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Research status and scope for biological control of sucking pests in India: Case study of thrips

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ABSTRACT: Thrips are an important group of sucking insects causing substantial yield losses in several tropical crops, as direct pests and/or as virus vectors. In India, thrips are significant pests on vegetables (e.g., chillies, onion), legumes (e.g., cowpeas, groundnuts), cereals (e.g., rice), spices (e.g., cardamom, turmeric), poly-house crops (e.g., rose) and plantation crops (e.g., tea). The emerging interest at national level in organic farming and export agriculture calls for development of appropriate and wide range of eco-friendly and biological products for thrips management. Entomopathogens (like *Verticillium lecani*) have shown promise for augmentative biological control (of *Scirtothrips dorsalis*), and there is scope for identifying more adapted and virulent strains of the entomopathogens, besides developing improved formulations for extending their shelf- and field life. Predators (like *Orius*) have also shown some potential, in natural conditions, but research has to be intensified on aspects like their mass production technology, field attack rate, predation potential, adaptation to physical and chemical stresses, besides biodiversity, tri-trophic interactions and behavioural and chemical ecology. Parasitoids (like *Ceranisus*) are of limited potential as biological control agents and emphasis is needed on their *in situ* conservation strategies, besides cost-effective mass rearing and release systems. Scope exists for strengthening multi-disciplinary approach and inter-institutional collaboration, possibly through working group and network strategies to establish a biological control based thrips management research experts' consortium so as to cater to scientific backstopping and complimentarity in relevant expertise. There is need to focus on research and development (R&D) with public–private partnerships, for widening the range and refining the technology options as well as the integration of different biological control agents with other pest control technologies, besides linking them to the crop management practices so as to evolve holistic Integrated Pest Management (IPM) strategies.

KEY WORDS: Biological control, natural enemies, thrips

INTRODUCTION

In the recent decades in India, there is increasing interest in adopting more of eco-friendly control methods as part of the Integrated Pest Management (IPM) approach. This is due to the build-up of awareness that continued resort to the use of synthetic pesticides is ecologically unsustainable, because of the associated problems of pesticide resistance and resurgence of pests caused by destruction of the native natural enemies of pests. In addition, there is emerging support at national level for promoting export oriented agriculture as well as organic farming as means of capturing niche markets and thus enhance the incomes and livelihood of the rural and farming communities in India. These market-linked farming systems call for adoption of "green" practices for maximising compliance to the regulations in export crops. As such, biological control is being more sought

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after as the major means of ecologically friendly management of insect pests on our agricultural crop ecosystems, especially those of the high value crops.

In the recent decades, there has also been a significant increase in the research and development (R&D) initiatives to promote the development and adoption of biological control technologies in India. Nevertheless, the target pests, which have received emphasis are more of chewing pests, especially lepidoptera, compared to sucking insect pests. It is gratifying that the present symposium is focussed on the latter group. While hemipteran pests are the more common target pests among the sucking insects, thrips offer special challenges and opportunities for biological control, due to their distinct feeding habit and often concealed habitat. Of course, thrips are also a significant production constraint to several agriculturally important including high value and export crops in the tropics. They are known to cause significant crop yield losses both as direct pests due to impaired crop growth and also as vectors of plant pathogens of crops (Ananthakrishnan, 1984).

This paper deals with thrips as case study, reviewing the current research status and future priority research thrusts for improved use of the biological control agents, towards their sustainable management, especially the key pest species of the high value crops in India.

1. Occurrence and economic importance of thrips in agro-ecosystems

1.1. Extent of losses caused in target crops

Ananthakrishnan (1984) has provided a sound analysis of the thrips species diversity associated with several crop ecosystems in India and elsewhere (Table 1). The author has drawn attention to the role of the non-target host plants in the population dynamics of thrips in the target crops. The available estimates of crop losses due to thrips include about 45 – 47 per cent loss in cardamom due to *Sciothrips cardamomi* (Varadarasan, 1995), while in tea, *Scirtothrips bispinosis* has been found to cause about 11-17 per cent loss (Selvasundaram *et al.*, 2004). Kandasamy *et al.* (1990) estimated that about 30 – 50 per cent loss in chillies was caused by *Scirtothrips dorsalis.* Quantitative yield loss due to *S. dorsalis* has also been found to be more than 90 per cent on chilli pepper, compared to 11- 32 per cent in sweet pepper, while quality loss of 88-92% was observed in sweet pepper (Kumar, 1995). In onion, Srinivas *et. al.*, (2004) reported that *Thrips tabaci* could cause yield loss in the range of 46-87 per cent, while Mohite *et al.* (1992) estimated the loss to be around 50 per cent in that crop. In paddy, *Haplolothrips ganglbaueri* has been known to cause 1.6 – 8.1% loss (Nair, 1986; Rao *et al.*, 1997), whereas in green gram *Thrips palmi* caused about 40 per cent loss (Sreekanth *et al.*, 2002).

Nevertheless, there is need to develop baseline data on crop losses caused by thrips in nationally important target crops across a network of benchmark sites, representing the agro-eco-zones of their cultivation. This would lay the foundation for developing bio-control strategies appropriate over space and time besides also providing convincing loss data for policy makers to justify funding the research for their control.

1.2 Effect of weather factors on thrips incidence

The importance of weather factors on thrips population has been studied only to a limited extent. A positive correlation of *S. dorsalis* incidence has been found with maximum temperature and negative association with rainfall, minimum temperature, mean relative humidity and mean vapour pressure in chilli ecosystem (Panickar and Patel, 2001; Varadarasan and Veeravel, 1995). In cotton, *Thrips tabaci* population levels showed significant positive correlation with wind speed, while in pigeon pea, there was significant negative correlation between *Megalurothrip* population and mean temperature (Panickar and Patel 2001). There are studies in which season, as such has an overall influence on the effects of individual weather factors. For instance, the incidence level of *S. dorsalis* on chilli has been reported to be grater during the dry season, when the temperature is 30°C and above, with no rainfall (Lingeri *et al.*, 1998; Manjunath *et al.*, 2001a). In onion, *T. tabaci* showed higher incidence level (78%) in Rabi season crops in Maharashtra (Srinivas and Lawande, 2004). The interaction of phenology with weather factors needs elucidation. For instance, in groundnut, *S. dorsalis* infestation was found to be greater where the drought stress for the crop was less. Thrips incidence was found to subsequently reverse and with the ageing of crop, they became more abundant at the wetter end of the gradient. Incidence of *S. dorsalis* was highest during March – April, with the emergence of new flush (Wheatly *et al.*, 1989). It may be pointed out that while these few studies have shown the potential role of climatic and host phenological factors, there is need for more holistic study of the ecosystem interactions, so as to establish a

Table 1. Examples of thrips and their host plants in India

Thrips species (Common name)	**Host Plant**
Anaphothrips sudanensis Trybom	Cereal crop +
Ayyaria chaetophora Karny	Pulses and Oilseeds ++
Caliothrips indicus (Bagnall)	Pulse crops ++
Frankliniella schultzei (Trybom)	Highly polyphagous pest of economically important plants and transmits tospo virus
Megalurothrips distalis Karny	Pulse crops ++
Canchaetothrips indicus (Bangnall)	Turmeric and Banana +
Retithrips syriacus (Mayet)	Rose, Castor, Cassava + Cotton, Grapevine, Groundnut
Rhipiphorothrips cruentatus Hood (Grapevine thrips)	Grapevine, Rose +
Sciothrips cardamomi Ramak (Cardamom thrips)	Major pest of cardamom
Scirtothrips bispinosus Bagnall	Tea and Coffee ++
Scirtothrips dorsalis Hood (Chilli thrips)	Polyphagous and important pest of crops
Selenothrips rubrocinctus Giard	Cashew, Cocoa +
Stenchaetothrips biformis (Bagnall) (Paddy thrips)	Paddy seedlings ++
Thrips hawaiiensis (Margan)	Polyphagous flower thrips ++
Thrips tabaci Lindeman (Onion thrips)	Important polyphagous pest of crops and vector of tospo virus

+ Indicates minor pest status; ++ Indicates seasonal pest status with appreciable density

sound ecological basis for developing biological control strategies for thrips. This is important since very often crop entomologists tend to focus on the target pest/crop in isolation from the other associated attributes of the target ecosystem, which can equally affect the potential impact of biological control.

2. Parasiotids as biological control agents

2.1 Natural occurrence of parasitoid species

The information on parasitoids natural enemies of thrips available in India is rather limited. The list of parasitoids of thrips recorded in India (Ananthakrishnan, 1984) is furnished below.

2.2. Impact and scope for conservation

There is very limited information on this aspect also in India. *Ceranisus maculatus* has been found to lay its eggs inside the body of larvae of *Rhipiphorothrips cruentatus*. The females of this eulophid are known to search for second and third instar larvae and pierce their abdomen with their ovipositor to lay their eggs inside, leading to subsequent death of the host (Rahman and Bharadwaj, 1937). Parasitism of *T.*

Parasitoid species	Thrips species	Crop
Ceranisus sp.	*Thrips tabaci*	Onion
Ceranisus maculatus	*Rhipiphorothrips cruentatus*	Grape
Megaphragma longiciliatum	*Frankliniella lilivora*	Grape
Thripastichus gentilei (Del Guercio)	*Rhipiphorothrips cruentatus*, *Gynaikothrips uzeli*	Grape
Thripobius semiluteus	*Panchaetothrips indicus*	Turmeric

tabaci on onion by *Ceranisus sp.* ranged from 2 to 18% during the season, but the incidence of the parasitoid was low (Saxena, 1981). Ananthakrishnan and Swaminathan (1977) reported the parasitisation of second instar larval stages of the gall forming thrips, *Schaedothrips orientalis* by *Tetrastichus thripiphonus* and the parasitism levels were as high as 20 per cent.

2.3 Further thrust on insect parasitoids and nematode parasites of thrips

Although parasitoids of thrips seem to have limited scope for augmentative biological control, the potential for cost effective mass rearing of the parasitoids and planting of nectar-sources for adult feeding could be studied.

3. Predators as biological control agents

3.1. Natural occurrence of predators

There are several predators reported to provide natural control of thrips in crop ecosystems in India. For instance, tea thrips are reported to be predated by the anthocorid – *Orius* sp., and predatory thrips like *Coleothrips intermedius* and *Mymarothrips garuda* (Muraleedharan, 1995). Singh (1993) reported feeding of *Carayonocoris indicus* and *Orius maxidentex* on *Megalurothrips distalis*, an anthophilous pest of legume crops. Mirid bugs, larvae of syrphids, lacewings, coccinellids, predatory mites, spiders, sphecid wasps and pseudoscorpion are reported among common predators of thrips on various crop plants (Ananthakrishnan, 1984; Varatharajan and James Keisa, 2000). The predatory inquiline, *Andropthrips flavipes* Schmutz, was recorded in galls caused by *Arrhenothrips ramakrishnae* Hood on leaves of *Mimusops elengi* and also in galls caused by *Schedothrips orientalis (*Ananthakrishnan), *Gynaikothrips flaviantennatus* Moult and *Brachythrips dantahasta* Ramakrishna on various plants. The predators feed on the eggs, first and second instar nymphs and to a very limited extent on pupae. The anthocorid, *Montandoniola moraguesi* (Put.) was also found preying on *G. flaviantennatus* and *S. orientalis,* but cross predation on *A. flavipes* within their galls was observed (Ananthakrishnan and Varadarasan, 1977). Natural populations of these predators have been successful in maintaining the pest populations at low levels (Muraleedharan and Ananthakrishnan, 1978; Ananthakrishnan and Sureshkumar, 1985). The important anthocorids liste' as potential predators of thrips by Muraleedhara nd Ananthakrishnan (1978) are *Carayonocoris indicus* Muraleedharan, which usually lived in the inflorescence of *Cassia marginata* in South India and fed on *Haplothrips ganglbaueri* Schmutz and *Frankliniella schultzei* (Tryb.), besides *M. moraguesi* , which lives in the galls of 20 species of Thysanoptera on as many host plants and feeds especially on *Gynaikothrips bengalensis* Ananthakrishnan; also *Xylocoris clarus* (Dist.), which lives in leaf litter in southern India and preys on litter insects including *Dexiothrips madrasensis* (Ananthakrishnan) (*Malacothrips madrasensis*) and *Apelaunothrips indicus* (Ananthakrishnan) (*M. indicus*); and *Scoloposcelis parallelus* (Motsch.) which was found on decaying bark of *Erythrina* spp. in August-September and preyed on fungus thrips (*Ecacanthothrips sanguineus* Bagn.). In India, anthocorids have been recorded as potential biological control agents of different species of thrips (Table 2). The majority of anthocorid research is records on different thrips pests, while very limited work has been done on production or field evaluation of anthocorid predators in thrips biological control in various crop ecosystems. Systematic studies are lacking on the seasonal occurrence of the different potential anthocorid predators in our country. Information is lacking on the extent of control of thrips exerted by the natural populations of anthocorid predators in the different agro-ecosystems. This information is necessary to identify the potential anthocorids which do a good job in nature and which need to be conserved.

3.2. Host range and seasonal incidence

Laboratory studies indicated that *Orius maxidentex* Ghauri and *Carayonocoris indicus* Muraleedharan had a greater preference for *Scirtothrips dorsalis* Hood over the other species offered, possibly because of their comparatively smaller size. The bugs appeared to recognize their prey only by touch (Kumar and Ananthakrishnan, 1984). Field studies on the seasonal occurrence of anthocorid predators were conducted by Kumar and Ananthakrishnan (1984). *C. indicus* appeared on *Cassia marginata* and mango after these began to flower and populations built up as thrips populations increased. Peak numbers of the predator were recorded on mango in March and on *Cassia* in July. *Orius maxidentex* was present from January. *Scymnus nubilus* Muls., *Laius externenotatus* Pic, *Orius albidipennis* (Reut.), *Chrysopa* sp. and *Aeolothrips collaris* Priesner were found preying on *Thrips tabaci* Lind on onion. The predators consumed 23-96 thrips larvae per day, but their incidence was very low in comparison with that of their prey (Saxena, 1981). Some control of *H. ganglbaueri* on rice was achieved by *O. maxidentex* which could feed on the larvae and adults (Ananthakrishnan and Thangavelu, 1976). Population fluctuations of three species of anthophilous thrips such as *Megalurothrips distalis*, *Frankliniella schultzei* and *Haplothrips ganglbaueri* were studied in the flowers of *Gliricidia sepium* (= *G. maculata*) in relation to the numerical response of their predator, *Orius minutus* L. It was found that *O. minutus* is an effective predator and that predation is density-dependent (Viswanathan and Ananthakrishnan, 1974).

3.3. Impact and scope for conservation

On sesame, *Orius maxidentex* fed on *Thrips palmi* Karny on the young foliage, migrating later to prey on *Frankliniella schultzei* (Tryb.) on the flowers. After the crop was harvested, the predator was abundant on the weed, *Croton sparsiflorus*, preying on *T. palmi*, until prey populations died out in September. *Orius* was also found preying on *Anaphothrips sudanensis* Tryb. and *Caliothrips graminicola* (Bagn. and Cam.) on *Panicum maximum*, peak numbers being recorded in June and July, and on *S. dorsalis* on *Prosopis spicigera*, peak numbers being recorded in May.

Field studies carried out in apple orchards in the Shimla district of Himachal Pradesh, indicated the importance of conservation of biotic agents in apple orchards. Insecticidal sprays appeared to be detrimental to predatory activity. Monocrotophos 0.05% alone did not give an effective level of control and was detrimental to predator activity. In various orchards, populations of *Thrips flavus* remained below the economic injury level and the high predator activity of the anthocorid *Orius* sp. appeared to keep the pest population at low levels (Gupta and Bhalla, 1993).

3.4 Mass rearing system development

3.4.1 Rearing of anthocorids

In India, very few attempts have been made to rear the anthocorid predators. Mukherjee *et al.* (1971) tried a synthetic diet for rearing *X. flavipes* (Reut.). Mass rearing methods have been standardised for four potential anthocorid predators, *Cardiastethus exiguus* Poppius (Ballal *et al.*, 2003a), *Blaptostethus pallescens* Poppius (Ballal *et al.*, 2003b) and *Xylocoris flavipes* (Reuter) and *Orius tantillus* Motschulsky (Chandish R.Ballal, unpublished).

Techniques to mass rear *Orius* spp. were not available in India till recently. At the Project Directorate of Biological Control, Bangalore, methods have now been standardised to multiply *Orius tantillus* on different host eggs. Earlier studies had indicated that the progeny production by *Orius maxidentex* when reared on sorghum midge was 35.1 per female and 23.6 per female when reared on thrips. There are problems associated with continuous multiplication of host insects like thrips and midges. Hence other alternate laboratory host eggs were tried. *O. tantillus* could be continuously multiplied for 12 generations on UV irradiated *C. cephalonica* eggs. However, the progeny production was very low, the mean value being 3.1 per female. The UV-irradiated eggs of *Sitotroga cerealella* was also tried. It has now been found that *O. tantillus* could be reared more efficiently on *S. cerealella* eggs than on *C. cephalonica* eggs (Fig 1). From a small number of field- collected females, 100 to 450 adults were obtained in each generation. The optimum temperature regime for multiplication of *O. tantillus* was found to be 24 and 28°C as progeny production was maximum at these two temperatures, the values being 28.8 and 26.2 per female, respectively.

3.5 Release for augmentative biological control

Manjunatha *et al.* (2001b) evaluated the efficiency of the predatory mite, *Amblyseius ovalis* for the control of yellow mite and thrips on chilli under field conditions and recorded significant control of thrips (0.81 per 3 leaves) in the released plots. Laboratory studies were conducted to check the feeding preference of *O. tantillus* on parasitised and un-parasitised eggs of *Helicoverpa armigera*.

Results of choice and no-choice tests showed their preference towards unparasitised eggs over that of parasitized eggs, thus indicating that it may be possible to integrate releases of anthocorids and trichogrammatids for biololgical control of lepidopteran pests/thrips in different crop ecosystems (Gupta and Ballal, 2006).

It has now been realised that anthocorids are effective predators and play a useful role in the natural control of many insect pests in the different parts of the world (Table 3). Techniques have been evolved in other countries to mass rear anthocorid predators and release them in the field or glass houses for management of several pests, especially thrips.

The following are projected as future thrust areas for utilising antrocorid predators in biological control of thrips:

Table 2. Known and potential predators of thrips in India

Predators	Host plant	Target thrips	Source
Orius sp.	Groundnut	Thrips	Singh *et al.* (1991)
ius albidipennis (Reut.)	Onion	*Thrips tabaci*	Saxena (1977) and (1981)
Orius bifilarius Ghauri	Polyphagous	*Thrips flavus* and *Thrips hawaiiensis*	Veer (1984)
Orius maxidentex Ghauri	Sesame, *Croton sparsiflorus* Morong, *Panicum maximum* Jacq. *Prosopis spicigera* L., rice	*Thrips palmi* *Frankliniella schultzei* *Thrips palmi* *Anaphothrips sudanensis* *Caliothrips graminicola* *Scirtothrips dorsalis* *Haplothrips ganglbaueri*	Kumar and Ananthakrishnan (1984) Ananthakrishnan and Thangavelu (1976)
Orius maxidentex Ghauri and *O. tantillus* Motsch. *O. insidiosus*, *O.maxidentex*, *Aeolothrips collaris*, *Scymnus nubilus*, *Laius externenotatus*, *Chrysopa* sp. and *C. orestes*	Onion and garlic Chilli, tea and other plants, rice Groundnut, sesbania and bajra Chrysanthemum, dahlia and marygoldVarious plants Onion	*Thrips tabaci* *Scirtothrips dorsalis*, *Baliothrips biformis* *Caliothrips indicus* *Microcephalothrips abdominalis* *Haplothrips ganglbaueri* *Thrips tabaci*	Muraleedharan and Ananthakrishnan (1978)
Orius minutus (L.)	*Gliricidia sepium* (Jacq.) (= *G. maculata*)	*Megalurothrips distalis* *Frankliniella schultzei* *Haplothrips ganglbaueri*	Viswanathan and Ananthakrishnan (1974)
Carayonocoris indicus Muraleedharan	*Cassia marginata* Roxb. and mango	*Haplothrips ganglbaueri* *Frankliniella schultzei*	Muraleedharan and Ananthakrishnan (1978) and Kumar and Ananthakrishnan (1984)
Montandoniola moraguesi (Put.)	Different plants	Gall makers,*Gynaikothrips* *flaviantennatus* Moult, *Schedothrips* *orientalis* (Ananthakrishnan) *Gynaikothrips bengalensis* Ananthakrishnan	Ananthakrishnan and Varadarasan (1977) Muraleedharan and Ananthakrishnan (1978)

Montandoniola moraguesi (Put.)	Black pepper	*Leptothrips karnyi*	Muraleedharan and Ananthakrishnan (1978)
Xylocoris clarus	Not mentioned	Thrips on litter material	Muraleedharan and Ananthakrishnan (1978)
Scoloposcelis parallelus	Not mentioned	Thrips infesting dead and decaying plant parts	Muraleedharan and Ananthakrishnan (1978)
Orius spp.	Egg plant	*Thrips palmi*	Nagai (1991)
Orius indicus (nymphs and adults)	*Cajanus cajan* (Flowers)	*Megalurothrips nigricornis*	Rajasekhara and Chatterji (1970)
Holothrips anacardii Hood	Rose	*Rhipiphorothrips cruentatus* Hood (Nymphs)	Dhaliwal (1975)

Table 3. Field releases of anthocorid predators for thrips biological control in other countries

Anthocorid	Host plant/ material	Host insect	Place	Source
Montandoniola moraguesi (Put.)	*Ficus retusa*	*Gynaikothrips ficorum* (Marchal)	Bermuda	Groves (1974)
Orius sp.	Cucumber	*Frankliniella occidentalis* Pergande	Germany	Buhl and Bassler (1992)
Orius insidiosus Say	Chrysanthemum	*Frankliniella occidentalis*	Netherlands	Fransen and Tolsma (1992)
	Ornamentals	*Frankliniella occidentalis*	Sweden	Sorensson and Nedstam(1993)
Orius laevigatus (Fieber)	Strawberry	*Frankliniella occidentalis*	France	Villevieille and Millot(1991)
	sweet pepper	*Frankliniella occidentalis*	UK	Chambers *et al.* (1993)
Orius majusculus (Reuter)	Cucumber	*Frankliniella occidentalis*	France	Trottin Caudal *et al.* (1991)
	Chrysanthemum	*Frankliniella occidentalis*	UK	Buxton and Finlay (1993)

- Methods should be standardised for mass production of thrips, which is an essential step for conducting evaluation studies using anthocorid predators
- Search for potential anthocorids for releases against thrips
- Taxonomy of anthocorids to be strengthened
- Studies on the interaction between thrips and anthocorids in different crop ecosystems during different seasons
- Mass rearing technologies to be standardised for anthocorid predators and available technologies to be disseminated to commercial insectaries
- Compatibility studies between anthocorid predators and other potential bio-agents (insect pathogens and parasitoids).
- Availabe anthocorid predators in culture to be evaluated against thrips

3.6 Other predators for thrips biological control

An experiment carried out on the effectiveness of controlling thrips in *C. annum* indicated that releasing of the first and second instar larvae of *Chrysoperla carnea* at 3 per plant, resulted in significant reduction of the pest (Wadaskar *et al.*, 2004).

4. Entomopathogens as biological control agents for thrips

4.1 Natural occurrence of pathogens and their incidence level

The pathogens reported as occurring on thrips or promising for their control are as below:

i. Protozoa

A microsporidian parasite - *Mrazekia* sp. has been found infecting the larval forms of *Scirtothrips oligochaetus* (Raizada, 1976).

ii. Entomopathogenic fungi

Certain species of *Cephalosporium* and *Aspergillus*, *Cladosporium cladosporioides* and *Entomophthora thripidium* are also reported to be effective against thrips species (Ananthakrishnan, 1984). A list of the mycopathogens recorded in India is furnished in Table 4.

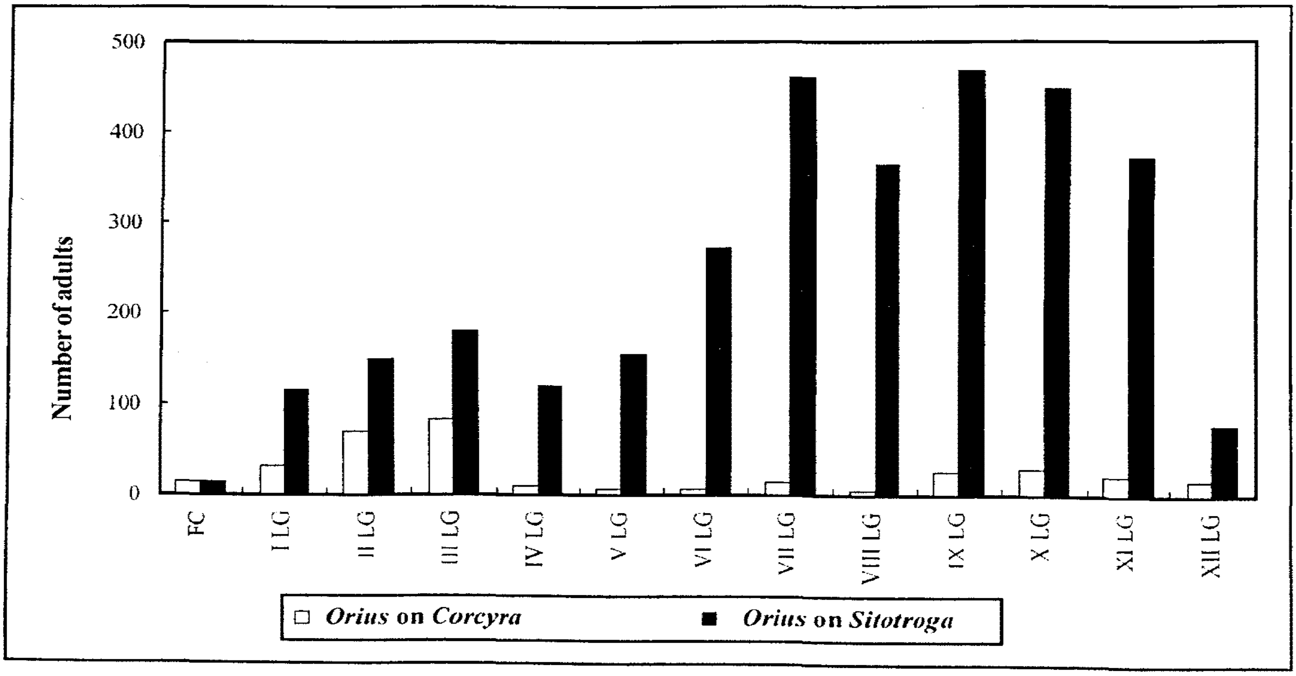

Fig. 1. ***Orius tantillus* reared for 12 generations on *Corcyra cephalonica* and *Sitotroga cerealella* (LG : Lab generation; FC : Field collected anthocorids; Chandish R. Ballal, unpublished)**

Table 4. List of myco-pathogens known as natural enemies of thrips in India

Myco-pathogens	Thrips
Cladosporium cladosporioides	*Scirtothrips dorsalis*
Trichothecium roseum	*Thrips tabaci*
Entomophthora thripidium	*Thrips tabaci*
Cephalosporium sp.	*Thrips tabaci*
Aspergillus sp.	*Thrips tabaci, Frankliniella intonia, Anaphothrips obscurus,*
Paecilomyces fumosoroseus	*Thrips tabaci*
Hirsutella thompsonii	Thrips in general
Verticillium sp.	*Frankliniella occidentalis*

iii. Nematode parasite

Flower inhabiting thrips such as *Frankliniella schultzei* and *Microcephalothrips abdominalis* occurring on sunflower were found infected by the nematode, *Anguillulina aptini* (Varatharajan, 1985).

4.2 Extent of natural control / impact

The natural incidence of entomopathogenic fungi at different phases in the life cycle of *T. inconsequences* was determined in sugar maple stands in Vermont. The most commonly isolated species were *Beauveria bassiana, Paecilomysis farinosus, Metarhizium anisopliae, V. lecanii, V. fusisporum* and *Hirsutella* sp. The incidence of the entomopathogen *V. lecanii* on *T. inconsequens* was found to vary with the microhabitat of the host. The highest incidence of (11.9 %) was recorded from larvae followed by adults (5.9 %), while only 1.9 % was recorded for thrips collected from under storey as well as from upper canopy (Brownbridge *et al.*, 1999).

Application of the entomopathogenic fungus *V. lecanii* caused significant reduction of the population of western flower thrips, *Frankliniella occidentalis* and a visible reduction in leaf damage on bush beans, *Phaseolus vulgaris* cv. marona (Meyer *et al.*, 2002) and thrips on cucumber (Gillespi, 1986).

4.3 Recent research advances at IIHR

IIHR has isolated an efficient strain of *V. lecanii* from *T. palmi* with higher infection potential on *S. dorsalis*. Efficacy of the isolate and its compatibility with different oils and stickers have been tested (Tables 5 and 6)

5. Progress and success in thrips biological control elsewhere

5.1 Promising research results on biological control of thrips

In countries like France, UK, Netherlands and Germany, anthocorid predators have been multiplied and released in the green houses and fields for the management of thrips. Amongst the different anthocorids, *Orius* spp. appears to be the most promising. *O. sauteri* is known to be an important predator of thrips, spider mites, aphids and eggs of lepidopterous insects in fields and orchards in Japan, China, Korea and Russian Far East and has been shown to be effective in suppressing *Thrips palmi* in egg plants (Yano and Van Lenteren, 1996). In Switzerland, *Orius majusculus* could reduce populations of thrips on sweet pepper and cucumber (Fischer *et al.*, 1992).

Artificial diets have been developed and evaluated for some anthocorids. *O. sauteri* could be reared on an artificial diet (Zhou and Wang, 1989). Castane and Zalom (1994) found that an artificial ovipositional medium made of carrageenan salt of potassium chloride and covered with paraffin wax was suitable for rearing *O. insidiosus*.

The anthocorid species, which have been commonly used for field releases, are *Anthocoris nemoralis*, and *Orius* spp. Anthocorids are now being commercially produced in several countries. In Ontario,

Table 5. Efficacy of *Verticillium lecanii* against different instars of *Scirtothrips dorsalis**

Treatments	Percent cumulative mortality (hours after inoculation)					
	Nymphs			Adult		
	24 hours	48 hours	72 hours	24 hours	48 hours	72 hours
$3x10^4$ (conidia/ml)	4.0(9.9)	8.0(15.9)	10.0(18.9)	5.0(10.0)	8.0(15.9)	12.0(21.00)
$3x10^5$ (conidia/ml)	8.0(15.9)	10.0(18.9)	12.5(23.6)	10.0(15.9)	12.0(20.5)	14.0(23.0)
$3x10^6$ (conidia/ml)	8.0(15.9)	14.0(22.1)	20.0(29.3)	18.0(22.1)	20.0(26.6)	32.0(35.0)
$3x10^7$ (conidia/ml)	14.0(22.1)	24.0(29.6)	40.0(43.3)	30.0(29.5)	32.0(34.6)	48.0(44.1)
$3x10^8$ (conidia/ml)	16.0(23.7)	26.0(30.9)	57.5(52.24)	30.0(28.9)	34 9(35.9)	52.0(46.5)
$3x10^9$ (conidia/ml)	24.0(28.3)	46.0(43.0)	72.5(62.12)	45.0(37.3)	52.0(41.8)	82.0(65.7)
Control	0 9(4.05)	0.0(4.05)	2.5(5.06)	0.0(4.05)	0.0(4.05)	2.5(7.0)
CV%	29.4	14.5	20.1	23.2	18.3	18.7
CD at 0.05	6.5	4.5	7.0	6.3	6.1	8.3

* Source: Ganga Visalakshi (unpublished), IIHR study.

Table 6. Compatibility of different vegetable oils and stickers on the growth of *Verticillium lecanii*

Treatment	Colony diameter in 'cm' (cumulative) 15th day	Per cent growth of mycelia over control (cumulative)	Rate of growth in 'cm' / per day (10 - 15th day)
Sun flower oil	2.43^{c}	- 6.54	0.061
Groundnut oil	1.20^{d}	- 53.85	0.020
Coconut oil	3.63^{b}	39.61	0.101
Gingili oil	1.27^{d}	- 51.15	0.022
Castor oil	3.47^{c}	33.46	0.096
Neem oil	4.47^{a}	71.92	0.129
Pongamia oil	2.43^{c}	- 6.54	0.061
Laboline	2.27^{c}	- 12.69	0.056
Triton X100	2.23^{c}	- 14.23	0.054
Control	2.60^{c}		0.067
CD=0.01	0.42		

* Source: Ganga Visalakshi *et al.* (unpublished), IIHR study.

the cost of production of *O. insidiosus* was 0.03 dollar per bug and up to 100,000 bugs could be reared per week and 200 to 600 bugs could be reared in one zip - lock plastic bag (Schmidt, 1994). In UK, releases of 1 or 2 individuals of *O. laevigatus* per plant could control *Frankliniella occidentalis* Pergande on pepper (Chambers *et al.*, 1993). In Germany, good results were achieved with 2 releases of *Orius* at fortnight intervals

Table 7. Differential pathogenicity of entomopathogenic fungi strains on *Megalurothrips sjostedti*-ICIPE, Kenya*

Fungal species	Strain	% germination
Beauveria bassiana	ICIPE 53	94.50
	ICIPE 59	100.00
	ICIPE 78	90.30
	ICIPE 82	100.00
	ICIPE 83	97.00
	TP-GHA	68.30
Metarhizium anisopliae	ICIPE 18	100.00
	ICIPE 20	72.50
	ICIPE 30	99.50
	ICIPE 60	94.30
	ICIPE 62	100.00

* Source: Ekesi *et al.* (1998)

(0.5-1 insect/m^2) against *F. occidentalis* in cucumbers (Buhl and Bassler, 1992). In France, the efficiency of *Orius majusculus* for the control of *F. occidentalis* on cucumbers was studied in greenhouses and the predator was shown to have great potential (Trottin Caudal *et. al.*, 1991).

Orius majusculus was introduced for the control of *F. occidentalis* on chrysanthemums in a greenhouse in the UK and appeared to reduce thrips numbers for at least the first two plantings. In Netherlands, *Orius insidiosus* was released on chrysanthemums for the control of *F. occidentalis* in greenhouses and pest numbers were reduced to a great extent (Fransen *et al.*, 1993). In Sweden, the predators *Amblyseius cucumeris* (= *Neoseiulus cucumeris*) and *Orius insidiosus* were very effective when they were released together on ornamental plants (*Saintpaulia impatiens*, *Gerbera* spp. and *Brachyscome multifida*) infested with *F. occidentalis* in greenhouses (Sorensson and Nedstam, 1993). *Orius laevigatus* was also observed to be a potential predator for the control of *F. occidentalis* on strawberries in greenhouses in France (Villevielle and Millot, 1991).

5.2 Deploying *Metarhizium* for biological control of thrips in cowpea and onion in Kenya

The collection, characterisation and selective deployment of promising native strains of *Metarhizium anisopliae* was one of the thrust areas in research on biological control of thrips on cowpeas and onion. The choice was facilitated by appropriate laboratory bioassays and pot culture studies. Native strains of *Metarhizium* with better growth and sporulation attributes were tested for their adaptation to a regime of temperatures and crop varieties and the better performing ones were selected for further testing (Table 7).

The research at ICIPE focussed on choice of highly adapted native strains and also further choice among them for strains that are equally effective for biological control of the cowpea flower thrips *Megalurothrips sjostedti*, the western flower thrips, *Frankliniella recidentallis*, as well as the onion thrips, *Thrips tabaci* (Ekesi *et al.*, 1998 and 1999; Maniania *et al.*, 2001 and 2003).

The field evaluation of *Metarhizium* for the control of thrips was invariably compared with synthetic insecticides, and competitiveness and cost effectiveness of the *Metarhizium* product could be clearly established. Biweekly sprays of *M. anisopliae* were found to provide significant reduction in thrips infestation and in damage ratings of onion thrips on par with biweekly sprays of demethoate in three field trials (Table 8, 9 and 10). Of course, significant increase in yield over control treatment could be observed with weekly sprays of *M. anisopliae* in one of the trials.

6. Complementary control methods for possible integration with thrips biological control

There are several promising control methods for thrips that can be complimentary to biological control

Table 8. Interaction of *Metarhizium* strains with temperature and crop cultivars – ICIPE study, Kenya*

	Insect directly exposed			Floral tissues sprayed		
Factor	F	DF	*P*	F	DF	*P*
Temperature	79.33	3,96	0.0001	61.45	3,96	0.0003
Variety	13.90	2,96	0.0001	10.81	2,96	0.0001
M. anisopliae	126.51	3,96	0.0001	104.51	3,96	0.0001
Temperature + Variety	0.86	6,96	0.5306	0.92	6,96	0.7412
Temperature + *M. anisopliae*	11.05	9,96	0.0011	8.74	9,96	0.0001
Variety + *M. anisopliae*	2.15	6,96	0.0041	3.41	6,96	0.0052
Temperature + Variety + *M. anisopliae*	0.24	18,96	0.6300	0.31	18,96	0.5407

* Source: Ekesi *et al.* (1998); [a]Means were angularly transformed before analysis; analysis of variance for mortality of *Megalurothrips sjostedti* interaction between temperature, variety and *Metarhizium anisopliae*

Table 9. Effect of *M. anisopliae* compared to synthetic insecticide (dimethoate) application on onion thrips damage ratings – ICIPE, Kenya*

Treatment	Damage rating (X ± SE) [a]		
	First trial	Second trial	Third trial
Control	3.4 ± 0.4[ab]	1.5 ± 0.2[ab]	3.2 ± 0.6[ab]
M. anisopliae weekly	2.4 ± 0.1[b]	1.1 ± 0.0[b]	1.5 ± 0.2[b]
M. anisopliae bi – weekly	2.1 ± 0.1[b]	1.3 ± 0.1[b]	1.7 ± 0.2[b]
Dimethoate bi – weekly	2.3 ± 0.1[b]	1.5 ± 0.0[b]	1.5 ± 0.1[b]

* Source: Maniania *et al.* (2000); [a] Damage rating: 1 – No apparent damage, 2 – Light damage: upto 25 % of the leaf area, 3 – Moderate damage: 26-50 % of the leaf area, 4 – Heavy damage: 51-75 % of the leaf area, 5 – Very heavy damage: above 75 % of the leaf area; [b]Means within a column followed by the same letter are not significantly different by SNK (P =0.05) test; [c]Applied at 10^{11} conidia ha^{-1}

Table 10. Effect of *Metarhizium* on onion yield, ICIPE, Kenya- study (Onion yield (Mean ± SE) following application of *M. anisopliae* and dimethoate to control onion thrips)*

Treatment	Damage rating (X ± SE) [a]		
	First trial	Second trial	Third trial
Control	22326.3 ± 1884.0 a[a]	10994.0 ± 1901.9a[b]	16142.5 ± 1820.7b[a]
M. anisopliae weekly [c]	23888.5 ± 2124.5a	15344.0 ± 3081.0ab	24172.3 ± 1828.8a
M. anisopliae bi – weekly [c]	26985.8 ± 4750.1a	12988.3 ± 1298.0ab	19039.3 ± 2657.6ab
Dimethoate bi – weekly	25748.0 ± 3327.7a	17191.8 ± 696.3a	18460.5 ± 2335.0ab

* Source: Maniania *et al.* (2000); [a] Means within a column followed by the same letter are not significantly different by SNK (P =0.05) test; [b] Applied at 10^{11} conidia ha^{-1}

Table 11. Experiments on cultural / trap practices for thrips control in India

Type of test	Practice/ product tested for safety	Parameters studied	Nature of results	Reference
Pot experiment in chillies against *Scirtothrips dorsalis*	Oil cake based vermicompost	1.Thrips population 2.Fruit yield	Lowest thrips population (14.0-16.5/3 leaves) fruit yield - 240 to 260 g/plant/pot	Subasmita *et al.* (2005).
Field trial - intercrops	Mung bean intercropped with pigeon pea, sorghum, maize, pearl millet, castor and cotton	Thrips population Peanut Bud necrosis virus incidence	Peanut, sorghum and maize inter crops recorded reduction in thrips population on 71, 62 and 57% (Rabi season); 69, 62 and 60 % reduction (Kharif season).	Sreekanth *et al.* (2004).
Field trap colour experiment (*Thrips palmi*)	4 colour traps were tested: White, yellow, blue and green	Captured population of thrips	White coloured traps captured significantly greater number. In all colour traps occurred in significant number in all the season.	Sarath Babu *et al.* (2004).
Field trial on chillies (*Scirtothrips dorsalis*)	Neem products and their combination (Neem oil (spray, seedling root dip) Neem cake (soil application)	Mean thrips population /5 leaves	Least population observed (3.88 thrips) in the combination of seedling root dip with 1% neem oil + neem cake soil application (500kg/ha) + neem oil spray 1% at weekly interval. compared to control (22.73).	Rao *et al.* (1999).
Crop trial - neem	Neem oil	Not mentioned	Effective on thrips larvae and pupae which occur in soil	Gupta and Singh (2002).

* Source: IIHR study by Ganga Visalakshi *et. al* (unpublished)

and could be targeted for integration. These include the following:

i) *Field sanitation:* Removal of weed hosts from the cropping areas, as weeds are often the reservoirs for thrips (Ananthakrishnan, 1984). This is applicable in general for vegetable crops, cotton, tea, cardamom, etc. Removal of dried leaf sheath, old panicles, dried flowers, as in the case of cardamom, can help expose the eggs which are laid within the leaf sheath for easier access to control interventions (Varadarasan, 1995; 2003).

ii) *Cropping practices*: Studies on thrips in groundnut indicated that intercropping with pearl millet significantly reduced the incidence of thrips besides also leaf miners and leafhoppers, compared with groundnut monocultures. Adjusting the planting period of chillies also reduced thrips infestation (Bagle, 1993). The available information on cultural practices is summarised in Table 11.

iii) Use of traps : Diraviam and Uthamasamy (1992) found that yellow sticky traps are effective not only to monitor thrips density, but also to trap the thrips as a means of population reduction. Infestations of *Scirtothrips dorsalis* on *Capsicum annuum* have been found significantly reduced due to yellow pan water trap (James Keisa *et al.*, 1996).

iv) *Botanicals*: A number of botanicals have been evaluated against rice thrips in the nursery / seedling stage (Samiayyan and Chandrasekaran, 1995). Neem pesticides were also reported to be effective against chilli thrips (James Keisa and Varatharajan, 1995) and onion thrips (Sattar Shah *et al.*, 2005).

vii) *Host plant resistance: Thrips palmi* is a common pest in Latin America, infesting legumes, cucurbits, solanaceous and ornamental plants; after repeated screening trials, five genotypes of *Phaseolus vulgaris* were identified as resistant to *T. palmi* (Cardona *et al.*, 2002).

viii) *Host plant constituents promoting natural control*: Volatile organic compounds (VOCs) like jasmonate-inducible plant defences can cause increased parasitism of the herbivores. In many plants, the defence systems against insect herbivores are induced through the octadecanoid pathway, which may also be involved in recruiting natural enemies of herbivores. For instance, in tomato plants, jasmonate induced resistance (JIR) resulted in reduced abundance of the herbivores in three feeding guilds such as leaf chewers, phloem feeders and cell content feeders (Thaler, 1999). Field application of jasmonic acid in a cotton field was found to significantly reduce the density of thrips, *Frankliniella occidentalis,* besides the aphid, *Aphis gossypii*. Similarly, the activity of the predatory thrips, *Scolothrips takahashii* was found to be enhanced by the herbivore-induced plant volatiles (Shimoda *et al.*, 1997; Takahashi *et al.*, 2001).

7. Major thrust areas for future research and development

7.1. Field identification and biosystematics of thrips species

- Improve capacity for field identification among bio-control scientists/staff
- Network among taxonomists for expert identification to assist bio-control scientists
- Establish molecular characterisation protocols and training to bio-control scientists

7.2. Biodiversity characterisation and repository support for bio-control agents

- Assemble native biodiversity with GIS-linked ecologically based-surveys
- Ensure biological/potency evaluation under standard methodology
- Provide electronic database on the accessions and avail free access to them

7.3. Develop cost effective product for commercialisation

- Verify the effectiveness of the product in thrips control
- Simplify the mass production system for cost effectiveness
- Ensure that product cost is competitive to alternative control options

7.4. Improve the product formulation and application technologies

- Identify /Develop strains tolerant to climatic stresses
- Include suitable additives for enhancing product shelf life
- Evolve suitable strategies for extending the field-life

7.5. Demonstrate economic and ecological benefits

- Assess the cost-returns for bio-agent versus chemical control
- Evaluate the impact on beneficial in the crop ecosystem
- Involve farmers as partners in ecosystem-based assessment

7.6. Integration and popularisation of bio-agents

- Select compatible components for crop protection and production
- Ensure maximising the synergy with timing adjustments
- Secure support from organic farming and export horticulture initiatives
- Provide market linkages for price incentives for the crop produce

There is a great scope for improved conservation and /or augmentation of natural enemies of thrips in many tropical agro-ecosystems. While research done so far in India has been focussed more on exploring and testing of different manipulations towards enhancing the impact potential of augmentative biological control, there is need to focus future research on thrips species identification, natural enemy biodiversity characterization up to strain level, establishing a live repository of promising strains, improvements in product formulation and application of biological control agents and development of cost-effective production system and protocols for in-house quality control. There is need to also support the validation of economic and ecological benefits of promising biological control agents and popularisation programmes through training of trainers and training material preparation for a cascading effect in dissemination and awareness building among end users. The solid ecological foundations laid by the pioneering and multi-faceted research of Prof. T. N. Ananthakrishnan and his team could provide a firm base for these initiatives. It is hoped that multi-disciplinary approach and inter-institutional collaboration will be nurtured in moving forward towards a holistic R and D programme, with pathogens, predators and parasitoids in that order of relative importance for evolving successful biological control technologies for key thrips pests in India.

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