Invited Article

Biopesticides for Insect Pest Management in Rice – Present Status and Future Scope

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Insect pests – major biotic stresses in rice

Of the hundred and more species of insects recorded as pests in rice, five pests *viz.*, rice yellow stem borer (YSB), *Scirpophaga incertulas* (Walker), gall midge (GM), *Orseolia oryzae* (Wood-Mason), leaf folder (LF), *Cnaphalocrocis medinalis* (Guenee), brown plant hopper (BPH), *Nilaparvata lugens* (Stal) and white backed plant hopper (WBPH), *Sogatella furcifera* (Horvath), are of national importance as their incidence has significant impact on rice yields across the diverse rice ecosystems. Other pests *viz.*, rice hispa, *Dicladispa armigera* (Olivier) occurring in Andhra Pradesh, Himachal Pradesh, Bihar, West Bengal, Orissa and north eastern region, green leafhopper, (GLH) *Nephotettix virescens* (Distant) prevalent in Bihar, West Bengal, Assam, Orissa, Madhya Pradesh, Andhra Pradesh and Tamil Nadu, gundhi bug, *Leptocorisa* spp. in Uttar Pradesh, Bihar, West Bengal, Orissa, Madhya Pradesh, Manipur and parts of Andhra Pradesh, climbing cutworm, *Mythimna separata* (Walker) in coastal upland rice growing areas, swarming caterpillar, *Spodoptera mauritia* (Boisduval) in low lying rice in Bihar, Gujarat, West Bengal, Assam and Orissa and thrips in several southern and eastern parts of India, have regional significance. Some pests such as rice mealy bug, termites, and case worm are pests of growing concern particularly in eastern region. Recently, leaf and panicle mites, black bugs, blue beetle have also started causing serious concern as emerging pests in some parts of the country.

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Biointensive management of insect pests –a potentially viable long term alternative

Biointensive approach of managing pests is an ecologically based strategy that focuses on long term solution for pest control through a combination of techniques such as use of resistant varieties, biological control, modification of agronomic practices and habitat manipulation. Use of biopesticides mainly, microbial insecticides and botanical products will have to be an integral component of such an approach to minimize the risks to the human health, beneficial and non target organisms and environment.

Natural regulation of insect pests in rice ecosystem by entomopathogens

Paddy ecosystems are richly endowed with natural regulatory mechanisms to take care of the insect pests and entomopathogens are one of the major groups among the natural enemies. Of the eleven insect pathogens reported to attack stem borer, *Bacillus thuringiensis* is the major one. Against leaf folder, eighteen fungal, two bacterial, two viral pathogens and two entomopathogenic nematodes have been reported. Among the entomopathogens reported on plant and leafhoppers, the fungi, *Pandora delphacis*, *Metarrhizium flavoviridae*, *Beauveria bassiana*, *Erynia radicans*, *Entomophthora*, *Entomophaga aulicae* and *Fusarium* sp. have shown promise. Though the natural action of entomopathogens against the pests has been well documented and reported their inherent ability to naturally regulate the pest populations below the economically damaging levels, has not been evident.

Efficacy of plant products against rice pests

Four major types of botanical products (pyrethrum, rotenone, neem and essential oils) have been widely used for insect pest management along with three others (ryania, nicotine and Sabadilla) in limited scale. Additional plant extracts and oils (eg. Garlic oil, *Capsicum* oleoresin etc.) have also been or being used in a limited way, specific to regions (Anand Prakash *et al.,* 2008). However, neem and its products with more potential have been better investigated than other products. Two types of crude botanical products can be obtained from the neem seeds. Neem oil, obtained by cold pressing of seeds and seed residue (cake) after removal of oil, which contains the major active principle, Azadirachtin. Neem seeds also contain 0.2 to 0.6% azadirachtin by weight and this active ingredient is concentrated to the level of 10 to 50% in the technical grade material used to produce commercial products. Neem oil and neem cake have been extensively tested for their efficacy against various pests of rice. There are several reports on their utilization in rice pest management (Table 1). However, their performance has been moderate and also inconsistent in comparison to chemical insecticides which have also been found superior in terms of their curative effect, easy application and availability.

Biopesticides – as key components of integrated pest management

Pest control methods have been evolving and diversifying in response to public awareness of environmental and health impacts of synthetic pesticides and resulting legislation. In this process, standardization of active principles of botanical products and their contents was done by suitably formulating them as biopesticides for reliable, better and consistent results. Biopesticides were also developed as key components of integrated pest management (IPM) programs, mainly as a means to reduce the load of synthetic chemical products that are being used for control of pests. The biopesticides used so far fall into two major categories *viz.*, microbial pesticides and botanical pesticides (Ranga Rao *et al.*, 2007).

Microbial insecticides

Microbial pesticides contain a microorganism (bacterium, fungus, virus, protozoan or alga) as the active ingredient which is relatively specific for its target pest(s). The most widely known microbial pesticides are derivatives of the bacterium *Bacillus thuringiensis* (Bt) which produces a toxin protein that is harmful mainly to lepidopterans. In the last decade, Bt transgenics have been developed which are considered equivalent to plant-pesticides where in the Bt toxin gene introduced into the plants own genetic material results in the plant itself manufacturing the toxin that kills the pest.

Evaluation of Bt formulations in rice

Several commercial formulations of Bt have been evaluated for their effectiveness against mainly leaf folder and stem borer in rice. Under the All India Coordinated Rice Improvement Programme (AICRIP), three commercially available formulations *viz.*, Delfin 85%, Dipel 3.5% and BTK II were evaluated focusing on their efficacy against leaf folder besides their concomitant effectiveness against stem borer was also investigated. It was evident that all the three formulations performed moderately against leaf folder, while the effect was marginal in case of stem borer, across ecosystems. The Bt formulations registered better effectiveness at higher doses, however the check insecticide chlorpyriphos showed consistent superiority both in terms of less pest incidence as well as higher yield.

Rath (1999) found that BTK II and Dipel 3.5% were more effective than Delfin 85% and Biolep. Roshan Lal (2001) observed that Bioasp, Biolep, Biotox, dipel and Delfin @ 2000 g a.i./ha were as effective as standard chlorpyriphos @ 250 g a.i./ha against leaf folder. Recent studies carried out on bio-efficacy of an indigenously developed Bt formulation (DOR Bt) at various concentrations by Directorate of Oil seeds Research (Ramandeep Kaur *et al.*, 2008; DRR, 2007-08) revealed that the formulation @ 2.0 kg/ha was effective in controlling the rice leaf folder (Fig 1) and increasing the grain yield of rice.

Evaluation of Bt formulations in combination with other components of IPM

Research efforts have also been aimed at evaluation of Bt formulations as one of the eco-friendly components of IPM modules for adoption across rice ecosystems along with other components such as botanical insecticides, insect growth regulators, biocontrol agents, conventional chemical insecticides as well.

Rao *et al.* (2003) reported that alternating the application of insecticides with Biobit or Dispel sprays were more effective than sole biopesticidal treatments in controlling leaf folder and increasing rice grain yield over control. The combination of biobit with systemic insecticides was also found to be economical as well as eco-friendly as it resulted in the best control of the pest and also conserved the natural enemies such as coccinellids and spiders in the rice field (Rao and Singh, 2003; Rao *et al.,* 2006). In another study, CAMB Bt (*Bacillus thuringiensis*) at 250 g/acre and CAMB fungi (*Metarrhizium anisopliae*) at 250 g/acre applied alone or in combination resulted in significant reduction in leaf folder and stem borer incidence (Shahid *et al* ., 2003).

Overall, the utility of Bt formulations in paddy ecosystems has been mainly limited by the inability of externally applied sprays to actually reach the target pest stages which are mostly hidden in case of stem borer which completes most of its life cycle within the plant system, while in case of leaf folder, the larvae feed remaining within the leaf folds thereby escaping exposure from direct spray. So, the timing of application is crucial for the effectiveness of Bt formulations. However, in recent times, the versatile biotechnology tool has provided a novel option of incorporating Bt genes like *cry IA (b)* and *cry IA (c)* which can trigger continuous production of insecticidal toxins in the plant system itself to overcome this problem. Already Bt transgenic rice varieties for resistance to yellow stem borer are in advanced stage of testing in India ((Manimaran *et al.*, 2011).

Studies on efficacy of other microbial insecticides in rice

In India, so far, eight microbial pesticides have been registered which include five of bacterial origin (four *Bacillus* species and one *Pseudomonas fluorescens*), three fungal origin (two *Trichoderma* species and one *Beauveria bassiana*) and one viral i.e. Nuclear Polyhedrosis Virus (NPV). In India, there are very few reports on evaluation of other microbial insecticides in rice, that too restricted to *Beauveria bassiana* based products, against leaf folder but without much success (Rao *et al.*, 2003; Sher Singh *et al.,* 2008).

Botanical insecticides

Botanical insecticides are synthetic derivatives of the naturally occurring secondary metabolites synthesised by plants species, which act on the insect growth and survival. They have long been advertised as attractive substitutes to synthetic chemical-insecticides, for controlling many insect pests because botanicals reputedly pose little threat to the environment or to the human health. Although, there is enormous scientific literature documenting bioactivity of plant derivatives to arthropod pests yet only pyrethrum and neem are well established commercially (Isman, 2006). In India, a wide variety of commercial neem formulations have been tested and sold and newer ones continue being marketed by local formulators.

Evaluation of efficacy of neem formulations in rice

Wide ranging greenhouse and field studies were carried out at the Directorate of Rice Research (DRR), Hyderabad to evaluate the efficacy of ready to use neem formulations against the insect pests of rice (Krishnaiah *et al.*, 2008). Evaluation studies were carried out on two types of neem formulations *viz.*, i) Oil based formulations with 300 ppm of azadirachtin and ii) Solvent based formulations with 1500 ppm or more of azadirachtin. The studies focused on antifeedant, growth regulating, development-modifying and insecticidal effects.

Under glasshouse conditions, studies on feeding deterrent effects revealed that Rakshak and Neemgold 4 were superior to Neem Azal T/S in case of BPH and leaf folder. Mayabini Jena (2005) also reported that antifeedant and oviposition deterrent activities were more prominent than the knock down effects. In case of leaf hoppers and plant hoppers, disruption of growth resulted in reduction in size and weight of insects after feeding on plants treated with crude or commercial neem formulations. Consequently the proportion of nymphs becoming adults was also affected. However, in lepidopterous insects larval pupal intermediaries were observed (Krishnaiah and Kalode, 1988). Although there are reports that oviposition by BPH, WBPH and GLH are affected when confined to plants treated with neem oil or neem formulations, there was no consistency in such effects (Kalode and Krishnaiah, 1991). Further, studies with neem formulations (Krishnaiah *et al.,* 2000) revealed that the oil based neem formulations were more effective in oviposition deterrency than solvent based neem formulations as sprays. The studies have revealed that constituents other than Azadirachtin also play a role in exercising toxic effect against BPH. Some neem formulations with high azadirachtin content like Neem Azal T/S have exhibited some systemic activity when given as a seedling root dip adversely affecting the growth and development of BPH and GLH nymphs when confined to treated plants (Krishnaiah *et al.*, 2000). Neem formulations as spray also adversely affected the survival of BPH through toxic effects. Saikia and Parameswaran (2001) also reported more than fifty per cent mortality of leaf folder larvae after direct exposure to neem azal –F 5% treatment.

The extensive research on the field efficacy of neem products has included evaluation of several neem based formulations for the control of brown plant hopper, yellow stem borer and leaf folder. Field experiments at DRR as well as multi- location trials under the All India Coordinated Rice Improvement Programme (DRR, 1995-97) revealed that neem formulations *viz.*, Achook, Nimbecidine, Neemax, Neemgold and Econeem at recommended concentrations (2% in oil based formulation) were moderately effective against stem borer (6.5 to 7.1% dead hearts-DH and 10.2 to 11.6% white ears-WE) and leaf folder (17.0 to 26.0 average damaged leaves - ADL per 10 hills) compared to standard insecticide check (5.4% DH, 8.0% WE and 19.2% ADL) but were significantly superior to control (11.3% DH, 14.8% WE and 42.4% ADL). The neem formulations were not effective against rice gall midge. It is also evident from other studies that the neem formulations effectively controlled BPH and WBPH, moderately suppressed stem borers but were less effective against gall midge compared to recommended insecticides. In all these studies, standard check insecticide treatments yielded significantly higher than neem formulations (Korat *et al.*, 1999; Dash *et al.*, 2001; Multani *et al.*, 2002). However, there are also few studies reporting the superiority or parity of commercial neem formulations in their performance compared to the recommended insecticides both in terms of reducing pest incidence and resulting in higher yields (Kaul and Sharma, 1999; Prasad *et al.*, 2004).

Studies on safety of neem formulations to natural enemies

There has been a general impression that neem and other plant products are safe to non target organisms. But, studies on impact of neem formulations on natural enemies (i.e., beneficial predators and parasitoids that attack pests) have documented effects ranging from harmless to adverse (Lim Guan Soon and Bottrell, 1994). Crude formulations of neem such as neem oil, neem cake and other non-edible oils and cakes have been reported to be safer to natural enemies compared to synthetic insecticides (Dash *et al.*, 2001). Investigations carried out at DRR, Hyderabad have revealed that commercial neem formulations such as Neemax, Rakshak, and Fortune Aza were also safer to planthopper predators like velid bug, *Microvelia douglasi atrolineata* and mirid bug, *Cyrtorhinus lividipennis* and egg parasitoid, *Trichogramma japonicum* (Jhansilakshmi *et al.,*1997a, 1997b & 1998). However, Neem Gold, Neem Azal and NG4 resulted in high mortality of velid predator (Jhansilakshmi *et al.,* 1997a). Other workers have also reported the safety of Fortune Aza to egg parasitoids (Borah *et al.,* 2001; Srinivasan *et al.,* 2001).

Evaluation of neem formulations in combination with other components of IPM

In order to make best use of the neem formulations in IPM there is a need to optimize the number as well as timing of their applications to derive maximum benefits. Trials conducted at DRR, Hyderabad revealed that carbofuran 3G @ 0.75 kg a.i./ha applied at 25 DAT followed by two sprays of NG 4 (2%) at 50 and 70 DAT reduced pest incidence and increased grain yield similar to three sprays of monocrotophos (0.4 kg a.i./ha/ application) at 25, 50 and 70 DAT revealing the possibility of reducing environmental contamination without lowering either pest control efficiency or grain yield. Replacement of monocrotophos at 50 DAT with NG 4 maintained similar level of pest control and grain yield. However, three NG 4 applications at 25, 50 and 70 DAT resulted in lower insect pest control and grain yield (Krishnaiah *et al.*,2000). Increase in the effectiveness of neem products when combined with insecticides has also been reported (Sharma and Kaul, 2003). In deep water rice also, integrated treatments with neem components plus one or two synthetic chemical applications were found very effective in controlling the pest population build up as compared to chemical control (Chakraborti, 2003). In another field study, combination of botanicals with egg parasitoid, *Trichogramma japonicum* reduced populations of both stem borer and leaf folder as well as resulted in conservation of spider population, compared to insecticidal treatments (Sher Singh *et al.*, 2008). Neem formulations have also been found quite useful in reducing disease incidence in addition to insect pests when integrated with other non-pesticidal components of IPM. Dodan and Roshan Lal (1999) reported that combination of nimbecidine application with pre-transplanting incorporation of burnt rice husk and release of egg parasitoid, *Trichogramma japonicum* reduced the incidence of neck blast disease as well as stem borer damage in rice on par with that of recommended pesticide combinations. Evaluation of different IPM modules in farmers fields at Karakkad village, Pattambi, Kerala over three years showed that IPM module comprising of alternate spraying of econeem formulation with ecofriendly insecticides coupled with release of egg parasitoids against leaf folder and monitoring of yellow stem borer with sex pheromone traps resulted in significant reduction of stem borer and leaf folder incidence resulting in highest yield and cost benefit ratio (Karthikeyan *et al.,* 2010).

Future Scope of biopesticides in rice IPM

Over the past 25 years, the research on biopesticides has evolved towards being more ecologically holistic and more oriented towards both production systems and industry's concerns. In the rice IPM scenario, biopesticides provide environmental friendly options in many ways. The relatively shorter duration of persistence of the available botanicals can be suitably exploited to prevent secondary pest out breaks resulting from misuse of synthetic insecticide application. Synthetic pesticides with single active principle are likely to induce the development of resistance in insects. Botanicals on the other hand contain complex array of compounds with multiple effects and there is less likelihood of development of resistance. Therefore, wherever possible, botanicals can be alternated with synthetic pesticides to hinder the development of insecticide resistance. Concurrently, with advances in development of latest and more efficient analytical techniques, research on identification of newer active principles of these biopesticides may lead to synthesizing newer molecules with better efficacy and enhanced persistence under field conditions.

But the biopesticides face a number of constraints in their development, manufacture and utilization. Lack of multidisciplinary research, inadequate public private partnerships and poor understanding of their quality aspects, are the critical bottlenecks. Generally, farmers are accustomed to quick knock-down effects of pesticides. Therefore, they may not be satisfied with the slower action of biopesticides. There is, thus, a need to educate farmers about the special behavioural effects of these products and also create awareness among extension specialists and policy makers for the potential utilization of biopesticides. More focused research efforts in production, formulation and development of effective delivery systems are needed to effectively harness their potential and convince the farmers about their role as equally efficient and eco-friendly alternatives to conventional chemical pesticides.

In the recent years, there has been a spurt in efforts to develop organic pest management methods in view of the strong influence and growth of the organic foods market in the developed countries and biopesticides do find a place in this context. In India also, there has been a distinct trend in the decreased use of conventional chemical insecticides with a concomitant but gradual increase in consumption of biopesticides (Fig 2).

There are also reports of rice pests already developing resistance to even newly introduced agrochemicals leading to synthetic chemicals being registered at a slower rate than in the past. This situation has helped to reopen the market for a new generation of biopesticides. With fast paced changes in development of effective delivery systems and possibility of identifying newer potential biomolecules, a relook at the utility of biopesticides may be worthwhile in future.

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Table 1: Efficacy of neem products evaluated against insect pests of rice (Anand Prakash *et al.*, 2008)

Neem product & dose/ conc.	Type of application	Target insects	Biological activity	References
Neem oil	Spraying	Hydrellia phillipina	Antifeedant	Murthy (1975)
Neem oil	Spraying	BPH	Strong repellency	Balasubramanian (1979)
Neem oil 10%	Spraying	LF and GLH	Antifeedant ; Reduced life span	Mariappan *et al*. (1982a)
Neem oil	Spraying	GLH & RTV	Population reduction	Mariappan and Saxena (1983)
Neem oil	Neem oil coated urea	Hydrellia philippina, N. virescens and BPH	Reduced incidence	Krishnaiah and Kalode (1984)
Neem oil		L.oratorius	Deformity	Saxena *et al.* (1985)
Neem coated urea	Soil application	GM, GLH & RLF	Reduced incidence	David (1986)
Neem Seed Kernel Extract (NSKE)	Spray application using ULV sprayer	BPH, RLF	Checked incidences of the test insects	Rajasekaran *et al*. (1987)
Neem oil		BPH	Insecticidal activity	Velusamy *et al*. (1987)
Neem oil (1%), neem cake extract(5%)	Spraying	BPH and WBPH	Reduced emergence	Ramaraju & Sundarababu (1989)
NSKE 5%+0.16% teepol	Spraying	LF	Reduced population significantly	Mohan and Gopalan (1990)
3% neem oil	Spraying	GM	Reduced infestation	Samalo *et al*. (1990)
1-4% neem oil	Spraying	LF and YSB	Reduced incidences	Singh *et al.* (1990)
5% neem oil	Spraying	L. acuta	Reduced population	Gupta *et al*. (1990)

3% Neem kernel powder	Spraying	N. virescencs	Inhibited nymphal growth	Krishnaiah and Kalode (1990)
Neem cake @150 kg/ha + 3% neem oil spray	Soil application and Spraying	LF	Effectively checked insect infestation	Krishnaiah et al. (1990), Krishnaiah and Kalode, (1990)
Neem cake with urea	Soil application	GLH and WBPH	Reduction in population	Viswanathan & Kandiannan, (1990)
2% neem oil	Spraying	LF, Hieroglyphus banian	Reduced infestation	Mohan *et al*. (1991)
Neemax	Spraying	WBPH	Reduction in pest incidence	Shukla *et al*. (1991)
Welgro	Spraying	WBPH	Reduction in pest incidence	Shukla *et al*. (1991)
Neem oil @7.5 kg/ha	Spraying	BPH and WBPH	Reduced infestation	Sontakke. (1993)
Welgro2%	Spraying	GM and YSB	Reduced incidence	Nanda *et al.* (1993)
Nemidin 1000 ppm	-	WBPH	Inhibition of larval development	Nelson *et al*. (1993)
Neem oil	Spraying	Gall midge, stem borer, leaf folder and WBPH	Reduction in damage and effect on predators	Sontakke (1993)
Neem oil (3%) and neem seed kernel extract (5%)	Spraying	WBPH and GLH	Reduction in populations	Shukla and Kaushik (1994)
Neem oil	Spraying	WBPH	Reduction in population	Sontakke *et al*. (1994)
Neem seed kernel extract and neem cake extract	Seedling root dip – Greenhouse study	GLH	Reduction in population and effect on growth and emergence	Dash and Senapati (1994)

Neem cake @150 kg/ha	Soil application	Hydrellia philippina	Reduce damage of whorl maggots	Bhatia *et al*. (1994)
0.5 and 1.0% Achook	Spraying	L. acuta	Effectively controlled the pest	Prakash and Rao (1994)
Margoside CK and Margoside OK 1%	Spraying	5th instar BPH	57-80% mortality	Jena and Dani (1994)
Neem seed kernel extract (5%)	Spraying	Leaf folder	Reduction in damage	Latha *et al.* (1994)
Neem seed kernel extract (5%)	Spraying	Leaf folder	Reduction in damage	Latha *et al.* (1994)
Neem cake	Pot experiments with pellets	WBPH	Persistent toxicity	Logiswaran and Venugopal (1995)
Neem cake, neem seed kernel extract (5%), neem leaf decoction and neem oil (3%)	Soil application and spraying	Leaf folder	Reduction in leaf damage	Ambethgar (1996)
Neem oil and neem cake	Seedling root dip, soil application and spray	GLH, BPH and predators of BPH	Reduction in incidence of GLH and BPH. Little effect on predators.	Babu *et al*. (1998)
Nimbecidine, Neemax, Neem Gold, Neem Azal T/S and Fortune Aza	Spraying	Leaf folder, WBPH and stem borer	Reduction in pest incidence	Korat *et al* ,(1999)
Neem oil based formulations	Spraying	GLH and rice yellow dwarf disease	Reduction in GLH survival and incidence of disease	Rajappan *et al*. (1999)
NSKE 5%, Neem azal F 5%, Neem Azal T/S	Spraying	LF and egg parasitoid, Trichogramma chilonis	Contact toxicity	Prabal Saikia and Parameswaran (2001)
Neemazal	Spraying	Hispa	Reduction in damage	Sharma and Kaul (2003)

Neem seed kernel extract	Laboratory studies	Leaf folder	Effect on gut enzymes	Nathan *et al*. (2004)
Neem oil, Neem seed kernel extract and neem seed kernel powder	Spraying	Gundhi bug	Reduction in bug population	Singh (2006)
Neem limonoids	Laboratory studies	Leaf folder	Toxicity and behavioural effects	Nathan *et al*. (2006)
NSKE 5%, Neem Oil 3%, Neem Leaf Extract 3%	Seed Treatment, Seedling root dip and Foliar spray	WBPH	Effects on survival and growth index	Sujeetha (2008)
Multiplex	Spraying	Gundhi bug	Reduction in grain damage	Singh *et al*. (2009)

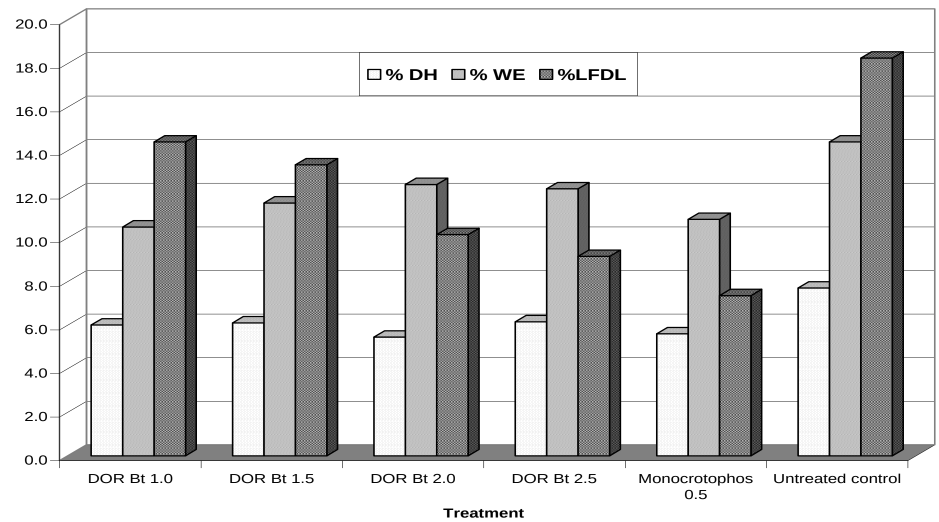

Figure 1: Efficacy of DOR Bt formulation against major rice pests (AICRIP, 2007-08)

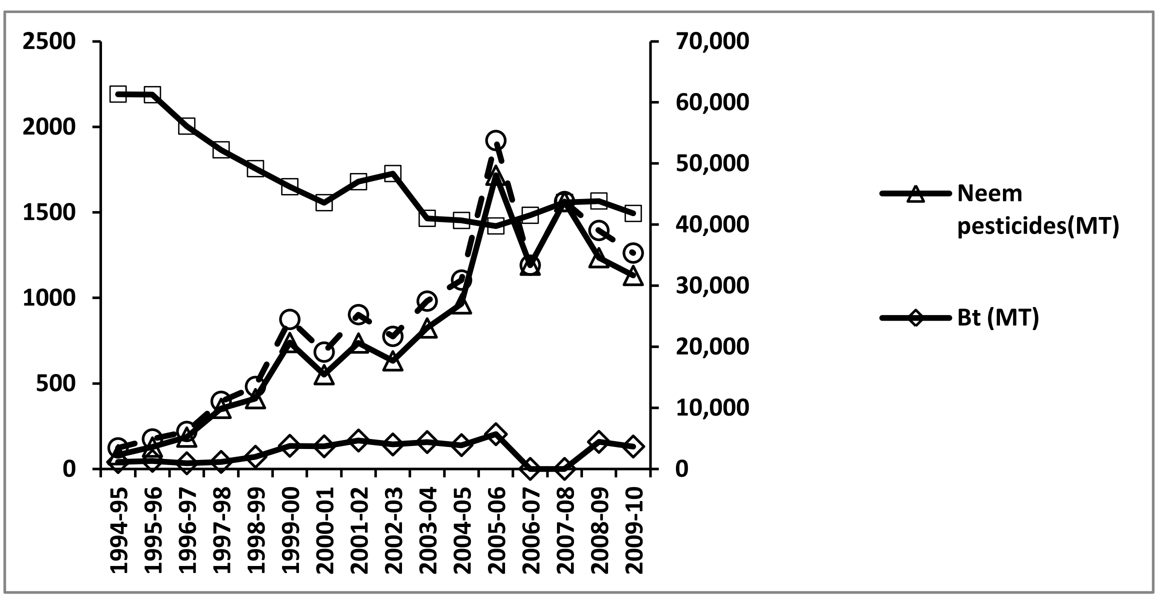

Figure 2: Consumption of pesticides (Metric Tonnes-MT) in India (1994-2010)

(Directorate of Plant Protection, Quarantine & Storage, Faridabad)