16&lt;sub&gt;b&lt;/sub&gt; [76.85]</td>
<td>21.76&lt;sub&gt;a&lt;/sub&gt; (4.77)</td>
<td>20.56&lt;sub&gt;a&lt;/sub&gt; (4.64)</td>
<td>42.43&lt;sub&gt;a&lt;/sub&gt; (6.59)</td>
<td>3,443.21&lt;sub&gt;a&lt;/sub&gt; (58.68)</td>
<td>50.05&lt;sub&gt;a&lt;/sub&gt; (7.8)</td>
</tr>
<tr>
<td>T4: Fipronil     (3ml/kg seed)</td>
<td>82.5&lt;sub&gt;c&lt;/sub&gt; [74.34]</td>
<td>20.15&lt;sub&gt;ab&lt;/sub&gt; (4.59)</td>
<td>18.31&lt;sub&gt;bc&lt;/sub&gt; (4.4)</td>
<td>37.61&lt;sub&gt;bc&lt;/sub&gt; (6.21)</td>
<td>3,103.77&lt;sub&gt;b&lt;/sub&gt; (55.71)</td>
<td>60.22&lt;sub&gt;d&lt;/sub&gt; (5.57)</td>
</tr>
<tr>
<td>T5: Fipronil     (5 ml/kg seed)</td>
<td>82&lt;sub&gt;d&lt;/sub&gt; [68.65]</td>
<td>16.68&lt;sub&gt;cd&lt;/sub&gt; (4.2)</td>
<td>19.73&lt;sub&gt;ab&lt;/sub&gt; (4.55)</td>
<td>36.65&lt;sub&gt;b&lt;/sub&gt; (6.13)</td>
<td>3,004.26&lt;sub&gt;b&lt;/sub&gt; (54.80)</td>
<td>62.04&lt;sub&gt;c&lt;/sub&gt; (5.26)</td>
</tr>
<tr>
<td>T6: Fipronil (7ml/kg seed)</td>
<td>81.16&lt;sub&gt;e&lt;/sub&gt; [66.80]</td>
<td>12.85&lt;sub&gt;c&lt;/sub&gt; (3.71)</td>
<td>19.1&lt;sub&gt;abc&lt;/sub&gt; (4.48)</td>
<td>31.45&lt;sub&gt;c&lt;/sub&gt; (5.59)</td>
<td>2,553.55&lt;sub&gt;c&lt;/sub&gt; (50.51)</td>
<td>58.98&lt;sub&gt;f&lt;/sub&gt; (5.19)</td>
</tr>
<tr>
<td>T7: Chlorpyriphos (4ml/kg seed)</td>
<td>84.33&lt;sub&gt;f&lt;/sub&gt; [61.9]</td>
<td>17.65&lt;sub&gt;bcd&lt;/sub&gt; (4.32)</td>
<td>14.79&lt;sub&gt;d&lt;/sub&gt; (3.97)</td>
<td>32.54&lt;sub&gt;bc&lt;/sub&gt; (5.79)</td>
<td>2,745.56&lt;sub&gt;c&lt;/sub&gt; (52.39)</td>
<td>56.78&lt;sub&gt;e&lt;/sub&gt; (4.86)</td>
</tr>
<tr>
<td>T8: Chlorpyriphos (6ml/kg seed)</td>
<td>81.66&lt;sub&gt;e&lt;/sub&gt; [53.8]</td>
<td>15.71&lt;sub&gt;d&lt;/sub&gt; (4.1)</td>
<td>11.4&lt;sub&gt;e&lt;/sub&gt; (3.52)</td>
<td>27.23&lt;sub&gt;d&lt;/sub&gt; (5.31)</td>
<td>2,224.4&lt;sub&gt;d&lt;/sub&gt; (47.17)</td>
<td>37.29&lt;sub&gt;e&lt;/sub&gt; (3.18)</td>
</tr>
<tr>
<td>T9: Chlorpyriphos (8ml/kg seed)</td>
<td>80&lt;sub&gt;a&lt;/sub&gt; [43.84]</td>
<td>12.7&lt;sub&gt;e&lt;/sub&gt; (3.69)</td>
<td>10.13&lt;sub&gt;f&lt;/sub&gt; (3.34)</td>
<td>21.5&lt;sub&gt;e&lt;/sub&gt; (4.68)</td>
<td>1,720&lt;sub&gt;e&lt;/sub&gt; (41.47)</td>
<td>25.86&lt;sub&gt;f&lt;/sub&gt; (2.47)</td>
</tr>
<tr>
<td>T10: Control (Water)</td>
<td>85.5&lt;sub&gt;a&lt;/sub&gt; [79.31]</td>
<td>19.01&lt;sub&gt;abc&lt;/sub&gt; (4.47)</td>
<td>17.85&lt;sub&gt;c&lt;/sub&gt; (4.34)</td>
<td>36.9&lt;sub&gt;b&lt;/sub&gt; (6.16)</td>
<td>3,154.88&lt;sub&gt;b&lt;/sub&gt; (56.18)</td>
<td>55.86&lt;sub&gt;d&lt;/sub&gt; (5.62)</td>
</tr>
</tbody>
</table>

SE(d) | 0.77 | 0.15 | 0.08 | 0.10 | 1.00 | 0.023

CD (P=0.05) | [1.65] | (0.31) | (0.16) | (0.22) | (2.1) | (0.05)

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
length as compared to control and it was observed that reduction in total length is with increase in the dose.

A close look of vigour indices showed that in case of imidacloprid, increase in dose results in relative increase in both vigour indices. Vigour Indices I and II were recorded in seed treatments as follows viz. highest for imidacloprid @7ml/kg (2788.33, 85.33); lowest for chlorpyriphos @25 ml/kg (793.02, 28.66); as against the control values (2420.4, 72.08), respectively (Table 4.4).

**Soybean** (Table 4.5 & Plate 4.1 & 5.1)

Effect of three different doses of three test insecticides on germination, seedlings total length and vigour indices of soybean is depicted in Table 4.5. All most all treatments including control, showed germination >80%, much above the ISTA (2008) recommendation. But, higher doses of chlorpyriphos showed detrimental effect on other seedling parameter viz. 27.23, 2224.4 and 37.29 (for 6 ml/kg dose); and 21.5, 1720, 25.86 (for 8 ml/kg seed) corresponding to total seedling length, vigour indices I and II respectively. The corresponding control values are 36.9 cm, 3154.88 and 55.86 (untreated seedlings) are much higher and statistically different (P < 0.05).

Highest vigour indices (I and II) recorded (3140.34, 63.84) for imidacloprid @4ml/kg seed showed the possibility of phytotonic effects on seedlings. In fipronil seed treatment (@ 3 and 5 ml/kg), there was also increase in Vigour Index-II indicating dry weight gain in seeds. The vigour index I is at par with control values.

**Rapid tetrazolium test (TZ) for maize and chickpea** (Table 4.6 & Fig 4.3 & 4.4)

Untreated seeds (control) offered only 1% dead seeds in both test-crops. Chlorpyriphos-treated seeds exhibited substantial increase in dead seeds (13, 20%) at higher doses (7 and 10 ml/kg) as depicted in Table 4.6. Dead seeds in chlorpyriphos treated seeds remained colourless. Dead seeds thus, indicate phytotoxic effect of chlorpyriphos at higher doses. Fipronil treatments also exhibited phyto-toxicity at higher doses (7, 10 ml/kg), but lesser effect as compared to chlorpyriphos. Contrary to the above to test-insecticides, imidacloprid did not cause any harmful effect on viability of seed. Even though there was ca. 2-3 fold increase in dose (1.5 to 5 ml/kg),
Table 4.6
Effect of insecticides on seed viability

<table>
<thead>
<tr>
<th>Treatment details</th>
<th>Maize</th>
<th>Chickpea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test-dose (ml/kg)</td>
<td>Germn. (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard seeds (%)</td>
</tr>
<tr>
<td>T₁: Imidacloprid</td>
<td>1.5</td>
<td>97</td>
</tr>
<tr>
<td>T₂: Imidacloprid</td>
<td>3</td>
<td>96</td>
</tr>
<tr>
<td>T₃: Imidacloprid</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>T₄: Fipronil</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>T₅: Fipronil</td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td>T₆: Fipronil</td>
<td>10</td>
<td>89</td>
</tr>
<tr>
<td>T₇: Chlorpyriphos</td>
<td>5</td>
<td>89</td>
</tr>
<tr>
<td>T₈: Chlorpyriphos</td>
<td>7</td>
<td>83</td>
</tr>
<tr>
<td>T₉: Chlorpyriphos</td>
<td>10</td>
<td>77</td>
</tr>
</tbody>
</table>

Similar to the previous T₇ and T₈ treatments, no phyto-toxicity is obtained as there was negligible increase in dead seeds (mere 1-2%). Similarly, in chickpea chlorpyriphos at higher test-doses i.e. 10, 12ml/kg resulted in higher dead seeds i.e. 16 and 19% respectively. Number of dead seeds also increased in higher test-doses of fipronil not that much high as in chlorpyriphos. Imidacloprid did not cause any harmful effect on viability of seed as clear from the fact that dead seeds obtained were only 1-2%. The safety of imidacloprid is very much pronounced from this investigation.
Fig 4.3.

Effect of insecticidal treatments on the seed viability for maize (HQPM-1)

Fig 4.4

Effect of insecticidal treatments on the seed viability for chickpea (PUSA-1003)
4.5. Discussion

Few scientists reported the effect of seed treatment chemicals on wheat seed germination in vitro. The reaction of seed treatment chemicals were reported in germination of other crops like groundnut (Narasimhulu and Kameswara Rao, 1989), chickpea (Chaudhary and Dashad, 2002), green gram (Dhillon et al., 2001), safflower and sesame (Charjan and Tarar, 1993), and okra (Gaikwad and Pawar, 1979).

Suppression of germination and subsequent growth by the pesticidal treatments indicates that some of the biochemical processes taking place during germination due to rapid imbibition rate, higher amount of seed leachate conductivity, seed respiration rate, intensity of dehydrogenase activity that reflect the vigour of seed as a effected by seed treatment which was experimentally described by Chaudhary et al. (2001). Chopra and Chandra, (1969) also reported reason for reduction in germination was due to significant reduction in the formation of reducing sugars and free amino acids in mustard.

Kashyap et al. (1994) investigated on the effect of seed treatment, period of storage of treated seeds on standard germination, abnormal seedlings, ungerminated seeds, vigour index and speed of germination in eight wheat cultivars. They found significant variation among various test cultivars, test-insecticides. Cultivar ‘Sonalika’ was most sensitive while ‘HD 2329’ was least sensitive to insecticidal seed treatment (chlorpyriphos, aldrin, endosulfan and formothion in different doses).

Adverse effects of pesticides on seed germination were demonstrated by several workers (Scopes, 1969; and Gifford et al., 1959). Laboratory trials also indicated that chlorpyriphos (@9 ml/kg) significantly inhibited the germination both in vitro and pot culture (Sithik, 2012). The results of our study revealed that the seed-treatments with test-doses of fipronil @ 6ml, 8ml (wheat);@7ml,10ml (maize); @10ml (chickpea); @7,10ml (groundnut); @7ml/kg (soybean) were detrimental. Similarly, for chlorpyriphos @4, 6ml/kg(wheat); @5,7,10ml/kg (maize); @10, 12ml/kg(chickpea);@12, 25ml/kg (groundnut); and @6, 8ml/kg (soybean) –were found detrimental to the seedlings of respective crops.

Pest control economics for various seed treatments was analyzed for few insecticides with recommended dose by Sithik (2012). Chlorpyiphos (20EC@4.5 ml/kg) was found
most cost-effective (Rs. 358/ha) followed by fipronil 5SC @ 6 ml/kg (Rs. 893), and imidacloprid 17.8SL @ 3.5 ml/kg (Rs. 1034). As chlorpyriphos is cheaper, and commonly available to farmers, it is most popular, but the toxic detrimental effect is very clear for this chemical. So field recommendations must be given with appropriate precautions.

5.6. Conclusion

This *in vitro* investigation reveals the effect of various seed-treatments on germination of wheat (HD-2967), maize (HQPM-1), chickpea (PUSA-1003), soybean (DS-9712) and groundnut (TAG-21). The chlorpyriphos higher dose significantly affected the germination *in vitro*. Higher-dose of chlorpyriphos has recorded drastic reduction in the germination as compared to control. In the former case (most popular seed treatment), higher dose resulted in least germination and minimum root and shoot length.

*In vitro* based crop-specific recommendations for insecticidal seed-treatments are those are having no deleterious effect on seedlings; as follows:

1. Wheat - imidacloprid @ 3-5; fipronil @ 4 and chlorpyriphos @2 ml/kg seeds.
2. Maize-imadacloprid @1.5-5; fipronil @ 5 ml/kg seeds are recommended and chlorpyriphos is not recommended.
3. Chickpea - imadacloprid@ 5-10; fipronil @ 5-7 and chlorpyriphos @7 ml/kg seeds.
4. Groundnut- imidacloprid@ 3-7; fipronil @ 5 and chlorpyriphos @6 ml/kg seeds.
5. Soybean - imidacloprid@ 4-6; fipronil @ 3-5 and chlorpyriphos @4 ml/kg seeds.

Acknowledgements

The senior author is grateful to Indian Council of Agricultural Research for providing fellowship throughout M.Sc. programme. We are also grateful to the Division of Entomology, Seed Science and Technology, Microbiology, Plant Pathology and Genetics and Central Library of IARI for providing necessary facilities for undertaking this study.
Plate- 4.1

Detrimental effect of chlorpyriphos in various test crops

Wheat

control chlorpyriphos

Maize

control chlorpyriphos control chlo+tricho+az
Chlorpyriphos 7, 10 & 12 ml/kg

Groundnut
Plate 5.1
Phytotonic effect of Imidacloprid in various test crops

Wheat

Maize
Research Paper-II
5. RESEARCH PAPER II

Combinatorial efficacy and compatibility of insecticides, biofungicides and biofertilisers for seed treatment in selected major field crops

5.1. ABSTRACT

Laboratory experiments were conducted to verify the compatibility of the termiticides as seed treatment chemicals (viz., chlorpyriphos, imidacloprid and fipronil) in five target crops (wheat, maize, chickpea, groundnut and soybean) with recommended doses of insecticides (@3, 3, 5, 5 and 4 ml/kg seed) for imidacloprid in five test-crops, along with bio-fertilisers @25g/kg seed (Azotobacter, Azospirillum, Mesorhizobium, Bradyrhizobium and Rhizobium japonicum) for test-crops - wheat, maize, chickpea, groundnut and soybean respectively; and also in combination with biofertiliser + biofungicide (Trichoderma harzianum @ 4 g/kg seed). The same combinations (with biofertiliser and biofungicide) were tested for other two termiticides viz., chlorpyriphos 20EC (@2, 5, 7, 6 and 4 ml/kg) and fipronil (@ 4, 5, 5, 5 and 3 ml/kg seed) for test-crops - wheat, maize, chickpea, groundnut and soybean, correspondingly.

The in-between paper method (Agarwal, 1995) is followed and this in vitro trial outcome advocates the following crop-specific recommendations for effective compatible combinatorial seed treatment measures (biocontrol agent and biofertiliser doses are same, i.e. 4 g/kg and 25g/kg seed). Supporting pot trial for pulse crop (chickpea) was carried out to verify the effect various combination treatments on root nodulations.

**Wheat:** 1) Imidacloprid @3ml/kg + *Azotobacter.* 2) imidacloprid @3ml/kg + *Trichoderma*+*Azotobacter.* 3) fipronil @4ml/kg + *Azotobacter.* 4) fipronil @4ml/kg, *Trichoderma*+*Azotobacter.*

**Maize:** 1) Imidacloprid @3ml/kg + *Azospirillum* 2) imidacloprid @3ml/kg + *Trichoderma*+*Azospirillum* 3) fipronil @5ml/kg + *Azospirillum*4) fipronil @5ml/kg + *Trichoderma* +*Azospirillum.*
Chickpea: 1) Imidacloprid @5ml/kg + Mesorhizobium 2) imidacloprid @5ml/kg + Trichoderma +Mesorhizobium 3) fipronil @5ml/kg + Mesorhizobium 4) fipronil @5ml/kg + Trichoderma +Mesorhizobium.

Groundnut: 1) Imidacloprid @5ml/kg + Bradyrhizobium 2) imidacloprid @5ml/kg + Trichoderma +Bradyrhizobium 3) fipronil @5ml/kg + Bradyrhizobium 4) fipronil @5ml/kg + Trichoderma+Bradyrhizobium.

Soybean: 1) Imidacloprid @4ml/kg + R.japonicum 2) imidacloprid @5ml/kg + Trichoderma +R. japonicum 3) fipronil @3ml/kg + R.japonicum 4) fipronil @3ml/kg + Trichoderma +R.japonicum.

These recommendations may be tested for the field level efficacy, and the insecticides tested here are essentially termiticides, but recommendations can well be used for sucking insect pests as well in the target-crops.

Key words: Azotobacter, Azospirillum, Bradyrhizobium, Mesorhizobium, Rhizobium japonicum, chlorpyriphos, fipronil, imidaclorpid, Trichoderma harzianum

5.2. Introduction

Importance of major cereals (wheat and maize) and pulses (chickpea, soybean and groundnut) is reflected from the fact that these five major field crops contributes about 115.44 million tonnes (wheat, 93.62 and maize, 21.82) and 28.06 million tonnes (chickpea, 8.4; groundnut, 5.43 and soybean,14.14million tonnes) according to Third Advance Estimate of Production of Food grains & Oilseeds and Other Commercial Crops, 2012-13.(Anonymous, 2013).Our first experimentation on recommendations for these five target crops, under the first objective, suggests the appropriate and right dose of imidaclorpid (@3, 3, 5, 5 and 4 ml/kg seed),for chlorpyriphos 20EC (@ 2, 5, 7, 6 and 4 ml/kg seed), and for fipronil (@ 4, 5, 5, 5 and 3 ml/kg seed) for target-crops wheat, maize, chickpea, groundnut and soybean respectively. These recommendations are insecticides alone and their compatibility with recommended bio-fertiliser(s) and bio-fungicide (T. harzianum) were tested in vitro for the above mentioned target crops.IPM packages of Govt of India, Ministry of Agriculture (Directorate of Plant Protection, Quarantine & Storage ‘DPPQ&S’, 2001) recommends chlorpyriphos 20EC@4 ml/kg seed of wheat. For maize, seed treatment with T. viridae or T. harzianum @4g/kg is
advocated. No insecticidal seed treatment is offered in this package (DPPQ&S, 2001). However Directorate of Maize Research, New Delhi recommends imidacloprid seed treatment @ 4ml/kg seed for termite and shoot fly (www.dmr.res.in). For chickpea seed treatment with same of T. viridae or T. harzianum @ 4 g/kg for diseases; and chlorpyriphos 20EC @15-20 ml/kg of seed for termites is recommended. seed treatment with carbosulfan 25EC and carbendazim 20%DS were also advocated for other insects and diseases. Biofertiliser like Rhizobium culture is also mentioned in the package. But these recommendations are in isolation, and nothing is mentioned regarding combination of these pesticides. In groundnut seed treatment with chlorpyriphos 20 EC @ 2.5-12.5 ml/kg seed for termite control and with bio-fungicide T. viride or T. harzianum @ 4g/kg seed for control of seed/seedling rot disease is suggested by DPPQ&S (2001). Almost no literature is available on compatibility of seed treatment insecticides, fungicides and biofertilisers in these field crops.

### 5.3. Materials and Methods

**5.3.1.** Seeds of test crops - wheat (HD-2967), maize (HQPM-1), chickpea (PUSA-1003, and soybean (DS-9712) were obtained from Seed Unit, Division of Genetics, Indian Agricultural Research Institute, New Delhi and groundnut seeds (TAG-21) was obtained from NRC for Groundnut, Junagadh (Gujarat). The seeds were treated with imidacloprid 48% FS (Gaucho® 600FS), fipronil 5SC (Regent®) and chlorpyriphos 20EC (Dursban®) each at recommended doses as obtained in the previous chapter (Research Paper-I). In maize, though chlorpyriphos is not recommended, dose @5ml/kg is taken for combinatorial test, expecting increase in germination above 90% (ISTA standard) when admixed with biofertiliser. These insecticidal treatments are done in combination with the bio-fungicide (T. harzianum@4g/kg seed), and also with the bio-fertilisers (@ 25g/kg seed). An untreated control was also included in the trial.

The insecticides were first added to water so as to make the final required volume of 50-100 ml according to different crop seeds, which was sufficient to soak one kg of seed. The seeds were spread on plastic trays, desired quantity of the only insecticide emulsion was then sprinkled on the seeds which were kept one hour in shade for drying, after drying these seeds were treated with bio-fungicide (T. harzianum@4g/kg)and these seeds
were subsequently treated with specific bio-fertilizer strain (@25g/kg seed) according to test-crop. Treated seeds were then subjected to germination test after 24 hours.

5.3.2. *In vitro* germination test

The seeds were germinated between two layers of germination paper in the germination chamber as detailed in previous chapter (temp. 20±1 to 25±1°C as per the test-crop) adopting in-between paper method (Agarwal, 1995). Replicates of 100 seeds (r=3) from each treatment (t=10) were sown in the paper towel. Normal seedlings, abnormal seedlings and ungerminated seeds were counted 7-10 days after sowing as per the test-crops according to ISTA (2008). Measurements for plumules, radicles and total length of seedlings were taken. Observations on mean values of radicles and plumules length of 10 seedlings in each replication; and dry weights of 10 seedlings in each replication were recorded for vigour index calculation.

5.3.4. Pot trial for root nodulation in pulse

In pulse (chickpea), a separate pot-culture trial is conducted to verify the effect of combinatorial treatments on the root nodulation. Same 8-treatments were taken as detailed in Table 3.4. Five seedlings in each replication were raised in the pots after required seed-treatments. The pots were maintained inside the walk-in-room germinator (temperature 20°C, relative humidity 70-75% as per the ISTA (2008) standard). Seedlings were watered at 6-days interval. Final observations on root nodules were taken 30-days after sowing.

5.3.5. Statistical analysis

The data were subjected to one factorial ANOVA following standard statistical package (OPSTAT online, www.hau.ernet.in/opstat.html).

5.4. Results and Discussion

Insecticides, biofertilizers (*Azotobacter*) and biofungicide (*T. harzianum*) are often required to be taken as seed treatments in field. In this combinatorial approach of compatibility assessment effect of different combinations on the seedling growth and development was verified for various crops.

**Wheat** (Table 5.1 & Plate 4.1 & 5.1)
In control the germination is 96.44 per cent. In all other combinatorial treatments T₁ (imidaclopid @3ml/kg + Azotobacter), T₂ (fipronil @4ml/kg + Azotobacter), T₃ (chlorpyriphos @2ml/kg + Azotobacter), T₄ (imidaclopid @3ml/kg + Trichoderma +Azotobacter), T₅ (fipronil @4ml/kg + Trichoderma + Azotobacter), T₆ (chlorpyriphos @2ml/kg + Trichoderma + Azotobacter) as mentioned in Table 5.1; the germination range was 83.33 to 97.39%. Treatments T₃ and T₆ showed detrimental effect and the germination percentage were <85%, so these combinations are not recommended as per ISTA standard. Therefore chlorpyriphos is not compatible with Azotobacter or along with T. harzianum and Azotobacter.

The total seedling length and Vigour indices I and II were 34.86 cm and 3362.58, 70.95 respectively in control. When the seeds were treated with Azotobacter, as expected there was increase in growth and development which is very much clear from values of root and shoot length and vigour indices as shown in Table 5.1.

When seeds were treated with imidaclopid and Azotobacter, recorded seedling parameters were still better than those in control, showing no compatible problem. Rather the higher values of seedling length and vigour indices implies possible phytotonic impact. When imidaclopid was taken along with T. harzianum and Azotobacter the same trend is maintained with statistical significance (P<0.05%). Thus it inferred that imidaclopid can be taken safely along with T. harzianum and Azotobacter.

Fipronil when taken in combination with Azotobacter exhibited slight decrease in germination but it is above the ISTA recommendation. Other parameters like root and shoot length and vigour indices are at par or better. Fipronil + T.harzianum + Azotobacter also proved to be compatible based on the test parameters as presented in Table 5.2.

Maize (Table 5.2 & Plate 4.1 & 5.1)

Seeds of maize were treated in different combination of test insecticides, Azospirillum and Trichoderma in following way: treatments T₁ (imidaclopid @3ml/kg + Azospirillum), T₂ (fipronil @5ml/kg + Azospirillum), T₃ (chlorpyriphos @7ml/kg + Azotobacter), T₄ (imidaclopid @3ml/kg + Trichoderma +Azospirillum), T₅ (fipronil
@5ml/kg + *Trichoderma* +*Azospirillum*), T<sub>6</sub> (chlorpyriphos @7ml/kg + *Trichoderma* +*Azospirillum*).

Significant increase in germination per cent in T<sub>1</sub> (which includes imidacloprid) was recorded as compared to control. Whereas T<sub>2</sub> and T<sub>5</sub> (including fipronil) resulted in slight decrease in germination and T<sub>3</sub> and T<sub>6</sub> (including chlorpyriphos) resulted in significant reduction in germination as compared to all other treatments. This showed compatibility problem of chlorpyriphos with *Trichoderma and Azospirillum*.

In total seedling length observed, the treatment T<sub>4</sub> showed significant increase in root and shoot length in addition to having dark green colour of shoot (Plate 2). This may be due to combine effect (phytotoxic/additive/synergistic impacts) of all three products (imidacloprid, *Trichoderma* and *Azospirillum*). Reverse results were recorded (drastic decrease in root and shoot length) in treatments of chlorpyriphos (T<sub>3</sub> and T<sub>6</sub>) in combinatorial approach. Hence compatibility problem of chlorpyriphos with *Azospirillum* and *Trichoderma* is clear from this investigation. Slight compatibility problem was also observed in treatments including fipronil (T<sub>2</sub> and T<sub>5</sub>) as minor reduction of total seedling length were recorded.

A close look of the table 5.2 indicates that treatments T<sub>1</sub> and T<sub>4</sub> which are combination of imidacloprid, *Azospirillum* and *T. harzianum*; resulted in substantial increase in both the vigour indices I & II (statistically significant with all other treatments at P=0.05); thus implies possible phytotoxic effect on seedlings with higher degree of compatibility among treated products. Combinatorial treatment of fipronil (T<sub>2</sub>, T<sub>5</sub>) recorded slight reduction in vigour indices in comparison to control. Whereas treatments (with chlorpyriphos, T<sub>3</sub>, T<sub>6</sub>), showed drastic reduction in vigour indices. Qualitatively, pale yellow coloured seedlings were also obtained (Plate 5.2). This is attributed to the poor compatibility of chlorpyriphos with *Azospirillum* and *Trichoderma*. 
Table 5.1

Germination percentage, seedling length and vigour indices for various seed-treatments (in combination: insecticide, bio-fungicide and bio-fertilizer) in wheat var. ‘HD-2967’

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root Length (cm)</th>
<th>Shoot Length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour index-I</th>
<th>Vigour index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1:im+azoto</td>
<td>97.39&lt;sub&gt;a&lt;/sub&gt; [80.68]</td>
<td>22.03&lt;sub&gt;a&lt;/sub&gt; (4.8)</td>
<td>18.13&lt;sub&gt;b&lt;/sub&gt; (4.37)</td>
<td>39.9&lt;sub&gt;b&lt;/sub&gt; (6.37)</td>
<td>3885.73&lt;sub&gt;a&lt;/sub&gt; (62.08)</td>
<td>78.20&lt;sub&gt;a&lt;/sub&gt; (8.9)</td>
</tr>
<tr>
<td>T2:fip+azoto</td>
<td>91.67&lt;sub&gt;c&lt;/sub&gt; [73.24]</td>
<td>19.87&lt;sub&gt;b&lt;/sub&gt; (4.57)</td>
<td>16.3&lt;sub&gt;cd&lt;/sub&gt; (4.16)</td>
<td>36.67&lt;sub&gt;c&lt;/sub&gt; (6.14)</td>
<td>3360.21&lt;sub&gt;c&lt;/sub&gt; (57.97)</td>
<td>69.24&lt;sub&gt;de&lt;/sub&gt; (8.38)</td>
</tr>
<tr>
<td>T3:chl+azoto</td>
<td>84.43&lt;sub&gt;d&lt;/sub&gt; [66.74]</td>
<td>16.93&lt;sub&gt;c&lt;/sub&gt; (4.24)</td>
<td>13.7&lt;sub&gt;f&lt;/sub&gt; (3.83)</td>
<td>30.63&lt;sub&gt;c&lt;/sub&gt; (5.62)</td>
<td>25.86.3&lt;sub&gt;d&lt;/sub&gt; (50.87)</td>
<td>46.16&lt;sub&gt;e&lt;/sub&gt; (6.87)</td>
</tr>
<tr>
<td>T4:im+tri+azoto</td>
<td>96.03&lt;sub&gt;ab&lt;/sub&gt; [78.49]</td>
<td>21.81&lt;sub&gt;a&lt;/sub&gt; (4.78)</td>
<td>19.1&lt;sub&gt;a&lt;/sub&gt; (4.48)</td>
<td>41.26&lt;sub&gt;a&lt;/sub&gt; (6.50)</td>
<td>3962.93&lt;sub&gt;a&lt;/sub&gt; (62.96)</td>
<td>78.75&lt;sub&gt;a&lt;/sub&gt; (8.93)</td>
</tr>
<tr>
<td>T5:fip+tri+azoto</td>
<td>93.11&lt;sub&gt;c&lt;/sub&gt; [74.77]</td>
<td>20.62&lt;sub&gt;a&lt;/sub&gt; (4.65)</td>
<td>15.7&lt;sub&gt;e&lt;/sub&gt; (4.08)</td>
<td>36.31&lt;sub&gt;c&lt;/sub&gt; (6.11)</td>
<td>3380.36&lt;sub&gt;c&lt;/sub&gt; (58.15)</td>
<td>68.90&lt;sub&gt;c&lt;/sub&gt; (8.36)</td>
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<tr>
<td>T6:chl+tri+azoto</td>
<td>83.33&lt;sub&gt;d&lt;/sub&gt; [65.88]</td>
<td>17&lt;sub&gt;c&lt;/sub&gt; (4.24)</td>
<td>16.7&lt;sub&gt;f&lt;/sub&gt; (3.81)</td>
<td>30.83&lt;sub&gt;c&lt;/sub&gt; (5.64)</td>
<td>2569.66&lt;sub&gt;d&lt;/sub&gt; (50.7)</td>
<td>56.39&lt;sub&gt;f&lt;/sub&gt; (7.58)</td>
</tr>
<tr>
<td>T7:azoto</td>
<td>95.17&lt;sub&gt;b&lt;/sub&gt; [77.45]</td>
<td>21.06&lt;sub&gt;ab&lt;/sub&gt; (4.7)</td>
<td>13.5&lt;sub&gt;c&lt;/sub&gt; (4.21)</td>
<td>37.7&lt;sub&gt;c&lt;/sub&gt; (6.17)</td>
<td>3604.22&lt;sub&gt;b&lt;/sub&gt; (59.51)</td>
<td>75.81&lt;sub&gt;b&lt;/sub&gt; (8.76)</td>
</tr>
<tr>
<td>T8:Control</td>
<td>96.44&lt;sub&gt;ab&lt;/sub&gt; [79.14]</td>
<td>18.46&lt;sub&gt;c&lt;/sub&gt; (4.73)</td>
<td>16.23&lt;sub&gt;c&lt;/sub&gt; (4.15)</td>
<td>34.86&lt;sub&gt;d&lt;/sub&gt; (5.99)</td>
<td>3362.58&lt;sub&gt;c&lt;/sub&gt; (98.0)</td>
<td>70.95&lt;sub&gt;c&lt;/sub&gt; (8.48)</td>
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<td>SE(d)</td>
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<td>0.055</td>
<td>0.03</td>
<td>0.048</td>
<td>0.436</td>
<td>0.04</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>[2.29]</td>
<td>(0.12)</td>
<td>(0.064)</td>
<td>(0.1)</td>
<td>(0.93)</td>
<td>(0.09)</td>
</tr>
</tbody>
</table>

[im=imidacloprid 48%FS (@ 3ml/kg), fip=fipronil5FS (@ 4ml/kg); chl=chlorpyriphos 20EC(@ 2ml/kg), tri=T. harzianum (@ 4g/kg); & azoto=Azotobacter (@ 25 g/kg seed)]

Figures in parentheses [  ] are arcsine-transformed values and in parentheses (  ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
### Table 5.2.

Germination percentage, seedling length and vigour indices for various seed-treatments (in combination: insecticide, bio-fungicide and bio-fertilizer) in maize var.‘HQPM-1’

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁: im+azosp</td>
<td>97.39&lt;sub&gt;a&lt;/sub&gt; [80.68]</td>
<td>21.70&lt;sub&gt;a&lt;/sub&gt; (4.76)</td>
<td>19.3&lt;sub&gt;a&lt;/sub&gt; (4.51)</td>
<td>40.73&lt;sub&gt;a&lt;/sub&gt; (6.46)</td>
<td>3966.88&lt;sub&gt;a&lt;/sub&gt; (63.00)</td>
<td>78.20&lt;sub&gt;a&lt;/sub&gt; (8.9)</td>
</tr>
<tr>
<td>T₂: fip+azosp</td>
<td>91.67&lt;sub&gt;c&lt;/sub&gt; [73.24]</td>
<td>19.70&lt;sub&gt;b&lt;/sub&gt; (4.55)</td>
<td>17.63&lt;sub&gt;b&lt;/sub&gt; (4.32)</td>
<td>38&lt;sub&gt;c&lt;/sub&gt; (6.25)</td>
<td>3483.08&lt;sub&gt;c&lt;/sub&gt; (59.03)</td>
<td>69.24&lt;sub&gt;de&lt;/sub&gt; (8.38)</td>
</tr>
<tr>
<td>T₃: chl+azosp</td>
<td>84.43&lt;sub&gt;d&lt;/sub&gt; [66.74]</td>
<td>16.66&lt;sub&gt;c&lt;/sub&gt; (4.20)</td>
<td>14.73&lt;sub&gt;c&lt;/sub&gt; (3.97)</td>
<td>31.73&lt;sub&gt;d&lt;/sub&gt; (5.72)</td>
<td>2679.47&lt;sub&gt;d&lt;/sub&gt; (51.77)</td>
<td>46.16&lt;sub&gt;g&lt;/sub&gt; (6.87)</td>
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<tr>
<td>T₄: im+tri+azosp</td>
<td>96.03&lt;sub&gt;ab&lt;/sub&gt; [78.49]</td>
<td>21.81&lt;sub&gt;a&lt;/sub&gt; (4.78)</td>
<td>19.26&lt;sub&gt;a&lt;/sub&gt; (4.50)</td>
<td>41.43&lt;sub&gt;a&lt;/sub&gt; (6.51)</td>
<td>3978.97&lt;sub&gt;a&lt;/sub&gt; (63.09)</td>
<td>78.75&lt;sub&gt;a&lt;/sub&gt; (8.93)</td>
</tr>
<tr>
<td>T₅: fip+tri+azosp</td>
<td>93.11&lt;sub&gt;c&lt;/sub&gt; [74.77]</td>
<td>21.61&lt;sub&gt;a&lt;/sub&gt; (4.75)</td>
<td>18&lt;sub&gt;b&lt;/sub&gt; (4.36)</td>
<td>40.61&lt;sub&gt;a&lt;/sub&gt; (6.45)</td>
<td>3781.38&lt;sub&gt;b&lt;/sub&gt; (61.5)</td>
<td>68.90&lt;sub&gt;c&lt;/sub&gt; (8.36)</td>
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<td>T₆: chl+tri+azosp</td>
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<td>15.23&lt;sub&gt;d&lt;/sub&gt; (4.03)</td>
<td>14.76&lt;sub&gt;c&lt;/sub&gt; (3.97)</td>
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<td>2491.4&lt;sub&gt;e&lt;/sub&gt; (49.92)</td>
<td>56.39&lt;sub&gt;f&lt;/sub&gt; (7.58)</td>
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<td>95.17&lt;sub&gt;b&lt;/sub&gt; [77.45]</td>
<td>22.46&lt;sub&gt;a&lt;/sub&gt; (4.84)</td>
<td>18.26&lt;sub&gt;b&lt;/sub&gt; (4.39)</td>
<td>40.6&lt;sub&gt;a&lt;/sub&gt; (6.45)</td>
<td>3863.91&lt;sub&gt;ab&lt;/sub&gt; (62.17)</td>
<td>75.81&lt;sub&gt;b&lt;/sub&gt; (8.76)</td>
</tr>
<tr>
<td>T₈: Control</td>
<td>96.44&lt;sub&gt;ab&lt;/sub&gt; [79.14]</td>
<td>21.4&lt;sub&gt;a&lt;/sub&gt; (4.73)</td>
<td>17.7&lt;sub&gt;b&lt;/sub&gt; (4.33)</td>
<td>39.21&lt;sub&gt;b&lt;/sub&gt; (6.74)</td>
<td>3782.16&lt;sub&gt;b&lt;/sub&gt; (61.51)</td>
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<td>SE (P=0.05)</td>
<td>1.071</td>
<td>0.075</td>
<td>0.037</td>
<td>0.046</td>
<td>0.5</td>
<td>0.04</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>[2.29]</td>
<td>(0.16)</td>
<td>(0.08)</td>
<td>(90.1)</td>
<td>(1.07)</td>
<td>(0.09)</td>
</tr>
</tbody>
</table>

<sup>[im=imidaclorpid 48%FS (@ 3ml/kg), fip=fipronil5FS (@ 5ml/kg); chl=chlorpyriphos20EC(@ 5ml/kg), tri=T. harzianum (@ 4g/kg); & azosp =Azospirillum (@ 25 g/kg seed)]</sup>

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05).
**Chickpea (Table 5.3)**

As in already studied crops with respect to combinatorial approach of seed treatment, germination of seeds in treatment which includes imidacloprid T₁ (imidacloprid @5ml/kg + *Mesorhizobium* and T₄ (imidacloprid @5ml/kg, *Trichoderma* and *Mesorhizobium*), recorded germination was higher than that of control but statistically at par with control value; as well as in treatments in which seeds were treated only with *Mesorhizobium* and showed no compatibility problem. Treatments, T₂ and T₅ (including fipronil) resulted in slight decrease in germination showing slight compatibility problem but it can be acceptable as germination is above ISTA specification (>85%). Combinations which include chlorpyriphos
<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
<th>*Root nodules (no./plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: im+rhizo</td>
<td>97.39&lt;sub&gt;a&lt;/sub&gt; [80.68]</td>
<td>21.21&lt;sub&gt;abc&lt;/sub&gt; (4.71)</td>
<td>18.13&lt;sub&gt;a&lt;/sub&gt; (4.37)</td>
<td>39.9&lt;sub&gt;abc&lt;/sub&gt; (6.4)</td>
<td>3885.73&lt;sub&gt;a&lt;/sub&gt; (62.34)</td>
<td>78.20&lt;sub&gt;a&lt;/sub&gt; (8.9)</td>
<td>12&lt;sub&gt;ab&lt;/sub&gt; (3.60)</td>
</tr>
<tr>
<td>T2: fip+rhizo</td>
<td>91.67&lt;sub&gt;c&lt;/sub&gt; [73.24]</td>
<td>20.03&lt;sub&gt;c&lt;/sub&gt; (4.58)</td>
<td>15.63&lt;sub&gt;c&lt;/sub&gt; (4.08)</td>
<td>36.67&lt;sub&gt;c&lt;/sub&gt; (6.14)</td>
<td>3360.58&lt;sub&gt;d&lt;/sub&gt; (57.97)</td>
<td>69.24&lt;sub&gt;d&lt;/sub&gt; (8.38)</td>
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<tr>
<td>T3: chl+rhizo</td>
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<td>16.66&lt;sub&gt;d&lt;/sub&gt; (4.20)</td>
<td>13.33&lt;sub&gt;d&lt;/sub&gt; (3.79)</td>
<td>30.33&lt;sub&gt;d&lt;/sub&gt; (5.6)</td>
<td>2581.33&lt;sub&gt;e&lt;/sub&gt; (50.62)</td>
<td>55.31&lt;sub&gt;e&lt;/sub&gt; (7.50)</td>
<td>8.66&lt;sub&gt;c&lt;/sub&gt; (3.11)</td>
</tr>
<tr>
<td>T4: im+tri+rhizo</td>
<td>96.03&lt;sub&gt;b&lt;/sub&gt; [78.49]</td>
<td>21.81&lt;sub&gt;ab&lt;/sub&gt; (4.78)</td>
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<td>40.93&lt;sub&gt;a&lt;/sub&gt; (6.48)</td>
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<td>78.74&lt;sub&gt;a&lt;/sub&gt; (8.93)</td>
<td>13&lt;sub&gt;a&lt;/sub&gt; (3.74)</td>
</tr>
<tr>
<td>T5: fip+tri+rhizo</td>
<td>93.11&lt;sub&gt;c&lt;/sub&gt; [74.77]</td>
<td>20.62&lt;sub&gt;bc&lt;/sub&gt; (4.65)</td>
<td>15.33&lt;sub&gt;c&lt;/sub&gt; (4.04)</td>
<td>35.97&lt;sub&gt;c&lt;/sub&gt; (6.08)</td>
<td>3349.36&lt;sub&gt;d&lt;/sub&gt; (57.88)</td>
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<td>11&lt;sub&gt;b&lt;/sub&gt; (3.46)</td>
</tr>
<tr>
<td>T6: chl+tri+rhi</td>
<td>83.33&lt;sub&gt;d&lt;/sub&gt; [65.90]</td>
<td>17&lt;sub&gt;d&lt;/sub&gt; (4.24)</td>
<td>13.5&lt;sub&gt;d&lt;/sub&gt; (3.81)</td>
<td>30.83&lt;sub&gt;d&lt;/sub&gt; (5.64)</td>
<td>2569.67&lt;sub&gt;e&lt;/sub&gt; (50.70)</td>
<td>54.72&lt;sub&gt;e&lt;/sub&gt; (7.47)</td>
<td>7.33&lt;sub&gt;d&lt;/sub&gt; (2.89)</td>
</tr>
<tr>
<td>T7: rhizo</td>
<td>95.60&lt;sub&gt;b&lt;/sub&gt; [67.33]</td>
<td>22.47&lt;sub&gt;a&lt;/sub&gt; (4.84)</td>
<td>16.16&lt;sub&gt;b&lt;/sub&gt; (4.21)</td>
<td>38.5&lt;sub&gt;b&lt;/sub&gt; (6.29)</td>
<td>3680.55&lt;sub&gt;b&lt;/sub&gt; (60.67)</td>
<td>76.16&lt;sub&gt;b&lt;/sub&gt; (8.75)</td>
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<td>T8: Control</td>
<td>96.44&lt;sub&gt;ab&lt;/sub&gt; [79.14]</td>
<td>20.83&lt;sub&gt;abc&lt;/sub&gt; (4.67)</td>
<td>15.26&lt;sub&gt;c&lt;/sub&gt; (4.03)</td>
<td>36.4&lt;sub&gt;c&lt;/sub&gt; (6.12)</td>
<td>3510.31&lt;sub&gt;c&lt;/sub&gt; (59.26)</td>
<td>70.95&lt;sub&gt;c&lt;/sub&gt; (7.67)</td>
<td>7.66&lt;sub&gt;d&lt;/sub&gt; (2.94)</td>
</tr>
</tbody>
</table>

SE(d) 0.887 0.08 0.042 0.056 0.512 0.032 0.109
CD (P=0.05) [1.9] (0.17) (0.09) (0.12) (1.1) (0.07) (0.0.23)

*Root nodules were observed in a separate pot culture trial (after 30 days of sowing).

[im=imidaclorpid 48%FS (@ 5ml/kg), fip=fipronil5FS (@ 5ml/kg); chl=chlorpyriphos20EC(@ 7ml/kg), tri=T. harzianum (@ 4g/kg); & rhizo=Mesorhizobium (@ 25 g/kg seed)]

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
resulted in decrease in germination percentage of seed in addition to pale yellow colour of seedling and reduced growth rate, which are statistically significant with control value and reveals major degree of incompatibility of chlorpyriphos with Mesorhizobium and Trichoderma.

In combinatorial seed treatments; total length of seedling in control was 36.4cm. Whereas it is increased significantly in treatment T_7 (seed treated with only Mesorhizobium; 38.5cm), T_2 (imidacloprid+ Mesorhizobium) and T_4 (imidacloprid+ Trichoderma +Mesorhizobium). In control Vigour Index-I and II were 3510.31 and 70.95 respectively. Vigour indices (I and II) increased substantially in T_1 (3885.73 and 78.20), T_4 (3930.99 and 78.74) and T_7 (3680.55 and 76.16). This implies possible phytotonic effect. In treatments T_3 and T_6 (including chlorpyriphos), drastic reduction in vigour indices (both I and II) was recorded. In all above measured parameters combination problem was major factor in treatments which includes chlorpyriphos.

**Root nodulation test – pot trial** (Table 5.3, Fig. 5.1 and plate 5.3)

Pot trial for root nodulation in chickpea is conducted separately. The results indicate that Rhizobium culture increased the root nodules in treated pulse seedlings (11 against 7.66 root nodules/seedling in control). Chlorpyriphos treatments (with Rhizobium and with Rhizobium + Trichoderma ) exhibited detrimental effect on root nodules [T_3= 8.66; T_6= 7.33 as against T_7 (with biofertiliser)= 11 root nodules/seedling]. Imidacloprid and fipronil both termiticidal seed treatments (along with biofertilizer and biofungicide ) showeded better root nodulation. Thus, these combinatorial treatments can further be taken for field validation.

In pulses, seed is also inoculated with adapted, efficient N_2-fixing strain of Rhizobium to ensure symbiotic efficiency for adequate nodulation and nitrogen fixation. Several workers reported that at recommended rate of application, these fungicides and insecticides have no suppressive effects on the growth parameters of legumes (Ghosh et al. 2003, Guene et al. 2004). On the other hand, fungicide and insecticides may adversely affect the legume- Rhizobium symbiosis, by inhibition of survival of the applied rhizobia on seed at sowing time. This may lead to slow establishment of rhizobia in the rhizosphere, which may reduce nodulation and N_2 fixation. Recently, Fox et al. (2007)
observed that pesticides chrysirin, methyl parathion, DDT, bisphenol A and pentachlorophenol reduced symbiotic efficiency of rhizobia in alfalfa. Keeping this in view, the compatibility of fungicide, insecticide and inoculant strain of *Rhizobium* was evaluated *in vitro* in chickpea and effect on germination, seedling lengths, and vigour indices were observed.
Fig 5.1.

Effect of combinatorial seed treatments on root nodulation of chickpea seedlings.
In control the germination recorded was 96.03 per cent, in all other combinatorial treatments viz., T₁ (imidacloprid @5ml/kg + *Bradyrhizobium*), T₂ (fipronil @5ml/kg + *Bradyrhizobium*), T₃ (chlorpyriphos @10ml/kg + *Bradyrhizobium*), T₄ (imidacloprid @5ml/kg + *Trichoderma* + *Bradyrhizobium*), T₅ (fipronil @4ml/kg + *Trichoderma* + *Bradyrhizobium*), T₆ (chlorpyriphos @2ml/kg + *Trichoderma* + *Bradyrhizobium*) as mentioned in Table 5.4; the recorded germination ranged between 88.07 to 96.23 per cent. Treatments T₃ and T₆ showed detrimental effect as there was substantial reduction in germination. But the germination percentage were above the 70% which is minimum seed germination standard according to ISTA (2008). So these combinations can be recommended for field validation trials. For T₂ and T₅ (including fipronil), the germination percentage were at par with control.

Vigour indices I and II were 2577.65 and 78.13 respectively when the seeds were treated with *Bradyrhizobium*, as expected there was increased growth and development which is very much clear from their values of total length and vigour indices I and II as compared to corresponding values 26.83, 2577.07 and 67.22 in control.

When seeds were treated with imidacloprid (5ml/kg) and *Bradyrhizobium*, recorded seedling parameters were still increased showing higher degree of compatibility. When imidacloprid was taken along with *T. harzianum* and *Bradyrhizobium*; same positive trend was maintained with statistical significance. Higher seedling length and vigour indices imply possible phytotonic impact. Thus it is inferred that imidacloprid can be taken safely along with *T. harzianum* and *Bradyrhizobium*.

Fipronil when taken in combination with *Trichoderma* and *Bradyrhizobium*, exhibited slight decrease in germination but it is above the ISTA recommendation. Other parameters like root and shoot length and vigour indices are at par or better. Fipronil + *T. harzianum* + *Bradyrhizobium* was thus proved effective and compatible combination based on the test parameters as presented in Table 5.4.
Table 5.4.

Germination percentage, seedling length and vigour indices for various seed-treatments (in combination: insecticide, bio-fungicide and bio-fertilizer) in groundnut var. ‘TAG-24’

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root length (cm)</th>
<th>Shoot length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour Index-I</th>
<th>Vigour Index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁:im+rhizo</td>
<td>96.23&lt;sub&gt;a&lt;/sub&gt; [78.78]</td>
<td>14.47&lt;sub&gt;abc&lt;/sub&gt; (3.93)</td>
<td>14.93&lt;sub&gt;a&lt;/sub&gt; (3.99)</td>
<td>29.40&lt;sub&gt;ab&lt;/sub&gt; (5.51)</td>
<td>2829.10&lt;sub&gt;ab&lt;/sub&gt; (53.2)</td>
<td>84.36&lt;sub&gt;b&lt;/sub&gt; (9.24)</td>
</tr>
<tr>
<td>T₂:fip+rhizo</td>
<td>96.00&lt;sub&gt;a&lt;/sub&gt; [78.45]</td>
<td>14.00&lt;sub&gt;bc&lt;/sub&gt; (3.87)</td>
<td>12.47&lt;sub&gt;b&lt;/sub&gt; (3.67)</td>
<td>26.47&lt;sub&gt;c&lt;/sub&gt; (5.24)</td>
<td>2540.90&lt;sub&gt;c&lt;/sub&gt; (50.42)</td>
<td>77.76&lt;sub&gt;c&lt;/sub&gt; (8.88)</td>
</tr>
<tr>
<td>T₃:chl+rhizo</td>
<td>88.07&lt;sub&gt;c&lt;/sub&gt; [69.77]</td>
<td>11.37&lt;sub&gt;d&lt;/sub&gt; (3.52)</td>
<td>9.13&lt;sub&gt;c&lt;/sub&gt; (3.18)</td>
<td>20.50&lt;sub&gt;d&lt;/sub&gt; (4.64)</td>
<td>1804.81&lt;sub&gt;d&lt;/sub&gt; (42.49)</td>
<td>56.07&lt;sub&gt;f&lt;/sub&gt; (7.55)</td>
</tr>
<tr>
<td>T₄:im+tri+rhizo</td>
<td>95.50&lt;sub&gt;b&lt;/sub&gt; [78.49]</td>
<td>14.97&lt;sub&gt;a&lt;/sub&gt; (4.00)</td>
<td>15.30&lt;sub&gt;a&lt;/sub&gt; (4.04)</td>
<td>30.27&lt;sub&gt;a&lt;/sub&gt; (5.59)</td>
<td>2890.31&lt;sub&gt;a&lt;/sub&gt; (53.77)</td>
<td>87.22&lt;sub&gt;a&lt;/sub&gt; (9.39)</td>
</tr>
<tr>
<td>T₅:fip+tri+rhizo</td>
<td>94.43&lt;sub&gt;b&lt;/sub&gt; [76.43]</td>
<td>14.53&lt;sub&gt;ab&lt;/sub&gt; (3.94)</td>
<td>12.40&lt;sub&gt;b&lt;/sub&gt; (3.66)</td>
<td>26.93&lt;sub&gt;c&lt;/sub&gt; (5.29)</td>
<td>2543.34&lt;sub&gt;c&lt;/sub&gt; (50.43)</td>
<td>74.29&lt;sub&gt;d&lt;/sub&gt; (8.68)</td>
</tr>
<tr>
<td>T₆:chl+tri+rhizo</td>
<td>88.50&lt;sub&gt;c&lt;/sub&gt; [70.15]</td>
<td>11.77&lt;sub&gt;d&lt;/sub&gt; (3.57)</td>
<td>8.30&lt;sub&gt;d&lt;/sub&gt; (3.05)</td>
<td>20.07&lt;sub&gt;d&lt;/sub&gt; (4.59)</td>
<td>1775.99&lt;sub&gt;d&lt;/sub&gt; (42.15)</td>
<td>54.28&lt;sub&gt;g&lt;/sub&gt; (7.44)</td>
</tr>
<tr>
<td>T₇:rhizo</td>
<td>96.07&lt;sub&gt;a&lt;/sub&gt; [78.54]</td>
<td>14.23&lt;sub&gt;abc&lt;/sub&gt; (3.90)</td>
<td>14.57&lt;sub&gt;a&lt;/sub&gt; (3.95)</td>
<td>28.80&lt;sub&gt;a&lt;/sub&gt; (5.28)</td>
<td>2766.65&lt;sub&gt;b&lt;/sub&gt; (52.61)</td>
<td>78.13&lt;sub&gt;e&lt;/sub&gt; (8.90)</td>
</tr>
<tr>
<td>T₈:Control</td>
<td>96.03&lt;sub&gt;a&lt;/sub&gt; [78.49]</td>
<td>14.03&lt;sub&gt;bc&lt;/sub&gt; (3.88)</td>
<td>12.80&lt;sub&gt;b&lt;/sub&gt; (3.71)</td>
<td>26.83&lt;sub&gt;b&lt;/sub&gt; (5.46)</td>
<td>2577.07&lt;sub&gt;c&lt;/sub&gt; (50.77)</td>
<td>67.22&lt;sub&gt;e&lt;/sub&gt; (8.26)</td>
</tr>
</tbody>
</table>

SE(d) = 0.798
CD (P=0.05) = 1.71

[im=imidaclorp 48%FS (@ 5ml/kg), fip=fipronil5FS (@ 5ml/kg); chl=chlorpyriphos20EC(@ 6ml/kg), tri=T. harzianum (@ 4g/kg); & rhizo=Bradyrhizobium (@ 25 g/kg seed)]

Figures in parentheses [  ] are arcsine-transformed values and in parentheses (  ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
**Soybean** (Table 5.5 & Plate 4.1 & 5.1)

In control the germination is 96.44 per cent, in all other tested combinatorial treatments T₁ (imidacloprid @4ml/kg + *Rhizobium japonicum*), T₂ (fipronil @3ml/kg + *R. japonicum*), T₃ (chlorpyriphos @4ml/kg + *R. japonicum*), T₄ (imidacloprid @4ml/kg + *Trichoderma* + *Bradyrhizobium*), T₅ (fipronil @3ml/kg + *Trichoderma* + *R. japonicum*), T₆ (chlorpyriphos @4ml/kg + *Trichoderma* + *R. japonicum*); the germination range were 83.33 to 97.39 per cent. T₃ and T₆ showed detrimental effect and the substantial reduction in germination percentage were recorded, however the germination percentage were >75% which is minimum seed germination standard according to ISTA. However, decision is to be taken based on other parameters as well (i.e. vigour indices). Combinations including chlorpyriphos resulted in decrease in germination (quantitative). Qualitatively pale yellow colour of seedlings (Plate 5.5) and reduced growth rate, which are statistically significant with control values indicates compatibility problem with *R. japonicum* and *Trichoderma*. For treatments with fipronil (T₂ and T₅), the germination percentage were affected slightly but not as much as in T₃ and T₆.

The total seedling length was 34.87 cm in control. Vigour indices I and II were 3362.58 and 57.58 respectively. When the seeds were treated with *R. japonicum*, as expected there was increased growth and development which is clear from values of total length (37.07 cm) and vigour indices I and II (3540.78, 75.58) as shown in Table 5.5.

When seeds were treated with imidacloprid (4ml/kg) and *R. japonicum*, the recorded seedling parameters were still better showing higher degree of compatibility. When imidacloprid was taken along with *T. harzianum* and *R. japonicum*, same positive trend is maintained with statistical significance. The higher values of seedling length and vigour indices implies possible phytotonic impact. Thus, it is inferred that imidacloprid can be taken along with *T. harzianum* and *R. japonicum* for higher growth rate and dry weight accumulation.
Table 5.5.
Germination percentage, seedling length and vigour indices for various seed-treatments (in combination: insecticide, bio-fungicide and biofertilizer) in soybean var. ‘DS 9712’

<table>
<thead>
<tr>
<th>Treatments details</th>
<th>Germination (%)</th>
<th>Root Length (cm)</th>
<th>Shoot Length (cm)</th>
<th>Total length (cm)</th>
<th>Vigour index-I</th>
<th>Vigour index-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁:im+rhizo</td>
<td>97.39&lt;sup&gt;a&lt;/sup&gt; [80.68]</td>
<td>21.70&lt;sup&gt;a&lt;/sup&gt; (4.76)</td>
<td>18.13&lt;sup&gt;b&lt;/sup&gt; (4.37)</td>
<td>39.57&lt;sup&gt;b&lt;/sup&gt; (6.37)</td>
<td>3853.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.20&lt;sup&gt;a&lt;/sup&gt; (8.9)</td>
</tr>
<tr>
<td>T₂:fip+rhizo</td>
<td>91.67&lt;sup&gt;c&lt;/sup&gt; [73.24]</td>
<td>19.70&lt;sup&gt;b&lt;/sup&gt; (4.55)</td>
<td>16.3&lt;sup&gt;c&lt;/sup&gt; (4.16)</td>
<td>36.67&lt;sup&gt;c&lt;/sup&gt; (6.14)</td>
<td>3359.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>61.37&lt;sup&gt;d&lt;/sup&gt; (7.9)</td>
</tr>
<tr>
<td>T₃:chl+rhizo</td>
<td>84.43&lt;sup&gt;d&lt;/sup&gt; [66.74]</td>
<td>16.6&lt;sup&gt;d&lt;/sup&gt; (4.20)</td>
<td>13.7&lt;sup&gt;e&lt;/sup&gt; (3.83)</td>
<td>30.63&lt;sup&gt;e&lt;/sup&gt; (5.62)</td>
<td>2586.37&lt;sup&gt;d&lt;/sup&gt;</td>
<td>46.43&lt;sup&gt;f&lt;/sup&gt; (6.89)</td>
</tr>
<tr>
<td>T₄:im+tri+rhizo</td>
<td>96.03&lt;sup&gt;ab&lt;/sup&gt; [78.49]</td>
<td>21.81&lt;sup&gt;a&lt;/sup&gt; (4.78)</td>
<td>19.1&lt;sup&gt;a&lt;/sup&gt; (4.48)</td>
<td>41.27&lt;sup&gt;a&lt;/sup&gt; (6.50)</td>
<td>3962.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.75&lt;sup&gt;a&lt;/sup&gt; (8.93)</td>
</tr>
<tr>
<td>T₅:fip+tri+rhizo</td>
<td>93.11&lt;sup&gt;c&lt;/sup&gt; [74.77]</td>
<td>20.63&lt;sup&gt;ab&lt;/sup&gt; (4.65)</td>
<td>15.67&lt;sup&gt;d&lt;/sup&gt; (4.08)</td>
<td>36.31&lt;sup&gt;c&lt;/sup&gt; (6.11)</td>
<td>3380.36&lt;sup&gt;c&lt;/sup&gt;</td>
<td>68.90&lt;sup&gt;e&lt;/sup&gt; (8.36)</td>
</tr>
<tr>
<td>T₆:chl+tri+rhizo</td>
<td>83.33&lt;sup&gt;d&lt;/sup&gt; [65.88]</td>
<td>17&lt;sup&gt;d&lt;/sup&gt; (4.24)</td>
<td>13.5&lt;sup&gt;e&lt;/sup&gt; (3.81)</td>
<td>30.83&lt;sup&gt;e&lt;/sup&gt; (5.64)</td>
<td>2569.67&lt;sup&gt;d&lt;/sup&gt;</td>
<td>56.39&lt;sup&gt;f&lt;/sup&gt; (7.58)</td>
</tr>
<tr>
<td>T₇:rhizo</td>
<td>95.17&lt;sup&gt;b&lt;/sup&gt; [77.45]</td>
<td>20.73&lt;sup&gt;ab&lt;/sup&gt; (4.66)</td>
<td>16.7&lt;sup&gt;c&lt;/sup&gt; (4.21)</td>
<td>37.07&lt;sup&gt;c&lt;/sup&gt; (6.17)</td>
<td>3540.78&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75.58&lt;sup&gt;b&lt;/sup&gt; (8.75)</td>
</tr>
<tr>
<td>T₈:Control</td>
<td>96.44&lt;sup&gt;ab&lt;/sup&gt; [79.14]</td>
<td>18.47&lt;sup&gt;c&lt;/sup&gt; (4.73)</td>
<td>16.23&lt;sup&gt;c&lt;/sup&gt; (4.15)</td>
<td>34.87&lt;sup&gt;d&lt;/sup&gt; (5.99)</td>
<td>3362.58&lt;sup&gt;c&lt;/sup&gt;</td>
<td>57.58&lt;sup&gt;e&lt;/sup&gt; (7.67)</td>
</tr>
<tr>
<td>SE(d)</td>
<td>1.071</td>
<td>0.07</td>
<td>0.03</td>
<td>0.048</td>
<td>0.437</td>
<td>0.029</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>[2.29]</td>
<td>(0.14)</td>
<td>(0.06)</td>
<td>(0.1)</td>
<td>(0.93)</td>
<td>(0.06)</td>
</tr>
</tbody>
</table>

[im=imidacloprid 48%FS (@ 4ml/kg), fip=fipronil5FS (@ 3ml/kg); chl=chlorpyriphos20EC(@ 4ml/kg), tri=T. harzianum (@ 4g/kg); & rhizo=Rhizobium japonicum (@ 25 g/kg seed)]

Figures in parentheses [ ] are arcsine-transformed values and in parentheses ( ) are square root transformed values. Figures are mean of 3 replicates (each replication=100 seeds). Figures in the same column followed by the same lowercase letters are not significantly different (P=0.05)
Plate-5.2
Effect of insecticides on root nodulation in Chickpea

Increase nodulation after treatment with imidacloprid + Trichoderma + Rhizobium

Decrease nodulation after treatment with chlorpyrifos + Trichoderma + Rhizobium
5.5. Conclusion

India has successfully reduced pesticide consumption without adversely affecting the agricultural productivity. This was facilitated by appropriate policies that discouraged pesticide use, and favoured IPM application. *Total Seed Treatment Campaign* is the noteworthy governmental policy in this aspect. However, it can be mentioned here that in real field situations the demands may be different. Simply advocating insecticidal treatments to farmers may not cater to the real field demand. In multi-pests and diseases conditions, combinatorial seed treatments may be required, for which this investigation is a real pioneer work for the farming community. Inclusion of the biofertilisers in the combination test still makes the seed-treatment package more realistic in a holistic-approach in view of ICM (Integrated Crop Management). Even though, this work is carried out under the M.Sc. thesis, and in vitro, the recommendations are to be taken to the field for ground reality validation. This work was supported by the National Fellow ICAR project, and field trials will be carried in future under the NF Project.

Acknowledgements

The senior author is grateful to Indian Council of Agricultural Research for providing fellowship throughout M.Sc. programme. Due acknowledgement is also expressed to the authorities of Divisions of Entomology, Seed Science & Technology, Microbiology, Plant Pathology and Genetics, and Central Library of IARI for providing necessary facilities for undertaking this study.
General Discussion
In the era of IPM and ICM (Integrated Pest Management & Integrated Crop Management), the issue of seed treatment has become more complex in the context of combinatorial approach of insecticides, fungicides (biofungicides), and biofertilisers. Compatibility of these pesticides for an effective recommendation is the crucial issue targeted in our investigation in few selected field crops of national importance. Recommendations of seed treatment for various crops are offered by Government of India on cereal crops - rice, wheat, barley; vegetables (potato, tomato, chilli, okra, leguminous and cruciferous crops), pulses (gram, pigeon pea, pea) and others (sugarcane, coriander, sunflower) etc. under its most ambitious programme Seed Treatment Campaign 2007. In this investigation, the five target crops are cereals (wheat, maize), pulse (chickpea) and oilseeds (groundnut, soybean). The study aimed at two-fold objectives; namely (1) to study the effect of different concentration of insecticide on germination percentage, root length, shoot length and vigour index of seedlings of target crops; and (2) to check the compatibility of insecticides, bio-fertilizer and bio-fungicide commonly used in seed treatment for selected crops, so as to verify seed treatment compatibility in IPM.

Research endeavours are directed to formulate the *eco-friendly and IPM-compatible seed treatment packages* for major field crops for sucking pests in general and against termites in particular. Three insecticides – chlorpyriphos, fipronil and imidacloprid were verified at three doses for their deleterious effects on the treated seedlings. One recommended test-dose of insecticides was taken and its compatibility is checked with bioagents–biofertilisers and biofungicide (*T. harzianum*). In chickpea and maize, supporting rapid tetrazolium tests were conducted to verify the hard and dead seeds in ungerminated seeds. Taking the results of insecticidal seed treatments (one dose from each insecticide), combinatorial efficacy and compatibility of insecticides were investigated *in vitro*, along with biofungicides and biofertilisers. Bio-fertilisers (*Azotobacter, Azospirillum, Mesorhizobium, Bradyrhizobium and R. japonicum*); and bio-control agent (biofungicide, *T. harzianum*) were taken as per the standard recommended
doses of 25 g/kg and @ 4 g/kg of test crop-seeds, respectively. This investigation outcome advocates the following crop-specific eco-friendly recommendations for effective, compatible combinatorial seed treatment measures. Supporting pot trial for pulse crop (chickpea) was carried out to verify the effect of various combination treatments on root nodulations. Pot trials are also undertaken in pulse (chickpea) to substantiate the adverse effect of various combinatorial seed-treatments on root nodulation. Crop-specific seed treatment specifications found safe and recommendable without deleterious effects to seedlings are offered alone (insecticides) as well as in combination:

Table- 6.1- Recommended doses of test insecticides based on in vitro investigation

<table>
<thead>
<tr>
<th>Target-crop</th>
<th>Insecticide alone</th>
<th>Recommendation based on in vitro investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose (ml/kg seeds)</td>
<td>Insecticide +Biofertiliser</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Imidacloprid</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fipronil</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Chlorpyriphos</td>
<td>2</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Imidacloprid</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Fipronil</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Chlorpyriphos</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Chickpea</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Imidacloprid</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Fipronil</td>
<td>5</td>
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<td>Groundnut</td>
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<td>3</td>
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<tr>
<td></td>
<td>Chlorpyriphos</td>
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</tbody>
</table>

C = Compatible, NC = Not compatible

These recommendations may be tested for the field level efficacy, and the insecticides tested here are termiticides, but recommendations can well be used for sucking insect pests as well in the target-crops.
In real field situations the demands for combinatorial seed treatments are quite relevant. Simply advocating insecticidal treatments to farmers may not cater to the relevant field demand. In multi-pests and diseases conditions, combinatorial seed treatments may be required, for which this investigation is a real pioneer work for the farming community. Inclusion of the biofertilisers in the combination test still makes the seed-treatment package more realistic in a holistic-approach in view of ICM (Integrated Crop Management). These *in-vitro* investigation based eco-friendly recommendations may to be taken to the field for ground reality validation. While discussing the contemporary scenario of pests and pesticides in India Gupta *et al.* (2009) suggested that pesticide-load to environment can substantially be reduced following zero-spray strategy like spot or local treatment and seed treatment tactics. Eco-friendly and sustainable development can be attained with right pesticides at right time and right dose following right methodology. This investigation is a way forward in this context.

Few scientists reported the effect of seed treatment chemicals on wheat seed germination *in vitro*. The reaction of seed treatment chemicals reported in germination of other crops like groundnut (Narasimhulu and Kameswara Rao, 1989), chickpea (Chaudhary and Dashad, 2002), green gram (Dhillon *et al.*, 2001), safflower and sesame (Charjan and Tarar, 1993) and okra (Gaikwad and Pawar, 1979).

For seed treatment in wheat, chlorpyriphos @4ml/kg seed was recommended by Directorate of Plant Protection, Quarantine & Storage ‘DPPQR&S’, 2001. Laboratory trials also indicated that higher doses (9ml/kg) of chlorpyriphos significantly inhibited the germination both *in vitro* and pot culture (Sithik, 2012). Bhanot *et al.* (1991) reported the effect of seed treatment with different insecticides on germination and damage by termite (*M. obesi*) and grain yields in wheat and chlorpyriphos 20 EC (1.5 ml/kg) was recommended for termite control in wheat.

For wheat fipronil 4ml/kg seed is found very effective causing least detrimental effect on seedling growth. Our result is in accordance with that of Shukla (2010). In this they have conducted an insecticidal seed treatment trial both in laboratory and field and evaluated chlorpyriphos 20EC, imidacloprid 200SL and fipronil 5FS @ 4, 5 and 6 ml/kg.
of seed, and observed fipronil 5 ml/kg as the best treatment based on germination percentage.

Imidacloprid is found to be phytotonic on seedlings of all test crops. Our result is in accordance with that of Jarande and Dethe (1994). They found phytotonic effect in cotton crop.

In chickpea (Chaudhary and Dashad, 2002), reported that chlorpyriphos @ 7ml/kg seed have deleterious effect on seed germination. Our result is in accordance with that of Kashyap et al. (1994) reported effect of chlopyriphos 20EC @ 1.5 ml/kg seed and same is recommended for seed treatment.

Cheema et al., (2009) a field experiment was conducted during 2005–08 to test the compatibility of the insecticide chlorpyrifos applied as seed treatment for the control of termites in chickpea (Cicer arietinum L.) with recommended fungicide Captan and Rhizobium inoculant. Insecticides chlorpyrifos @ 10 ml/kg seed had no adverse effect on germination, nodulation when applied alone or in combination with the recommended fungicide Captan and Rhizobium inoculant, thus, indicating the compatibility amongst all the 3 components, viz. insecticide, fungicide and Rhizobium inoculant for seed treatment in chickpea. However our result is contrary to this result in which we found that chlorpyriphos 20EC @7ml/kg cause detrimental effect on nodulation which resulted in reduce nodulation.

Rubens et al, (2009) conducted one experiment in that the compatibility between seed treatment with fungicides in single or mixed applications (including Benomyl, Captan, Carbendazin, Carboxin, Difenoconazole, Thiabendazole, Thiram, Tolyfluanid) and bradyrhizobial inoculants was examined in laboratory, greenhouse and field experiments in Brazil. Bacterial survival on the seeds was severely affected by all fungicides, resulting in mortalities of up to 62% after only 2 h and of 95% after 24 h. Fungicides also reduced nodule number, total N in grains and decreased yield by up to 17%. Regarding the future thrust, effect of seed treatment chemicals against insect pests can be verified in the field. The biochemical basis of compatibility maybe analyzed. Reasons for phytotonic/phytotoxic effect of chemical on seedling can be tested in depth.
Summary and Conclusion
7. SUMMARY AND CONCLUSION

This *in vitro* investigation was carried out in order to develop *Eco-friendly and IPM-compatible seed treatment packages* for major field crops against termites. Three insecticides particularly recommended for termites – chlorpyriphos, fipronil and imidacloprid were verified as seed treatment at three doses for their deleterious effects on the emerged seedlings. One recommended test-dose of insecticide from each was taken and its compatibility is checked with bioagents- biofertilisers and biofungicide (*Trichoderma harzianum*). Bio-fertilisers (*Azotobacter, Azospirillum, Mesorhizobium, Bradyrhizobium and Rhizobium japonicum*); and bio-control agent (biofungicide, *T.harzianum*) were taken as per the standard recommended doses of 25 g/kg and @ 4 g/kg of test crop-seeds, respectively. Test-crops taken are wheat, maize, chickpea, groundnut and soybean. *In vitro* investigation was inclusive of the standard germination test adopting in between paper method (Agarwal, 1995). In chickpea and maize, supporting rapid tetrazolium tests were conducted to verify the hard and dead seeds in ungerminated seeds. Pot trials is also undertaken in pulse (chickpea) to substantiate the adverse effect of various combinatorial seed-treatments on root nodulation.

Crop-specific seed treatment specifications found safe and recommendable without deleterious effects to seedlings are:

**Insecticides alone** -

Wheat – imidacloprid @ 3-5; fipronil @ 4 and chlorpyriphos @2 ml/kg seeds.

Maize - imidacloprid @ 1.5-5; fipronil @ 5 ml/kg seeds. Chlorpyriphos is not recommended.

Chickpea – imidacloprid @ 5-10; fipronil @ 5-7 and chlorpyriphos @7 ml/kg seeds.

Groundnut – imidacloprid @ 3-7; fipronil @ 5 and chlorpyriphos @6 ml/kg seeds.

Soybean – imidacloprid @ 4-6; fipronil @ 3-5 and chlorpyriphos @4 ml/kg seeds.
Combinatorial approach –

**Wheat:** 1) Imidacloprid @3ml/kg + Azotobacter. 2) imidacloprid @3ml/kg + Trichoderma+Azotobacter. 3) fipronil @4ml/kg + Azotobacter. 4) fipronil @4ml/kg, Trichoderma+Azotobacter.

**Maize:** 1) Imidacloprid @3ml/kg + Azospirillum. 2) imidacloprid @3ml/kg + Trichoderma +Azospirillum. 3) fipronil @5ml/kg + Azospirillum. 4) fipronil @5ml/kg + Trichoderma +Azospirillum.

**Chickpea:** 1) Imidacloprid @5ml/kg + Mesorhizobium. 2) imidacloprid @5ml/kg + Trichoderma +Mesorhizobium. 3) fipronil @5ml/kg + Mesorhizobium. 4) fipronil @5ml/kg + Trichoderma +Mesorhizobium.

**Groundnut:** 1) Imidacloprid @5ml/kg + Bradyrhizobium. 2) imidacloprid @5ml/kg + Trichoderma +Bradyrhizobium. 3) fipronil @5ml/kg + Bradyrhizobium. 4) fipronil @5ml/kg + Trichoderma + Bradyrhizobium.

**Soybean:** 1) Imidacloprid @4ml/kg + R. japonicum. 2) imidacloprid @5ml/kg + Trichoderma + R. japonicum. 3) fipronil @3ml/kg + R. japonicum. 4) fipronil @3ml/kg + Trichoderma + R. japonicum.

These recommendations may be tested for the field level efficacy, and the insecticides tested here are termiticides, but recommendations can well be used for sucking insect pests as well in the target-crops.

India has successfully reduced pesticide consumption without adversely affecting the agricultural productivity. This was facilitated by appropriate policies that discouraged pesticide use, and favoured IPM application. *Total Seed Treatment Campaign* is the noteworthy governmental policy in this aspect. However, it can be mentioned here that in real field situations the demands may be different. Simply advocating insecticidal treatments to farmers may not cater to the relevant field demand. In multi-pests and diseases conditions, combinatorial seed treatments may be required, for which this investigation is a real pioneer work for the farming community. Inclusion of the biofertilisers in the combination test still makes the seed-treatment package more realistic in a holistic-approach in view of ICM (Integrated Crop Management). These *in vitro*
investigation based eco-friendly recommendations may to be taken to the field for ground reality validation.
Abstract
Eco-friendly and IPM-compatible seed treatments for some field crops against termites

Seed treatment plays crucial role in protecting the emerging seedlings from insect-pests and diseases. Recommendations of seed treatment for various crops are offered by Government of India under its most ambitious programme Total Seed Treatment Campaign 2007. Use of seed treatments in crops like wheat, maize, chickpea, groundnut and soybean has increased considerably over the past few years. But mostly the field recommendations are not based/supported by in vitro tests. Laboratory evaluations were made with three insecticides – imidacloprid (600FS), fipronil (5FS) and chlorpyriphos (20EC) (each at three doses) to verify deleterious effects of test-doses for the test-crops, following in between paper method. In chickpea and maize, supporting rapid tetrazolium tests were conducted to verify the hard and dead seeds in ungerminated seeds. Phytotoxicity is observed in chlorpyriphos treatments; interestingly imidacloprid exhibited phytotoxic effects on the emerged seedlings of all test crops.

Following seed-treatment-recommendations are safe as no deleterious effects to seedlings are observed.

Wheat – imidacloprid@ 3-5; fipronil@ 4 and chlorpyriphos @2 ml/kg seeds.

Maize - imidacloprid@ 1.5-5; fipronil @ 5 ml/kg seeds. Chlorpyriphos is not recommended.

Chickpea – imidacloprid@ 5-10; fipronil @ 5-7 and chlorpyriphos @7 ml/kg seeds.

Groundnut – imidacloprid@ 3-7; fipronil @ 5 and chlorpyriphos @6 ml/kg seeds.

Soybean – imidacloprid@ 4-6; fipronil @ 3-5 and chlorpyriphos @4 ml/kg seeds.

These seed-treatment rates may be tried for further field validation for concerned insect-pests to be controlled. Taking the results of insecticidal seed treatments (one dose
from each insecticide), combinatorial efficacy and compatibility of insecticides were investigated in vitro, along with biofungicides and biofertilisers. Bio-fertilisers (Azotobacter, Azospirillum, Mesorhizobium, Bradyrhizobium and Rhizobium japonicum); and biocontrol agent (biofungicide Trichoderma harzianum) were taken as per the standard recommended doses of 25 g/kg and @ 4 g/kg of of test-crop seeds, respectively. The in-between paper method is followed and this investigation outcome advocates the following crop-specific recommendations for effective compatible combinatorial seed treatment measures. Supporting pot trial for pulse crop (chickpea) was carried out to verify the effect of various combination treatments on root nodulations.

Wheat: 1) Imidacloprid @3ml/kg + Azotobacter. 2) imidacloprid @3ml/kg + Trichoderma + Azotobacter. 3) fipronil @4ml/kg + Azotobacter. 4) fipronil @4ml/kg, Trichoderma + Azotobacter.

Maize: 1) Imidacloprid @3ml/kg + Azospirillum 2) imidacloprid @3ml/kg + Trichoderma + Azospirillum 3) fipronil @5ml/kg + Azospirillum 4) fipronil @5ml/kg + Trichoderma + Azospirillum.

Chickpea: 1) Imidacloprid @5ml/kg + Mesorhizobium. 2) imidacloprid @5ml/kg + Trichoderma + Mesorhizobium. 3) fipronil @5ml/kg + Mesorhizobium. 4) fipronil @5ml/kg + Trichoderma + Mesorhizobium.

Groundnut: 1) Imidacloprid @5ml/kg + Bradyrhizobium 2) imidacloprid @5ml/kg + Trichoderma + Bradyrhizobium 3) fipronil @5ml/kg + Bradyrhizobium 4) fipronil @5ml/kg + Trichoderma + Bradyrhizobium.

Soybean: 1) Imidacloprid @4ml/kg + R. japonicum 2) imidacloprid @5ml/kg + Trichoderma + R. japonicum 3) fipronil @3ml/kg + R. japonicum 4) fipronil @3ml/kg + Trichoderma + R. japonicum.

These recommendations may be tested for the field level efficacy, and the insecticides tested here are essentially termiticides, but recommendations can well be used for sucking insect pests as well in the target-crops.
कुछ फसलों हेतु दीमकों के विरुद्ध पर्यावरण-मित्र एवं आई पी एम संगत बीजोपचार

सार

नवोदितों को कीट-पीड़कों एवं रोगों से सुरक्षा प्रदान करने में बीजोपचार महत्वपूर्ण भूमिका निभाता है। उपने सर्वाधिक महत्वाकांक्षी कार्यक्रम, 'सकल बीज-उपचार कंप्यूटर 2007', के अन्तर्गत भारत सरकार ने अनेक फसलों हेतु बीजोपचार की संस्थानीय की हैं। विस्तार कुछ वर्षों में, कुछ फसलों यथा, गेहूँ, मक्का, चना, मूंगफली एवं सोयबीन में बीजोपचारों का उपयोग उल्लेखनीय रूप से बढ़ा हैं किन्तु अधिकांशतः, प्रक्षेत्र संस्थानीय, सजीव कोशिकाओं के बाहर किए गए प्रयोगशाला प्रयोगों से आधारित/समर्थित नहीं होती हैं। परीक्षण-फसलों में परीक्षण-सुरक्षा के विषेष प्रभावों की पुष्टि करने के लिए तीन कीटनाशियाँ— इमिडाक्लोप्रिड (600 एफ एस), फायरनिल (5 एफ एस) एवं क्लोरपरायीफोस (20 ए एस) (प्रत्येक की 3 सुरक्षा के साथ) का प्रयोगशाला में मूल्यांकन किया गया तथा तत्पश्चात कागजों के बीच अंकुरण विधि का अनुप्रयोग किया गया। चने एवं मक्का में अनकुरित बीजों में सतर्क एवं मृत बीजों की पहचान हेतु त्वरित टेट्राजोलियम परीक्षण किए गए। क्लोरपरायीफोस उपचारों में पादपविशिष्टता देखी गई जबकि इमिडाक्लोप्रिड ने नवोदितों पर फायरटोपिनिक प्रभाव दर्शाएं संस्थानीय किए गए निम्नलिखित बीजोपचार सुरक्षित हैं क्योंकि पौध पर कोई विषेष प्रभाव नहीं देखे गए।

गेहूँ— इमिडाक्लोप्रिड 3–5; फायरनिल 4 एवं क्लोरपरायीफोस 2 मिली प्रति कि ग्रा बीज की दर से।

मक्का— इमिडाक्लोप्रिड 1.5–5 एवं फायरनिल 5 मिली/कि ग्रा बीज की दर से।
क्लोरपरायीफोस की संस्थानीय की गई है।

चना— इमिडाक्लोप्रिड 5–10; फायरनिल 5 एवं क्लोरपरायीफोस 7 मिली प्रति कि ग्रा बीज की दर से।

मूंगफली— इमिडाक्लोप्रिड 3–7; फायरनिल 5 एवं क्लोरपरायीफोस 6 मिली प्रति कि ग्रा बीज की दर से।

सोयबीन— इमिडाक्लोप्रिड 4–6; फायरनिल 3–5 एवं क्लोरपरायीफोस 4 मिली प्रति कि ग्रा बीज की दर से।
जिन कीट-पीड़कों का नियंत्रण किया जाना है, उनके सन्दर्भ में इन बीजोपचार दरों को आगे खेल में पुष्टि की जा सकती है। कीटनाशियाँ द्वारा बीजोपचार के इन परिणामों (प्रत्येक कीटनाशी की एक दर) को ध्यान में रखते हुए, जैविक कककनाशियों के साथ संगतता का अध्ययन किया गया। जैव-उद्योग (एजेंटीबैक्टर एजेंस्ट्राफायरिस्म, मीजेजोजोरियम, ब्रेडीजाईजोरियम एवं राइजोजोरियम जैनोपोनिकम) एवं जैविक नियंत्रण कार्य (जैविक कककनाशी, ट्रायकोडोर्मा हार्वियनर्म) परीक्षण-फसल बीजों हेतु क्रमशः 25 कि ग्रा पति कि ग्रा एवं 4 ग्रा पति कि ग्रा बीज की संस्तुत मानक दरों का उपयोग किया गया। इसके प्रश्नात इन विद्यमान पेपर विधि (अग्रवाल, 1995) तथा एक प्रभावी संयुक्त बीज बचाव हेतु फसल-विशेष के लिए निम्नलिखित संस्तुतिः की गई। जड़-प्रतियों पर इन संयुक्त बीजोपचारों के प्रभाव को सुनिश्चित करने के लिए दलन फसल (चना) हेतु गमलों में भी ट्रायल किए गए।

सह-1. इमिडाक्लोप्रिड 3 मि ली / जि ग्रा + एजेंटीबैक्टर, 2. इमिडाक्लोप्रिड 3 मि ली / जि ग्रा + ट्रायकोडोर्मा + एजेंटीबैक्टर, 3. फायरोनिल 4 मि ली / जि ग्रा + एजेंटीबैक्टर, 4. फायरोनिल 4 मि ली / जि ग्रा की दर से + ट्रायकोडोर्मा + एजेंटीबैक्टर

सहकर 1. इमिडाक्लोप्रिड 3 मि ली / जि ग्रा + एजेंस्ट्राफायरिस्म, 2. इमिडाक्लोप्रिड 3 मि ली / जि ग्रा + ट्रायकोडोर्मा + एजेंस्ट्राफायरिस्म, 3. फायरोनिल 5 मि ली / जि ग्रा + एजेंस्ट्राफायरिस्म, 4. फायरोनिल 5 मि ली / जि ग्रा बीज की दर से + ट्रायकोडोर्मा + एजेंस्ट्राफायरिस्म

चना 1. इमिडाक्लोप्रिड 5 मि ली / जि ग्रा + मीजेजोजोरियम 2. इमिडाक्लोप्रिड 5 मि ली / जि ग्रा + ट्रायकोडोर्मा + मीजेजोजोरियम 3. फायरोनिल 5 मि ली / जि ग्रा + मीजेजोजोरियम 4. फायरोनिल 5 मि ली / जि ग्रा + ट्रायकोडोर्मा + मीजेजोजोरियम

सूगफली 1. इमिडाक्लोप्रिड 5 मि ली / जि ग्रा + ब्रेडीजाईजोरियम 2. इमिडाक्लोप्रिड 5 मि ली / जि ग्रा + ट्रायकोडोर्मा + ब्रेडीजाईजोरियम 3. फायरोनिल 5 मि ली / जि ग्रा + ब्रेडीजाईजोरियम 4. फायरोनिल 5 मि ली / जि ग्रा बीज की दर से + ट्रायकोडोर्मा + ब्रेडीजाईजोरियम

सोयबीन 1. इमिडाक्लोप्रिड 4 मि ली / जि ग्रा + रा. जैनोपोनिकम, 2. इमिडाक्लोप्रिड 5 मि ली / जि ग्रा + ट्रायकोडोर्मा + रा. जैनोपोनिकम, 3. फायरोनिल 3 मि ली / जि ग्रा + रा. जैनोपोनिकम 4. फायरोनिल 3 मि ली / जि ग्रा बीज की दर से + ट्रायकोडोर्मा + रा. जैनोपोनिकम

खेत स्तर पर इनकी प्रभाविता हेतु इन संस्तुतिः का परीक्षण किया जा सकता है तथा इन अर्थव्यय में परीक्षण किए गए कीटनाशी निश्चित रूप से दीमकनाशी हैं किन्तु चुंबक-कीटपीड़कों एवं लक्षित फसलां हेतु इन संस्तुतिः का उपयोग अवश्य प्रभावी हैं।
Bibliography


DMR (Directorate of Maize), 2009. (www.dmr.res.in assessed on 22 June 2013).


http://www.nrcsoya.nic.in/zonewiseprodtech.html


Kumar, V., Kumar, B.V. and Narula, N. 2001. Establishment of phosphate-solubilizing strains of Azotobacter chroococcum in the rhizosphere and their effect on wheat cultivars under green house conditions. Microbiological Research, 156(2): 87-97.


OPSTAT online, www.hau.ernet.in/opstat.html


www.ficci.com/events (accessed on 07-07-2012)

www.hau.ernet.in/opstat.html (accessed on 01-06-2012)

www.ppqs.gov.in/seedtreatment.html (accessed on 27-11-2011)


*= Original paper not referred