Novel strategies for overcoming pests and diseases in India

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Abstract

The losses incurred due to pests and diseases have been a consistently reported feature. Changes in cropping patterns including the cultivation of high yielding varieties and hybrids have added to the problem in some areas. Plant breeding has been successful to some extent in keeping up with new and evolving diseases and pests. Innovation in agronomic practices, advent of chemicals for control, and more recently genetic engineering tools have been providing new opportunities for reduction of crop losses due to these biotic pressures. Insect control is even more important as many viral diseases are transmitted by insects. Molecular markers and other genomics information are allowing more precision in breeding for greater tolerance to diseases in many crops. India has commercialized genetically modified cotton which provides resistance to the bollworm complex of pests. Broad spectrum resistance is now possible with genetic engineering. Marker assisted breeding is being used in rice and other crops for disease resistance strategy. Still better understanding the mechanism of resistance for disease and pests, will allow better deployment of technologies for different pests and diseases.

Media Summary

Losses caused by plant diseases and pests are as old as plants themselves. Various strategies to control diseases and pests have been successful to different levels. New biotechnology tools are providing new levels of protection against certain pests and diseases. Both genetically engineered crops and utilization of molecular tools are improving plant breeding effectiveness.

Key words

GMOs, transgenes, Molecular markers, losses due to pests and disease

Introduction

One of the most important crop improvement objectives has been the enhancement of tolerance to biotic stresses. Identification of resistance sources and use of these in plant breeding programs has resulted in substantial gains in crop productivity. Despite the ongoing efforts, productivity in India for major crops is far below the global averages, largely due to persisting problems of pests and diseases. India also witnessed the epidemic of brown spot of rice in 1942 which led to large scale famine and large number of deaths. In addition, abiotic stresses like drought and salinity, resource inputs in the form of seeds, fertilizers, pesticides and water also play a role in lower productivity.

Crop biotechnology is providing unique opportunities to produce plants with desired genetic traits which had been difficult to achieve using conventional techniques. Genetically Modified Crop (B.t. Cotton) has been approved in India for commercial cultivation and is already providing substantial benefits to the farmers by providing enhanced protection against cotton pests, particularly bollworm complex. Many other products are also in the regulatory pipeline. Regulatory/Biosafety guidelines are in place in India that provides a framework for conducting genetic engineering activities in plants. In addition to the GM crops, many new tools have become available which provide greater effectiveness of the breeding efforts, such as the use of molecular markers.

Strategies for control of disease and insect pests

Green revolution has brought in the necessary impetus to Indian agriculture making India self sufficient in food grains and great improvement in production of other crops as well. However, the high input demands require that we re-look at how technologies can be deployed that are sustainable and improve productivity. With increase in pest problems and resultant indiscriminate use of pesticides there is concern of environmental problems and ecological imbalance (Zadoks and Waibel, 1999). India consumes nearly USD 630 million worth of pesticides annually in agriculture, of which USD 380 million worth are used on the cotton crop alone for the control of bollworms and sucking pests. It is estimated that about USD 250 million worth of pesticides are used only for the control of bollworms in cotton (Anonymous, 2001). Other key pests of similar importance are yellow stem borer in rice, stem borers of sorghum and maize, fruit and shoot borer of brinjal, fruit borer of tomato and diamond back moth of cruciferous crops, cabbage and cauliflower. These pests are perennial and persistently causing losses to these economically important crops. Farmers are unable to control these pests to desired level in spite of spending millions of dollars on pesticides. As one possible alternate strategy to chemical pest control, genetically engineered crops and microbial pesticides can be used due to their effectiveness. In India, transgenic Bt crops are under intense trials and Bt cotton has been approved for commercial cultivation. More such crops are likely to enter the scene in the near future because the benefit of transgenic crops far outweighs the perceived risks associated with these.

Crop losses by insect pests

India is basically an agricultural country and it has most variable climatic regions owing to its geographic features. Total arable land area is 168 m ha and major part of it falling under tropical climate, and a variety of cereals, oil seeds, pulses, vegetable and horticultural crops are being cultivated (Table.1). India has achieved self sufficiency in food grains but there is an urgent need to improve our productivity in all crops to meet future challenges. India needs to produce additional 5 - 6 m t of food grains every year to keep pace with the growth of our population (Paroda, 1999). In realizing this, one of the important stumbling blocks seems to be the yield losses due to insect pests. There is an urgent need to assess such losses, in order to frame strategies to overcome them.

Table 1: Area and production of important field crops in India (2000-2001)

Crop	Area m ha	Production m t	Productivity Kg /ha
Rice	44.36	84.87	1913
Wheat	25.07	68.76	2743
Sorghum	9.99	7.71	772
Maize	6.56	12.07	1840
Pigeonpea	3.68	2.26	616
Food grains	119.78	195.91	1636
Rape seed & Mustard	4.47	4.21	941
Castor	1.08	0.86	805
Safflower	0.43	0.2	473
Sunflower	1.33	0.73	549
Cotton	8.58	9.65	191
Chilli*	0.92	1.02	1112
Vegetable & root crops	6.25	93.92	15031
Onion	0.45	4.72	10517

Banana	0.48	16.17	33486
Cabbage	0.25	5.62	22890
Cauliflower	0.26	4.7	18317
Okra	0.35	3.35	9581
Tomato	0.46	7.28	15865

Source: Center for Monitoring Indian Economy- December, 2002, (data available for 1999-2000)

Therefore to assess the yield losses, studies are being carried out systematically, still the losses caused by individual pests are not distinguished from the whole pest complex. Yield loss estimates vary depending on type of cultivar, density of pest population, time of pest attack in relation to crop phenology and cultural practices followed,. Another problem is that most of the studies are conducted in small experimental plots in research stations rather than in farmers' fields, which may not give the exact picture of the losses caused. Here the focus is on the important pests belonging to Lepidoptera, Diptera and Coleoptera causing economic losses to field crops and the role played by transgenics in overcoming such losses. A survey carried during 1950s revealed that fruits, cotton, rice and rice and sugarcane suffered significant yield losses due to insect pests (Pradhan, 1964) (Table 2).

Table 2: Losses in field crops due to insect pests under traditional agriculture

Crop	Loss in yield (%)
Rice	10
Wheat	3
Maize	5
Sorghum & millets	5
Cotton	18
Sugarcane	10
Fruits	25

Introduction of high yielding varieties together with increasing application of agrochemicals increased the productivity of land with a concomitant increase in the proportion lost to insect pests in India and other developing Asian countries (Dhaliwal and Arora, 1994). Conservative estimates project direct losses due to insect pests amount to USD 6350 million annually (Table 3). However, even the limited information available from various sources reveals that crop losses due to insect pests are higher for the region than for the other parts of the world (APO, 1993) (Table 4).

Table 3: Estimated crop losses caused by insect pests under modern agriculture*

Crop	Actual production (1993-94) (Mt)	Estimated loss in yield due to insect pests		Possible production in the absence of pest	Estimated losses (million USD)
		Percent	**Total (Mt)**		
Rice	**79**	**25**	**26.3**	**105.3**	**2058**
Wheat	**59.1**	**5**	**3.1**	**62.2**	**263**
Maize	**9.5**	**25**	**3.2**	**12.7**	**215**
Sorghum and millets	**16.5**	**35**	**8.9**	**25.4**	**580**
Pulses	**13.1**	**30**	**5.6**	**18.7**	**815**
Groundnut	**7.8**	**15**	**1.4**	**9.2**	**273**
Rapeseed - Mustard	**5.4**	**35**	**2.9**	**8.3**	**523**
Seed cotton	**5.4**	**50**	**2.7**	**10.8**	**675**
Sugarcane	**227.1**	**20**	**56.8**	**283.9**	**950**
		Total			6354

*Source: Dhaliwal and Arora(1996)

Insect pests on an average cause 25-30% yield loss in vegetables. Diamond back moth is the most important pest of cruciferous crops, which has developed resistance to several classes of insecticides. It has become a menace in cabbage and cauliflower causing up to 52 % losses in marketable yield in India. In brinjal shoot and fruit borer has remained major pest since two decades due to poor natural enemy complex and extensive use of pesticides. The pest starts infesting the shoot tips few weeks after transplanting and bores in to fruits till harvesting. Crop losses in brinjal due to shoot and fruit borer ranges from 25.82-92.50 % and yield reduction of 20 – 60 %. Another key pest of brinjal is the stem borer, which tunnels in to stem and cause plant to wither and die. Of late its infestation is growing to epidemic proportions in some states. Hadda beetles devastate the crop in some pockets, where adult beetles as well as grubs feed on the foliage and completely skeletonise the brinjal plant. In okra, fruit borer is the main pest and the larva bores in to shoot or fruit eating on internal contents causing withering up of plant and reduction in marketable value of the fruit. In tomato Helicoverpa is the key pest and it feeds on buds, flowers and fruits causing on an average 46% yield loss.

Table 4. Major insect pests (Lepidoptera, Diptera and Coleoptera) of field and vegetable crops and extent of losses caused by them

Crop	Major pests		Insect Order	% Crop loss	Reference
	Common name	***Scientific name***			
		Cereals			
Rice	Stem borer	*Scirpophaga incertulas*	Lepidoptera	10 – 48	AICRIP, 1988
	Leaf folder	*Cnaphalocrocis medinalis*	Lepidoptera	10 – 50	Nair, 1995
	Whorl maggot	*Hydrellia spp*	Diptera	20 – 30	Nair, 1995
	Gall midge	*Orseolia oryzae*	Diptera	8 - 50	Nair, 1995
	Hispa	*Dicladispa armigera*	Coleoptera	6 – 65	Nair, 1995
Wheat	Ghujia weevil	*Tanymecus indicus*	Coleoptera	NA*	
	Army worm	*Mythimna separata*	Lepidoptera	20 - 42	Mathur, 1994
Sorghum	Stem borer	*Chilo partellus*	Lepidoptera	55 - 83	Jotwani, 1971
	Oriental army worm	*Mythimna separata*	Lepidoptera	55.7	Giraddi and Kulkarni, 1983
	Pink borer	*Sesamia inference*	Lepidoptera	NA	
	Shoot fly	*Atherigona soccata*	Diptera	22 - 80	Taneza and Nwanze, 1994

	Earhead caterpillar	*Helicoverpa armigera*	Lepidoptera	18 – 26	Rawat et.al, 1970
Maize	Stalk borer	*Chilo partellus*	Lepidoptera	24 - 36	Chatterji et.al, 1969
	Shoot fly	*Atherigona soccata*	Diptera	10 – 61	Nair, 1995
	Pink borer	*Sesamia inference*	Lepidoptera	NA	
		Pulses			
Pigeonpea	Pod borer	*Helicoverpa armigera*	Lepidoptera	14 – 100	Nath et.al, 1977
	Pod webber	*Maruca testulalis*	Lepidoptera	20 - 60	Singh and Allen, 1980
	Pod fly	*Melanagromyza obtusa*	Diptera	10 – 60	Nair, 1995
		Oil seeds			
Sunflower	Capitulum borer	*Helicoverpa armigera*	Lepidoptera	30 – 60	Dhaliwal & Arora, 1994
Safflower	Safflower caterpillar	*Prospalta capensis*	Lepidoptera	NA	
Mustard	Diamond back moth	*Plutella xylostella*	Lepidoptera	NA	
Castor	Semi looper	*Achoea janata*	Lepidoptera	NA	
	Capsule borer	*Conogethes punctiferalis*	Lepidoptera	15 – 41	AICRP, 2001-02
		Fiber crops			

Cotton	Spotted bollworm	*Earias vittella*	Lepidoptera	30 – 40	Panwar, 1995
	American bollworm	*Helicoverpa armigera*	Lepidoptera	20 – 80	Monga and Jeyakumar, 2002
	Pink bollworm	*Pectinophora gossypiella*	Lepidoptera	20 – 95	Panwar, 1995
	Tobacco caterpillar	*Spodoptera litura*	Lepidoptera	NA	
		Vegetables			
Cabbage	Diamond back moth	*Plutella xylostella*	Lepidoptera	20 - 52	Chellaiah & Sreenivasan, 1986
	Cabbage webber	*Crocidolomia binotalis*	Lepidoptera	NA	
	Cabbage borer	*Hellula undalis*	Lepidoptera	NA	
Cauliflower	Diamond back moth	*Plutella xylostella*	Lepidoptera	20 - 52	Chellaiah & Sreenivasan, 1986
Okra	Shoot and fruit borer	*Earias vittella*	Lepidoptera	NA	
	Fruit borer	*Helicoverpa armigera*	Lepidoptera	NA	
Tomato	Fruit borer	*Helicoverpa armigera*	Lepidoptera	15 - 46	Singh, 1991
Brinjal	Shoot and Fruit borer	*Leucinodes orbonalis*	Lepidoptera	25 – 92	Mall, 1992
	Stem borer	*Euzophera perticella*	Lepidoptera	NA	
	Hadda beetle	*Epilachna vigintioctopunctata*	Coleoptera	NA	

		E. dodecastegma	Coleoptera	NA	
Chilli	Fruit borer	*Helicoverpa armigera*	Lepidoptera	NA	
	Fruit borer	*Spodoptera litura*	Lepidoptera	NA	
Melons	Melon fruit fly	*Dacus cucurbitae*	Diptera	50 - 100	Panwar, 1995
	Pumpkin beetle	*Raphidopalpa foveicollis*	Coleoptera	NA	
		R. intermedia	Coleoptera	NA	
		R. cincta	Coleoptera	NA	

NA* – Not available

Crop losses caused by diseases:

Bacterial blight of rice assumed epidemic proportions in India in the early 1960s. Similarly rice tungro and yellow dwarf also appeared in different areas. *Alternaria* blight in wheat, downy mildew in pearl millet, sterility mosaic and *Alternaria* in pigeon pea continues to be critical.

Plant diseases present a major constraint to sunflower production and can lead to significant reduction of harvested seeds as well as the quality. More than 30 fungal diseases are reported for sunflower with only a few of them being pathogenic and infectious. Downy mildew, rust, verticillium wilt, Alternaria spot are some of the diseases that can lead to 15% production loss. Viral diseases had not been reported until recently in sunflower. Parts of India have seen epidemic proportion incidence by Tobacco Streak Virus (TSV) resulting in 6- to 100% loss due to sunflower necrosis.

Geminiviruses cause significant crop losses in crops like cotton, tomato, okra, chilli and others. Despite the amount of effort that has gone into geminivirus control research, no sustained resistance has been found.

Plant viruses also cause considerable damage to various cucurbits including bottle gourd. Nearly, 30 viruses are known to infect cucurbit crops under field conditions (Lovisolo, 1980). Viral diseases result in losses through reduction in growth and yield and are responsible for distortion and mottling of fruits, making the product unmarketable. Fruit set can be dramatically affected by some viruses. With the exception of *Squash mosaic virus* (SqMV), which is seed borne in melon and transmitted by beetles, the other major viruses are transmitted by several aphid species in a non-persistent manner. Some major Cucurbit viruses include *Squash mosaic virus* (SqMV), *Cucumber mosaic virus* (CMV), *Watermelon mosaic virus 2* (WMV-2), Papaya ringspot virus - W (formerly, *Watermelon mosaic virus 1)*, and *Zucchini yellow mosaic virus* (ZYMV). *Tobacco ringspot virus*, *Tomato ringspot virus*, *Clover yellow vein virus*, and *Aster yellow mycoplasma* were considered to be minor viruses, that infect cucurbits. Bottle gourd is affected mainly by Cucumber green mottle mosaic- tobamovirus, Melon necrotic spot- carmovirus, and Zucchini yellow fleck- potyvirus. Bottle gourd mosaic disease is widely prevalent in almost all the bottle gourd growing states of India, causing losses through reduction in growth and yield.

Technology deployment

Transgenic Bt cotton for pest control

The bacterium species *Bacillus thuringiensis* has contributed numerous proteins that provide insecticidal properties for improvement in crop production. On such Bt protein, CryIAc, has been used globally for protection of cotton plants against Bollworm species, through both external spray application and insertion of the Bt gene responsible for CryIAc protein production into the genome of cotton varieties (known as “genetically modified” or “transgenic” cotton). The advantage of transgenic Bt cotton is based on the inherent production of Bt protein by the cotton plant itself, thereby providing continual protection for plant parts against Bollworm pests. From a global perspective, in the year 2001 Bt cotton was commercially grown in 7 countries and on approximately 4.3 million hectares. All such countries commercializing Bt cotton in 2001 were based on variety cultivation. India was the first country to introduce commercial cultivation of Bt using hybrid cotton technology, in the year 2002.

The major benefits of Bt cotton cultivation globally have been: 1) substantial reduction in Bollworm insecticide usage, and 2) potential for productivity (yield) improvements due to the inherent Bollworm protection. The Bt gene currently being utilized for cotton hybrid cultivation in India is effective against three species of Bollworm pest (commonly known as “American”, “Pink”, and “Spotted”) which damage cotton bolls through feeding, and result in substantial yield loss with adverse impact on cotton lint quality. India is also the greatest consumer of synthetic insecticides for use in cotton cultivation, and therefore deployment of Bt cotton can be beneficial for Indian agriculture through reduction in insecticide usage, in addition potential yield gains.

In India Bt cotton is permitted for commercial cultivation. In addition to the above GEAC recommended following guidelines to Bt cotton growers to counter the possible development of resistance to *inplanta* expressed Bt toxin by bollworms.

- Plant one seed per hill, Bollgard? cotton should be planted in the centre of the plot. For one acre area plant 5 rows of non-Bollgard? cotton seed (as refuge belt) surrounding the Bollgard? plot.
- For more than one acre area, the field where Bollgard? cotton is planted shall be fully surrounded by a belt of land in which non-Bollgard? variety shall be sown. The size of the refuge should be such as to take atleast 5 rows of non-Bollgard? cotton or shall be 20% of the total sown area whichever is more

Experimental results from multi location trials suggest that by cultivating Bt cotton, farmer can save a minimum of 50 % amount spent on insecticidal sprays against bollworms (Ghosh, 2001). The experimental trials are underway for other important crops like rice, sorghum, maize, pigeonpea, tomato, brinjal, cabbage and cauliflower, to introduce the transgenic technology and relieve the woes of farmers ravaged by loss of their crops due to pest problems.

IPM interventions

- Seed treatment with chemical pesticides to avoid sucking pests attack.
- Inter cropping with legumes to augment natural enemy population and trap cropping to reduce damage by important pests to main crop.
- Bird perches for alighting insectivorous birds to predate on insects.
- Pheromone traps for monitoring or mass trapping of moths.
- Scouting to monitor status of pests and beneficials at regular intervals.
- Augmenting biocontrol agents like *Trichogramma / Chrysoperla.*
- Spraying biopesticides like Ha NPV and neem seed kernel extract (NSKE).
- Topping the cotton plants at the time of high oviposition by *Helicoverpa.*
- Periodical removal and destruction of dropped squares, dried flowers, premature bolls and infested shoots.
- Yellow sticky traps and light traps to control sucking pests like white flies, jassids and aphids.

Chemical control

- Need based use of chemical insecticides.
- Avoidance of external application of Bt products when Bt cotton is grown.

Disease resistance: Geminivirus control as an example

Obtaining crops resistant or tolerant to the geminiviruses is very difficult, because their insect vector, the whitefly *Bemisia tabaci*, is difficult to control as whiteflies are developing resistance to insecticides and are increasingly spreading over larger parts of the world. No commercial crop variety is tolerant or resistant to these viruses because the resistance achieved through classical breeding is overcome by emergence of new viral strains or species. Further Geminiviruses have complex lineage as they cause similar diseases in different geographical areas, such as the Indian subcontinent, the African/Mediterranean region or the Americas but are different from each other. The studies on the putative functions of genes from different gemini-viruses led to development of viral genes mediated resistance against geminiviruses. Tobacco primary transformants expressing anti-sense RNA to the AL1 gene of tomato golden mosaic virus (TGMV) were partially resistant to TGMV. But most of the time geminivirus DNA derived resistance was limited to particular strain of virus with a narrow resistance spectrum as has been reported as in transgenic tobacco. As researchers have reported evolution of new viruses or virulent strain of gemini-viruses that are associated with severe epidemic and spread of viral disease to areas that were previously unaffected. The natural recombinant between two or more distinct geminiviruses by processes such as deletion, inversion, duplication and rearrangement are frequent because of broad host range of geminiviruses, irrespective of their preferred host and due to their mixed or co infections. Hence crop plants are prone to infection by more than one gemini virus at a time. Therefore, developing new strategies to produce geminivirus resistant plant has become more important in recent years. An attempt to endow plants with broad-based resistance against rapidly expanding family of gemini viral pathogens has been initiated in the recent years. One such strategy is to equip plants with a gene 5 protein (g5p) from an *Escherichia coli* M 13 phage. The g5 protein during rolling circle replication binds non-specifically and preferentially to viral single stranded DNA forming superhelical g5-ssDNA complexes and prevented movement of geminivirus in wild *Nicotiana benthamiana* plants inoculated with ToLCV-Nde isolate modified to produce g5 protein in place of ToLCV coat protein. Similarly in Tomato and Okra, tolerance is seen against many viral strains from across the country in India when the plants carrying g5 are challenged with viriferous whiteflies. These plants are now been evaluated in the greenhouse and undergoing the Indian biosafety regulations.

Conclusion

With increasing availability of information and understanding on how plant pathogens and pest cause damages, new strategies are being devised to enhance protection that is possible. Plant breeding and biotechnology tools in combination are already providing new materials for better plant management. The pest management tools that have been deployed have had a positive impact on the environment by reducing the amount of chemical pesticides that are applied to these crops.

References

Anonymous 2003. Bt cotton seeds of plenty; Empty promise, Times of India, March, 15.

APO, 1993. Pest control in Asia and Pacific. Report of a seminar. Sept. 24 – Oct. 4, 1991. Asian productivity Organization, Tokyo, Japan.

Chatterji, S. M., Young, W. R. Sharma, G. C., Sayi, I. V., Chahal, B. S., Khare, B. P., Rathore, Y. S., Panwar, V. P. S. and Siddiqui, K. H. 1969. Estimation of losses in yield of maize due to insect pests with special reference to borers. Ind. J. Ent. 31:109 – 115.

Chellaiah, S. and Srinivasan, K., 1986. Bio ecology and Management of diamond back moth in India. In:" Diamond back moth Management Proceedings of International workshop, Thainan, 11 -15, March, 1985. AVRDC, Taiwan, pp 63 – 76.

CMIE (Center for Monitoring Indian Economy) Agriculture. December, 2002, Mumbai.

Dhaliwal, G. S. and Arora, R. 1994. Trends in agricultural insect pest management. Commonwealth Publishers, New Delhi.

Dhaliwal. G.S. And Arora. R. and Heinrichs, E. H., 1998. Insect pest management. In " G. S. Dhaliwal and E. H. Heinrichs, (eds), "Critical issues in insect pest management.". Commonwealth Publishers, New Delhi, pp: 1 – 25.

Ghosh, P. K., 2001 Genetically engineered crops in India with special reference to Bt cotton. IPM Mitr. (2):8-28.

Giraddi, R. S. and Kulkarni, K. A. 1983. Estimation of crop losses in sorghum due to armyworm Mythimna separata (Walker)(Lepidoptera:Noctuidae). In "Crop losses due to insect pests (eds. Krishnamurthy Rao, B. H. and Murthy, K. S. R. K.) Special issue of Ind. J. Ent. Pp: 235 – 246.

ICRISAT (International Crop Research Institute for Semi Arid Tropics) 1992. The medium term plan. ICRISAT, Patancheru, Andhra Pradesh, India.

Jadocs, J. C. and Waibel, H. 1999. From pesticides to genetically modified plants: History, economics and politics. Netherlands J. Agril. Sci. 48 pp:125-149.

Jotwani, M. G., Chandra, D., Young, W. R., Sukhani, T. R., Saxena, P. N. 1971. Estimation of avoidable losses caused by insect complex on sorghum hybrid CSH 1 and increase in yield over untreated control. Ind. J. Ent. 33:375 – 383.

King, A. B. S., 1994. In : Matthews, G. A., Tunstall, J. P. (eds.), Insect pests of cotton. Commonwealth Agricultural Bureau International, UK, pp: 39 – 106.

Krishnaiah, K. 1993. Changing scenario of rice insect pest problems. In :H. C. Sharma and M. Veerabadra Rao (eds.) Pests and pest management in India – The changing scenario. Plant Protection Association of India., Hyderabad. Pp:11 – 18.

Lovisolo, O. 1980. Viruses and viroid diseases of cucurbits. Acta Hortic. 88:33-82

Mall, N. P., Pande, R. S., Singh, S. V. and Singh S. K., 1992. Seasonal incidence of insect pests and estimation of losses caused by shoot and fruit borer on brinjal. Ind. J. Ent 54(3):241 – 247.

Mathur, L. M. L, 1994. Advances in insect pest management in maize. In " Trends in agricultural insect pest management ". Commonwealth Publishers, New Delhi, pp: 113 – 160.

Monga, D and Jeyakumar,P., 2002. Cotton field ecology-Introduction to insect pest and diseases in relation to growth and development. In " National training course on IPM in cotton, rice and vegetable crops", NCIPM, New Delhi.

Nair, M. R. G. K., 1995, Insects and mites of crops in India.

NASS USDA report 2001, Acerage.

Nath, D. K., Sen B. and Pal, S. R., 1977. Insect pests occurring in Sunflower, Helianthus annuus in west bengal. Sci and Cult. 43: 180 – 181

NCIPM Annual Report, 2001 – 2002.

Panwar, V. P. S., 1995. Pests of fiber crops. In " Agricultural insect pests of crops and their control". pp. 87- 104.

Paroda, R. S. 1999. For a food secure future. Hindu survey of Indian agriculture.

Pradhan, S. 1964. Assessment of losses caused by insect pests of crops and estimation of insect population. In: Entomology in India. Entomological Society of India, New Delhi, India, pp: 17 – 58.

Rawat, R. R., Jakhmola, S. D. and Sahu, M. R. 1970. Assessment of losses of hybrid sorghum CSH 1 to earhead caterpillar and comparison of insecticidal controls. PANS 16: 367 –369.

Sarup, P., Sharma, V. K., Panwar, V. P. S., Siddiqui, K. H. and Aggarval K. N., 1977. Economic threshold of Chilo partellus (Swinhoe) infesting maize crop. J. Ent. Res. 1: 92 – 99.

Singh, D. 1991. Pests of solanaceous vegetables in "A decade of research on pests of horticultural crops, 1980 – 1990", Group discussion of entomologists working on coordinated prioject of horticultural crops held at CIHNP, Luknow.

Singh, R. P., and Allen, D. R.1980. Pests, diseases, resistance and protection in cowpea. Pages 419 – 443. In "Advances in legume science" (Summerfield, R. J., and Bunting, A. H., eds.). Kew, Richmond, Surrey, UK: Royal Botanic Gardens.

Taneja, S. L. and Nwanze., K. F., 1994. Current status and strategies for management of insect pests of sorghum and millets. In "Trends in agricultural insect pest management ". Commonwealth Publishers, New Delhi, pp: 161 – 185.