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Review

Plant protection: Paramount to food security in India

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India carries the heavy burden of feeding a billion plus population. While it is a challenge in itself, the task is compounded further by limited resources and crop losses due to pest and diseases. Though beating the odds of diminishing land and water resources remain bleak, pest and disease inflicted crop losses can be managed with suitable crop protection techniques. Pesticide, integrated pest management (IPM), biopesticdes, Bt technology among many others have been in use for pest and disease management. Unfortunately in India, the presence of these crop saving measures and techniques have not been able to tame the mounting crop losses. The future of India's agriculture depends a lot on developing a suitable and economically feasible plant protection exercise.

Key words: Plant protection, pesticides, food security, integrated pest management (IPM), biopesticides, India.

INTRODUCTION

Ever-growing population, climatic changes and unprecedented losses due to pests and diseases pose serious threat to food security. Precisely food security implies availability of adequate food to everyone in all times to come. Food is one of the three basic needs of man, without which his survival is at stake. Plants constitute the basic source of food. Healthy plants not only guarantee bountiful harvest but ensure nutritional essence as well. Plants are to be nurtured like a child from the very beginning to prevent invasion from biotic and abiotic agents by employing integrated crop management. Plant health management is crucial to food security, which is jeopardized due to unprecedented threat by large number of insect-pests, diseases, weeds and several edaphic and environmental stresses. Every year in India, pests and diseases eat away, on an average, 20 to 30% of food, worth about Rs. 50,000 crore, produced by the farmers. Due to unabated rise in population, reduction in arable land will be an ongoing process, hence we may have to strive hard to grow more food from limited land, employing innovative strategies and more importantly adopting multipronged initiative and timely diagnostic and management strategies to combat attack from pests and environmental stress, and manage plant health to mitigate losses. This review presents: (1) Protection through pesticides, (2) benefits of pesticide use, (4) nano and spurious pesticides, (5) modern pesticide application technologies, (6) pesticide residue, (7) promotion of biocontrol, IPM and organic farming, (8) GM crops and (9) future of plant protection.

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PLANT PROTECTION

Plant protection is the science and practice of managing pests, plant diseases, weeds and other pest organisms that damage agricultural crops and forestry. Agricultural crops include field crops (maize, wheat, rice, etc.), vegetable crops (potatoes, cabbages, etc.) and fruit and horticultural crops.

Major thrust areas of plant protection

The major thrust areas of plant protection are:

1. Promoting integrated pest management (IPM).
2. Ensuring availability of safe and quality pesticides for sustaining crop production from the ravages of pests and diseases.
3. Coordinating the quarantine measures for reporting, detecting and eliminating exotic pests.
4. Fulfilling the requirements set out in the WTO/SPS agreement and protocols including the preparation of a country pest list, conducting pest risk analyses and surveillance for economically important pests and diseases.
5. Testing bio-pesticides (bio-rationals) and other chemicals generally regarded as safe (GRAS) to ensure that they afford the farmer the protection needed and to put in place the necessary regulations for the importation of these bio-pesticides.
6. Ensuring that the country is well served with respect to being able to respond, identify and manage new pest incursions. This involves the continued close relationship with the Plant Quarantine section and focuses on strengthening existing laws and regulations as well as providing technical expertise and training to the quarantine staff.
7. Assisting in the education of farmers, schools and other tertiary institutions and the public in general about pests and diseases of plants.

Protection through pesticides

Plant diseases and other pests cause 40% reduction in yield worldwide (Oerke et al., 1994). As per recent estimates every year in India, pests and diseases eat away, on an average, 20 to 30% of food, worth about Rs. 50,000 crore, produced by the farmers (Agriculture Today, 2014). Pesticides play an important role in plant protection. Pesticides are the basic tools for managing plant pests. Man in his endeavor to provide protection to plants and ensure food availability to ever growing population has greatly depended on pesticides, which have been used since 19th century. I earnestly believe that pesticide would still continue to be used as the most important arsenals of controlling plant pests to ensure food security. However, their use has to be made judiciously, which unfortunately is not, and their reckless and indiscriminate use has created more problems. Pesticides came under serious criticism with the publication of ‘Silent Spring’ in 1962 by Carson (1962), who apprehended threat to man and environment. Another publication, ‘Silent Spring Revisited’ by Marco et al. (1987) also corroborates the concerns of Rachel Carson. Today, indiscriminate use of pesticides has undoubtedly adversely affected ecological balance resulting in pest resurgence, aggravation of minor pests, pesticide resistance, and environmental pollution and more importantly their residues in food and feed, posing serious health hazards to man and animal. The use of endosulfan in Kerala has created furor due to unprecedented health hazards leading to neurological problem in children which led to the ban of the pesticide in Kerala (Srivastava, 2013). Now the big question before us is – whether pesticides are really responsible for hazards or its man’s folly which has created these problems? This paper will now probe and see what best can be done for the society.

In India, pesticide use, which is approximately 500 g/ha is too small as compared to those in developed nations such as UK, USA, China and Japan (Table 1) and therefore I leave it to you to think and ponder whether such low amount can pose threat to the environment. In India, 229 pesticides are registered as against 5487 in China. Amongst registered pesticides in India, fungicides are hardly 39 in number (Srivastava, 2013). Indigenous production of pesticides is more than the domestic consumption and a large quantity of pesticides is being exported to foreign countries. However, the consumption of chemical pesticides has declined from 75,033 metric tones in terms of technical grade in 1990-91 to 50583 metric tones in 2011-12 (Bhardwaj and Sharma, 2013). Managing the pest problem with less number of pesticides is a good sign and efforts are being made to encourage introduction of more low volume and high efficiency pesticides. The major benefits of pesticides are:

1. Use of pesticides improves crop yields.
2. It helps to keep food prices in check for the consumer.
3. Pesticides allow consumers to consume high-quality produce that is free of insect blemishes and insect contamination.
4. Pesticide products are used to control household pests like termites, roaches, ants, rats and other pests.
5. Herbicides are used to control vegetation that clogs navigable and other waterways or threatens to obstruct highway, utility and railroad rights of way.
6. Pesticides are used to protect and enhance lawns, gardens, public parks, playing fields, lakes and ponds for public enjoyment.

There are wide inter-state disparities in the consumption of pesticides. While states like Andhra Pradesh, Uttar

Table 1. Pesticides consumption in some of the major countries.

Name of country	Pesticide consumption (Kg/ha)
USA	7.0
Europe	2.5
Taiwan	17
Japan	12
Korea	6.6
India	0.5

Pradesh and Maharashtra recorded high consumption of pesticides during the year 2011-12, states like Jharkhand, Odissa, Himachal Pradesh, Uttaranchal and the north eastern states recorded very low consumption of the same during the said period. Though the consumption figures for states like Jharkhand and Uttaranchal showed improvement in recent times, the total quantity of pesticides consumed is still very less. Further, there are wide variations in consumption of pesticides in respect of certain states from year to year. For example, while Andhra Pradesh recorded a consumption of 1541 metric tons of technical grade pesticides during 2007-08, the same declined to 1015 MT during 2009-10. The State recorded a huge rise in consumption during 2010-11 at 8869 MT but declined a bit to 8529 MT during 2011-12. Rajasthan's consumption figure of 3804 MT during 2007-08 came down to 1652 MT for 2011-12. Similarly, states like Odisha witnessed a steady decline of consumption of pesticides over the years, from a peak of 1588 MT in 2009-10 to 491 MT in 2011-12. So, there is a need to devise an effective mechanism to assess the demand and availability of pesticides in the states in terms of formulations.

Information provided by State Governments reveal that around 90 million hectares of cropped area is within the ambit of pesticides usage, leaving out significant swathes of agricultural land in the country where pesticides are not being applied to crops. Different estimates show that more than 50% of consumption of pesticides is garnered by insecticides, whereas herbicides and fungicides together contribute about 30 to 40% of total pesticide consumption. Among the crops, cotton, rice, vegetables and fruits account for the largest share of pesticide consumption in the country. In fact most of the hazards faced by the society are due to indiscriminate use of insecticides and therefore a course correction is required. Pesticides are poisonous entities and hence need to be used with utmost care. LD_{50} values are indicative of their toxicity, which for common man is reflected by colored triangles – green denoting less toxic while red, is extremely toxic. Pesticides most frequently responsible for hazards are organochlorine, organophosphates and carbamates insecticides. Fungicides, conversely do not pose much hazards except organo-mercurials. It may however be clearly understood that there are many commodities, including beverages and drugs, whose LD_{50} is comparable with pesticides. Should we then blame pesticides for hazards or users for reckless use?

Pesticide residue

The consumption of pesticide in India is one of the lowest in the world (Table 2). However, despite the low consumption of pesticides, India has more problem of pesticide residues *vis-a-vis* other countries and these have entered into food products and underground water because of non-prescribed use of chemical pesticides, wrong advice and supply of pesticides to farmers by vested interests, non-observance of prescribed waiting period, pre-marketing pesticide treatments during storage and transport, use of sub-standard pesticides, effluents from pesticide manufacturing units, continued use of persistent pesticides for public health programmes, lack of awareness and lack of aggressive educational programmes for farmers/consumers. Presence of pesticide residues in agricultural produce – particularly fruits and vegetables, milk and eggs, has become a matter of concern. There is sufficient evidence that it is a widespread phenomenon and that too with insecticides but again a man-made problem for his selfish gain, ignoring the principle of 'safe use of pesticides. There were instances when Indian products were banned from export owing to the presence of the pesticides over the prescribed limit. Recently, the domestic market has also been plagued by similar incidents.

Most recently, Saudi Arabia has banned Chilli from India due to the presence of pesticide residue. India's basmati trade has also been rocked by problems of pesticide residue. Several US-bound consignments were rejected due to the presence of traces of pesticides such as Bavistin, Isoprothiolane and Tricycalzole that have not been registered with the US food and Drug Administration (USFDA). Without USFDA approval, the chemical present in rice consignement have been considered as illegal and not safe for human consumption. In June, 2010, a Humberg based lab issued reports to buyers objecting that organic Basmati rice imported from India had elevated levels (0.03%) of Carbendazim and Isoprothiolane. This stalled the export of 20,000 tonnes of organic rice from India. In 2010, the Europion Union (EU) rejected three consignments of bhindi from India because of the same reason. Higher level of monocrotophos, acephate and triazaphos residues were found in these consignments. The EU has a tolerance limit of 0.05 mg/kg for moncrotophos residue in bhindi, while for acephate and trizophos, the maximum residue limit is 0.02 and 0.01 mg/kg, respectively. In the consignment that was rejected, the monocrotophos residue level was 0.13 mg/kg and that of acephate 0.13 mg/kg.

Table 2. Consumption of pesticides in states of India.

S/N	States/UTs	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12
1	Andaman & Nicobar	-	6.24	14.00	-	-
2	Andhra Pradesh	1541.00	1381.00	1015.00	8869.00	8529.00
3	Arunachal Pradesh	16.00	10.00	10.00	10.00	17.45
4	Assam	158.00	150.00	19.00	150.00	160.00
5	Bihar	870.00	915.00	828.00	675.00	655.00
6	Chandighar	-	-	-	-	-
7	Chhattisghar	570.00	270.00	205.00	570.00	510
8	Dadra & Nagar Haveli	-	-	-	-	-
9	Daman & Diu	-	-	-	-	-
10	Delhi	57.00	57.00	49.00	48.00	46.00
11	Goa	2.30	8.90	10.30	8.90	8.40
12	Gujarat	2660.00	2650.00	2750.00	2600.00	2540.00
13	Haryana	4390.00	4288.00	4070.00	4060.00	4050.00
14	Himachal Pradesh	296.00	322.00	328.00	328.00	315.00
15	Jammu & Kashmir	1248.00	2679.00	1640.00	1817.75	1711.13
16	Jharkhand	81.00	85.00	88.50	84.30	151.37
17	Karnataka	1588.00	1675.00	1647.00	1858.00	1272.00
18	Kerala	780.00	272.00	631.00	657.32	629.46
19	Lakshadweep	-	-	-	-	-
20	Madhya Pradesh	696.00	663.00	645.00	633.00	850.00
21	Maharashtra	3050.00	2400.00	4639.00	8317.00	6723.00
22	Manipur	26.00	30.36	30.36	29.81	29.81
23	Meghalaya	6.00	-	6.10	10.33	9.42
24	Mizoram	44.00	44.25	39.05	3.91	0.39
25	Nagaland	5.00	17.83	13.58	-	15.00
26	Odisha	-	1155.75	1588.00	870.50	491.00
27	Pondicherry	41.00	39.00	39.29	39.29	39.78
28	Punjab	6080.00	5760.00	5810.00	5730.00	5690.00
29	Rajasthan	3804.00	3333.00	3527.00	3623.00	1652.00
30	Sikkim	6.00	2.68	4.22	-	-
31	Tamil Nadu	2048.00	2317.00	2335.00	2361.00	1968.00
32	Tripura	27.00	38.00	55.00	12.00	30.06
33	Uttar Pradesh	7332.00	8968.00	9563.00	8460.00	8527.00
34	Uttaranchal	270.00	221.10	222.00	198.54	233.20
35	West Bengal	3945.00	4100.00	N/A	3515.00	3730.00
	Grand Total	**41637.3**	**43860.07**	**41821.4**	**55539.65**	**50583.47**

The Delhi High Court has recently directed the Delhi government to set up a Pesticide Residue Management Cell (PRMC) under the control of food commissioner of the state. The high court had acted suo moto on a report of NGO Consumer Voice, which had in 2010, found that 35 varieties of vegetables and fruits, picked from Delhi markets and tested for pesticide content, had toxins beyond permissible limits. The court's order came after it was informed that 5.3 percent of vegetables and 0.5 percent of fruits sold in Delhi had pesticide residue above the prescribed maximum residue limit (MRL). The bench noted that by one calculation the entire population of Delhi was consuming food items with pesticide residue beyond permissible limits. The report also claimed that pesticide components such as Chlordane, Endrin, Heptachlor, Ethyl and Parathion are used in growing a number of vegetables, which have the potential to cause serious neurological problems, kidney damage, skin diseases, cancer and other diseases.

Plans to counteract the problem of pesticides residue

Highest contamination in food occurs due to abuse of pesticides in fields. Good agricultural practices are key to contain the residues level below MRL. The Department of

Agriculture and Cooperation, Ministry of Agriculture is regularly monitoring the pesticides residues under the central sector scheme, 'Monitoring of Pesticide Residue at National Level'. The scheme monitors the pesticides residue in agricultural commodities and environment so that corrective measures can be taken, as required. The scheme involved monitoring and analysis of pesticides residues in agricultural commodities in different agro ecological regions of the country to address the concerns of food safety and impact of pesticides on India's food and agricultural trade. 22 laboratories of different department and ministries are part of this network. These laboratories are equipped with latest equipments and manpower to carry out residue related work. There are more than 29 private pesticides residue laboratories recognized by the Agriculture and Processed Food Products Export Development Authority (APEDA) for pesticide residue analysis in agri-export commodities. Besides this, National Institute of Plant Health Management (NIPHM), Hyderabad imparts training on pesticides residues through an identified course programme.

Food Safety and Standards Authority of India (FSSAI) lays down standards for articles of food and regulate their manufacturer, storage, distribution, sale and import to ensure availability of safe and wholesome food for human consumption. Besides following scientific method of crop production, various physical methods like washing dislodge pesticide residues present on the surface of the produce. For residues present inside the matrix of the produce, safe waiting period and cooking would serve to degrade the molecules to non toxic levels. Farmers, stake holders and officials involved in marketing of the produce must be apprised of the permissible residue limits for each commodity and the waiting periods before the beginning of the season, harvesting of the produce and before marketing for domestic as well as export.

India cannot out rightly reject the use of pesticides in its crops but instead choose to be cautious. The best way to tackle this is to adopt chemical which is recommended to the specific crop and the right dose. There is a need to sensitize growers and bring a change in their attitude towards mankind and have to take a balanced approach and in any case, total reliance on pesticides has to be abandoned. Simultaneously pesticide industry has to take cognizance of widespread hazards of certain pesticides in certain areas, and therefore such pesticides need not be marketed/promoted in such areas, and relief needs to be provided and use of such deadly pesticides should be totally stopped in such areas.

Curbing spurious pesticides

Farmers currently put lesser emphasis on brand whereas they are highly price sensitive. This essentially brings us back to the problem of spurious pesticides in the market. In the pursuit of cheaper fix for crop problems, farmers get duped by fake pesticides. Agrochemicals Policy Group (APG), the industrial body representing the crop protection companies, including the pesticides manufacturers and formulators, has estimated the crop loss at Rs. 6,000 crore annually due to use of spurious pesticides. The fake pesticides are inferior formulations, which not only fail to kill pests but also inflict damage to the crops. Poor and marginal farmers fall prey to such cheap products and end up with low crop yield (Kumar and Gupta, 2012). About 30% of the sugarcane crops in the second largest sugar producing state of Uttar Pradesh are lost due to fake pesticide products. The most recent to fall prey to the fake products is Jammu's Rs 4,000 crore apple industry.

Under the present arrangement, there is no mandatory requirement for checking of pesticides for their spurious content or 'misbranding' at the factory or manufacturers' level. Normally the process to test and inspect pesticides is initiated on the basis of complaints from farmers, by which time the pesticides are already in the market. The very fact that a sizeable number of samples were found spurious during testing, clearly shows that the existing system is either grossly inadequate or is not strong enough to monitor and check the quality control of pesticides effectively at every level till it reaches the farmers for usage. In fact, there is absence of quality checking mechanism even for major manufacturers of pesticides and that they should have looked into it being responsible for production of pesticides. Since safe use of pesticides is crucial not only for the farmers in view of increased soil stress due to over use of chemical pesticides but for the safety of human beings, animals and environmental sustainability. Therefore, the existing mechanism needs to be strengthened and made effective and more vigilant to check any spread of spurious and ineffective pesticide. The Government should work out a mechanism to make testing of pesticides mandatory at every possible level right from the factory level till it reaches the farmers, since this would require adequate number of testing laboratories and well trained Inspectors.

There are a total of 71 pesticides testing laboratories in the country which includes 68 State Pesticides Laboratories in 21 States and one Union Territory, two Regional Pesticides Testing Laboratories at Chandigarh and Kanpur and one Central Insecticides Laboratory in Faridabad. While the State like Tamil Nadu have 15 laboratories, other States like Assam, Bihar, Kerala, Odisha, Madhya Pradesh, West Bengal have only one laboratory each and the States like Jharkhand and Meghalaya do not have any such facility at all. There are 10,757 insecticide inspectors under state government that is, Department of Plant Protection, Quarantine and Storage. These inspectors have drawn 49,013 pesticides samples during 2013-14 to control the flow of spurious pesticides into market. Only 1073 (2.19%) pesticides

Table 3. Bio-pesticides usage.

Year	Bio-pesticides
2007-08	1873.00
2008-09	1459.00
2009-10	3366.00
2010-11	5151.00
2011-12	6506.00
Total	**18355.00**

Source: Directorate of Plant Protection, Quarantine and Storage.

samples were found misbranded and 469 misbranded cases have been prosecuted. During 2013-14, 124 pesticides samples (including biopesticides) have been drawn by the Central Insecticides inspectors and 23 samples were found to be misbranded. The prosecution is being launched against the dealers and manufacturers of these pesticides. Four accused have been convicted by the different courts for manufacturing misbranded pesticides during 2012-13.

A number of small player play a very important role in respect of formulation and production of pesticides in the country. While that brings down the cost of pesticides, the same increases the incidents of usage of spurious and ineffective pesticides in the country. In fact, a large scale usage of spurious pesticides is the main issue of concern, which happens primarily due to inadequate number of accredited pesticides testing laboratories. The existing Pesticides Laboratories at the State and Central levels are highly inadequate and there is an imperative need to establish well equipped pesticide testing laboratories in adequate numbers in each State across the country, keeping in view the needs of the crops grown in the region and manned by well trained staff. So far, only 4 out of 68 State Pesticides Testing Laboratories have been accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL). Both Regional Pesticides Testing Laboratories are accredited by NABL, whereas the Chemistry and Bio Assay Divisions of the Central Insecticides Laboratories have been accredited for testing of chemical pesticides and bio-pesticides, respectively. Efforts are being made to improve standard of infrastructure and laboratory practices in remaining labs for them to be accredited in the near future. Lack of accredited and well-equipped laboratories in the States is an important issue which has a direct bearing on the quality of pesticides available to farmers. Infrastructure for testing quality and composition of bio-pesticides, particularly to investigate presence of chemical pesticides, is deficient in States. In cases of misbranding of pesticides, prosecutions in States also tend to take a long time. The Department should initiate appropriate action to get establish well equipped pesticide testing laboratories in adequate numbers in each State across the country.

Promotion of biopesticides

Bio-pesticides are typically microbial biological pest control agents that are applied in a manner similar to chemical pesticides. Most beneficial advantages of bio-pesticides are that they are the harmful residues are not detected. They can be cheaper than chemical pesticides when locally produced. They can be more effective than chemical pesticides in the long-term. They are biodegradable (Kumar, 2014c; Kumar et al., 2014). Biopesticide formed only a meager percentage of total pesticides used in the country. Bio-pesticides usage has displayed a resolutely upward trend during the previous plan period as is evident from Table 3.

The government of India has adopted measure to promote biological control of pests in India through establishment of 31 Central IPM centres in 28 states and one UT. The biological control laboratories have also been established in these centers. There are 352 bio control labs including bio control laboratories established by Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), private sector lab, and private sector lab funded by GOI through grant in aid. These bio-control labs are engaged for multiplication, release and sale of different bio-control agents against different pests and weeds. A total 47,489 million biocontrol agents have been released by ICPMCs since 1919-92. The biocontrol agents are being released through inundative and inoculative methods. These releases were able to manage the pests like sugarcane pyrilla and sugar cane borers, cotton bollworms, apple wooly aphid and San Jose scale, different lepidepterous pest of vegetable cropsrice etc. Different types of bio control agents like insect parasitoids, insect predators, spiders, insect pathogens like nuclear polyhedrosis virus (NPV) and biopesticides like antagonistic fungi such as *Trichoderma viride* and *Trichoderma harzianum* and entomogenic pathogenic fungi like *Beauveria bassiana* and *Metarhizium spp*. are being produced in these biocontrol laboratories. The consumption of biopesticides is increasing every year. The annual consumption of bio-pesticides was 1,873 MT in 2007-08 which has increased to 8,110.35 MT in 2011-12- barely sufficient to cover less than 2% area of the 328 million ha under cultivation while the present requirement of quality bio- pesticides is to the tune of 1,00,000 tones. During 2011-12, a total of 7.96 lakh hectares was covered for pest monitoring activity. Similarly, the area coverage for augmentation and conservation of ‘friendly insects’ during 2011-12 was 7.60 lakhs hectares. Global awareness against use of synthetic pesticides and pesticide residues in food materials are a concern and may become international trade barriers. Therefore the eco friendly methods of crop protection and bio-control based IPM system are the need of the day.

The concerted efforts at the central and state level to popularize IPM approach among the farmers have created

significant awareness in favour of biopesticides/bioagents. The steps taken to encourage the use of biopesticides/bioagents are summarized as under:

1. The guidelines for registration of biopesticides have been simplified.
2. Farmers, local entrepreneurs, NGOs have been encouraged for production of the same with assistance of ICAR (KVK) and Department of Biotechnology (DBT).
3. Central assistance as grants-in-aid provided to PDBC (ICAR) for research, development and production of bio-control agents.
4. Grants-in-aid provided to the States/UTs for infrastructural development for production of biocontrol agents and biopesticides by establishing SBCLs.
5. The Farmer's Field Schools (FFSs), training-cum-demonstration are playing major role in the promotion and popularization of biopesticides and biocontrol agents among the users.
6. Commercialization of biopesticides is allowed during the validity of provisional registration for 2 years which is also extendable for another 2 years when the applicants have made efforts to generate data to obtain regular registration under Section 9(3).
7. The Government is also promoting organic farming in the country which emphasizes enhanced use of bio-fertilizers and biopesticides, besides advocating greater use of organic manures, compost and vermi compost as substitutes for chemical pesticides and fertilizers.

It is evident that the use of bio-control agents in combating pests is on the rise, yet significant challenges posed by short shelf life, standardization and quality, storage and transportation need to be addressed by agricultural research institutions in the near future (Kumar and Upadhyay, 2003; Kumar et al., 2009). Quality of bio-pesticides, particularly in relation to threat of lacing with chemical pesticides is an emerging problem in different parts of the country. Infrastructure for laboratory analysis of bio-pesticides remains inadequate in the country (Kumar, 2013b).

NANOPESTICIDES: A NEW HOPE

Nanotechnology visualized as a rapidly evolving field has potential to revolutionize agriculture and food systems. Conversion of macro-materials into nano size particles (1 to 100 nm) gives birth to new characteristics and the material behaves differently. Nanoparticles can be produced by different methods, chemical and biological, the former is commercially used. Nano-materials can be potentially used in the crop protection, especially in the plant disease management. Nanoparticles may act upon pathogens in a way similar to chemical pesticides or the nano-materials can be used as carrier of active ingredients of pesticides, host defense inducing chemicals, etc. to the target pathogens. Because of ultra small size, nanoparticles may hit/target virus particles and may open a new field of virus control in plants. The disease diagnosis, pathogen detection and residual analysis may become much more precise and quick with the use of nanosensors.

We utilized nano-technological interventions for developing nano-pesticides with potent fungicidal and miticidal properties. Nanosulphur and nano-hexaconazole were prepared using encapsulation technique (Gopal et al., 2011a, b; Chaudhary et al., 2010). Nano-hexaconazole was characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), and Fourier transform infrared spectroscopy (FT-IR) etc. and it was found to be less than 100 nm in size. Nano-hexaconazole is five times more effective in controlling pathogens and nano-sulphur is ten times more effective for controlling mites as compared to its water dispersible powder (WDP) formulations (Gopal et al., 2012). Therefore, nanotechnology has potential to provide green and efficient alternatives for the management of pests in agriculture without harming nature.

Modernization of pesticide application technologies

Application of pesticides for the management of diseases, pests and weeds has great role in maintaining crop health. Scientific research efforts focused on the improvement of pesticide application in agriculture is essential for crop protection and environmental safety as well. Basic fungicide application strategy should be focused on application system development, drift management, efficacy enhancement and remote sensing. Future research on application system should include sensor controlled hooded sprayers, new approaches to direct chemical injection and aerial electrostatic sprayers, new approaches to direct chemical injection and aerial electrostatic sprayers. For the accurate field application, on broad flow controllers should be used. Aircraft parameters such as boom position and spray release height can be suitably altered to determine their effect on the drift. The basic drift management research should be focused on testing of low dirft nozzles, evaluation of pulsed spray technologies and evaluation of drift control adjuvant. With the changing agricultural practices, pesticide formulations have also been changed. For the control release of fungicides in the target areas, micro-encapsules of fungicide play an important role (Tsuji, 2001). Microencapsulation of pesticides has considerably improved handling safety due to hazards and exposure reduction.

Recent advances in electronics, remote sensing and computer application have resulted in the precision application of pesticides. Advances in electronics has played an important role in the developments related to the controlled use of pesticide by better matching

applications to the target requirements. Specified infected crop patches should be identified and selectively sprayed with the effective fungicides. Patch spraying can considerably reduce the excessive use of pesticide in the target environment. In widely spaced row crops like vegetables, fully automated detection system based on image analysis can be developed which in turn will guide the application of pesticides only in crop rows.

Remote sensing technique is being used in many countries to identify disease infected areas in the field so that spray can be directed only to those areas. In India too, this can be employed specifically in those crops where fungicide are used over a wide area like apple scab or potato late blight for specific application of fungicides in the infected patches.

Pesticide transport models are being used as a tool to develop effective pesticide management studies by the use of Root Zone Water Quality Model (RZWQM) as discussed by Malone et al. (2004). It has been show that if key input parameters are calibrated, RZWQM models can adequately simulate the process involved in pesticide in different agro climatic zones of India for effective and specific use of fungicide in different crops.

With the increased emphasis on protected cultivation in Indian, management of diseases in the green house environments could be tackled by using specific fungicide application. A new approach to fungicide application in green houses has been named as 'Envirosol technology'. This technology uses carbon dioxide to deliver pesticides as aerosol droplets into enclosed spaces like green houses. Envirosol products such as Permigas, Pestigas, and Insectgas are commercially available. For instance, Floragas and Hortigas have been developed as postharvest fumigants for the treatment of cut flowers and asparagus (Carpenter and Stocker, 1992). Growers use high volume of spraying with motorized pumps and reduced volume spraying with thermal pulse jet foggers in controlling greenhouse diseases and pests. These applications too have runoff of excessive pesticide. Hence, specific users friendly greenhouse fungicide application technologies have to be developed in the future.

So, improved methods of application and judicious use of pesticide can greatly reduce the environmental and health hazards. Chemigation, direct injection, closed system handling and fertilizer impregnation technology would be of great use in this endeavor. Besides, pesticide should be used as an important component of IPM for reduced use of chemicals. An effective education programme about the specific and judicious use of pesticides can play an important role in future programmes on pest management and increased agricultural production

Host resistance

Host resistance is one of the most important means of fighting against plant diseases/pests and therefore greater reliance should be given to host resistance in agrarian system, rather than resorting to use of pesticides, which poses health hazard problem to applicator, consumer and pollute environment and affect biodiversity by their impact on ecosystem. It is therefore desirable to use as far as possible resistant or tolerant cultivars in consultation with agriculture department or agricultural university.

INTEGRATED PEST MANAGEMENT

To educate the farmers about ill-effects of the pesticides, need-based use of chemical pesticides and correct application techniques, an integrated pest management programme has also been started by the Government. Integrated Pest Management (IPM) is an eco-friendly approach which uses cultural, mechanical and biological tools and techniques for keeping pest population below economic threshold levels. This approach attaches a high premium on the efficacy of bio-control agents and bio-pesticides. However, need based and judicious use of chemical pesticides is permitted (Kumar, 2010a). With this objective, IPM helps in maximizing crop protection with minimum input costs, minimizing pollution in soil, water and air reducing occupational health hazards, conserving ecological equilibrium and reducing pesticide residue loads in food. Farmers of India do follow the IPM wherever they have been given proper technical guidance and awareness about the judicious use of chemical pesticides viz., Jind (Haryana), Ananad (Gujarat), Hoogly (WB), Astha (Maharashtra), Bambawad (UP), Gulbarga and Bidar (Karnataka), etc. However, our recent data indicates extreme lack of awareness about integrated pest management not only among farmers across the nation but also in the ranks of field functionaries. Availability of appropriate inputs of IPM also impedes following principles of the same.

Impact of IPM

The impact of IPM is reported to have presumably led to reduction in consumption of chemical pesticides from 65,462 MT during 1994-95 to 47,020 MT during 2001-02. There is a marginal increase in the trend towards use of bio-pesticides from 8,110.35 MT in 2011-12 to 902 MT during 2001-02.

Steps taken by government to popularize IPM

National Centre for Integrated Pest Management (NCIPM) was set up in 1988 under the Indian Council of Agricultural Research. There are 31 Central Integrated Pest Management Centres (CIPMCs) located in 28 States and one Union Territory. CIPMCs undertake following activities:

1. Surveillance and monitoring of insect pests and diseases.
2. Augmentation and conservation of natural enemies.
3. Production and releases of bio-control agents.
4. Human resources development through Farmers Field Schools (FFSs), season long training programmes etc.

NCIPM has achieved successes in validating and harmonizing IPM technologies in different crops. To facilitate popularizing IPM approach among farming community under Central Scheme 'Promotion of Integrated Pest Management' of Department of Agriculture and Cooperation, Government of India, information system for IPM has been created, which helps in efficient reporting and dissemination of information on pests surveillance, rearing of host culture, production and release of biological control agents in the field, conservation of naturally occurring biological control agents for control of crop pests and transfer of innovative IPM skills/methods/techniques to extension workers and farmers through conduct of training and farmers Field schools in all states.

Implementation of Integrated Pest Management in India needs a unified strategy in terms of development and country wide IPM programme, which ought to include improved planning, co-ordination, funding communication, networking at the central level with a concrete policy by the Government of India for the same. Agriculture is a state subject. Central agencies put their best efforts to provide necessary help and technical backstopping to state agencies. Better coordination between state and central bodies can improve lab to land transfer of technologies. Due to different initiates taken by the ICAR, the transfer of technology from research labs to farms has picked up and hopes to improve further in days to come. As of now, 77 crop specific package of practices have been prepared to help farmers and extension functionaries adopt IPM approach to combat pests and diseases in an environmentally friendly manner. However, the challenge is in periodic updating and improvement of these packages of practices so that prescription to farmers and extension functionaries are in tune with new knowledge and innovation. An important issue that confronts the sector relates to devising ways and means to enhance relevance and acceptability of package of practices among farmers in different agro-climate zones characterized by regional variations in farming traditions, practices and crop cycles. There is also a need to assure farmers that management solutions offered for control of pests and diseases conform to principles and standards of good agricultural practices.

Plant quarantine

Plant quarantine regulatory measures are operative through the "Destructive Insects & Pests Act, 1914 in the country. The purpose and intent of this Act is to prevent the introduction of any insect, fungus or other pest, which is or may be destructive to crops. The import of agricultural commodities is presently regulated through the Plant Quarantine (Regulation of Import into India) Order, 2003 issued under DIP Act, 1914 incorporating the provisions of New Policy on Seed Development, 1988. Further, the significance of Plant Quarantine has increased in view of globalization and liberalization in international trade of plants and plant material in the wake of Sanitary and Phytosanitary (SPS) Agreement under World Trade Organization (WTO). The phytosanitary certification of agricultural commodities being exported is also undertaken through the scheme as per International Plant Protection Convention (IPPC) (1951). The primary objectives of the Scheme are:

1. To prevent the introduction and spread of exotic pests that are destructive to crops by regulating/restricting the import of plants/plant products and,
2. To facilitate safe global trade in agriculture by assisting the producers and exporters by providing a technically competent and reliable phytosanitary certificate system to meet the requirements of trading partners.

The Directorate of Plant Protection, Quarantine and Storage, Faridabad under the Department of Agriculture and Cooperation is the nodal agency for plant quarantine and export certification. To facilitate exports and imports of agricultural commodities, an important e-governance initiative has been undertaken with the launch of the Plant Quarantine Information System (PQIS) in April, 2011. The PQIS aims to reduce lead time in processing of import permits, release orders for import consignments and phytosanitary certificates for exports. Since April, 2011, 61,175 import permits, 160,628 import release orders and 452,395 phytosanitary certificates have been issued online using the PQIS. The Department of Agriculture and Cooperation is coordinating with the Customs Authorities in the integration of PQIS with the Electronic Data Interchange system being currently in use in the Customs Department to further facilitate imports and exports of agricultural commodities through a single window clearance system. There are 35 plant quarantine stations at different airports, seaports and land frontiers implementing the plant quarantine regulations. Qualitative and quantitative improvements in infrastructure and manpower is imperative at plant quarantine stations in the country to curb possibility of detection of quarantine pests and pesticides residues in Indian agriculture export consignments and wood packaging material. The NPQS, New Delhi and RPQSs at Chennai, Kolkata, Amritsar and Mumbai have been strengthened with modern equipment for plant quarantine testing, etc., to facilitate speedy clearance of imports and exports under the Food and Agricultural Organization - United Nations Development Programme (FAO-UNDP) Project.

Promotion of organic farming

Organic farming is another option to cut down pesticide use. Fashioned by environmentalists, organic farming is aimed at producing commodities without using pesticides and other agrochemicals. Although produce with organic certificates may fetch higher prices it cannot feed ever-increasing population and more so bearing the higher cost in times of inflation. Further reliance on certification needs reassurance. It appears more to be an illusion. It may, however, be practiced in Western world where population has stabilized and their kitty may allow them to bear the higher cost, but certainly not India for obvious reasons (Srivastava, 2005a). However, incentives of higher return has motivated farmers in producing organic food – especially in and around metros, where organic food has become the buzz word when it comes to healthy diet free from pesticide residues. Incidentally, in the European Union, Member States shall ensure by 1 January, 2014, adoption of IPM for sustainable agricultural production. One should not have blinkered vision towards pesticides, and it must be clearly understood that in the event of outbreak of diseases and pests, pesticides can only offer respite, and therefore their importance cannot be ruled out. What is important is the rational use of pesticides with right intention keeping in view mankind, environment and eco-system. Meanwhile repeated use of systemic insecticides and fungicides has to be avoided, and use of novel fungicides, bio-pesticides need to be promoted. Simultaneously the government has to exercise implementation of Central Insecticide Act (1967) in all earnest.

Green molecules (GM) - An alternative

It is aimed at developing transgenic or genetically modified crops. GM could be another route by which pesticide usage could considerably be reduced and simultaneously realizing higher yield. India commercia-lized its first transgenic crop, Bt cotton in March, 2002 (Bambawale et al., 2004) and now Bt cotton has completed its 12 years journey with remarkable success. Bt cotton covers 90% of India's cotton growing area. In 2011-12, the productivity of Bt cotton is 485 kg lint per ha, with 560 kg lint per ha in 2007. With Bt, India became a global exporter of cotton; since 2005, exports have been between 600,000 to 1.5 million tons each year. The Biotech industry credits the technology for bumper harvest, though farmers and activists blame the seed for failing the crops and debt traps. In fact biotech could be considered crucial to second green revolution since Bt crops have ability to fight against pests and require little or no pesticides. Bt cotton is the only transgenic crop currently approved for cultivation in India. Bt brinjal is under moratorium for commercial release. However, there are valid health and environment concerns regarding adoption of GM crops. To date, countries where genetically modified organisms (GMOs) have been introduced in fields, have reported no significant health damage or environmental harm. Some of the concern related to gene flow and pest resistance has been addressed by techniques of genetic engineering. However, the lack of observed negative effects does not mean that they cannot occur. Scientist call for a cautious case by case assessment of each product or process prior to its release in order to address legitimate safety concerns. Science cannot declare any technology completely risk free. Genetically engineered crops can reduce some environmental risks associated with conventional agriculture, but will also introduce new challenges that must be addressed. Society will have to decide when and where genetic engineering is safe enough.

Pant health clinic

Failure in timely diagnosis of diseases and other pests has often been responsible for devastating losses. Reducing crop losses by keeping pests at bay is crucial to food security. Plant clinic is an innovative paradigm which plays a vital role in assuring food security and ushering prosperity by providing timely diagnosis and rendering necessary advice to the growers, gardeners and other stakeholders for managing pest problem in India. Plant clinics are all about plant health. Though the major role of plant clinic lies in diagnostics and advisory, the activities of plant clinic extend beyond plant clinic, with emphasis on extension, working more closely with farmers and organizations involved in promoting food production. Srivastava (2005b, 2008, 2009) has redefined the role of plant clinics beyond diagnostics and advisory. These are:

1. Training and teaching to students.
2. Training farmers and extension personnel on field diagnosis of pests and diseases.
3. Producing fleet of plant doctors, keeping a vigil on bio-terrorism/invasive pathogen,
4. Promoting integrated pest management, monitoring pest/diseases distribution and their outbreak.
5. Issuing pest alerts.
6. Organizing plant health camps for creating awareness regarding likely appearance of pests/diseases.
7. Strengthening mobile clinic approach during disease/pest outbreak.
8. Reaching farmers through internet, mobile leaflets, handouts, hand bills etc.
9. Collaboration of development agencies/input dealers and media.

In India, plant health clinics need to be equipped with diagnostic facility with excellent communication skill and facility/ICT, and trained manpower since diagnosis is experience driven process, organizing trainings, maintaining linkages with development agencies/

electronic/print media. With monitoring and surveillance of diseases and pests, issuing pest alerts and their faster dissemination through electronic media, SMSs should be on the card. Plant health camps, training to farmers on field diagnosis of pests and diseases should be organized once or twice during the season. Clinic on wheels must be ready to face epiphytotics/pest outbreak by rushing to the affected area with a team of experts. Enrichment circulars, bulletins, leaflets should be brought out on regular basis for updating growers' knowledge to face the challenges. To improve the working of clinic with respect to the feedback from farmers, agencies must go into inspection and self-evaluation and monitoring and look at the future for the well-being of farmers producing food for us. Creation of well-organized clinics modeled on human clinic would not only boost food security but would help the image of the plant doctors, commanding same respect the human doctors or veterinarians enjoy. Let us rediscover Plant Health Clinic, which can heal the wound of farmers by providing unstinted plant health care support by extending timely diagnosis and recommendation to save the crops from ravages of diseases and pests. Let all governments rise to the occasion to save huge crop losses by supporting creation of plant clinics.

Future strategies

1. Identification and use of biopesticides.
2. Studying the bio-ecological factors affecting sustainability of bioagents.
3. Identification and development of stress resilient bio control strains.
4. Simplification of process of registration for biopesticides with strict and adequate quality check from Govt. Departments.
5. Increased support to biopesticide industry for scaling up of production as a matter of Govt. policy which shall also enable generation of employment for small /micro industries at village level in line with concepts of model bio village.
6. Perfection of bio control based IPM system.
7. Improving awareness levels of field functionaries and farmers in IPM apart from fast tracking of crop protection advisories through KVKs, NGO etc.
8. Development of an Integrated Decision Support System for Crop Protection Services to monitor the pest dynamics through e-pest surveillance, analyze pest risks, provide pest forecasts along with mobile based dissemination of advisories keeping in view prevailing weather and change in climate.
9. The farmers should be educated on the merits and demerits of the pesticides. They should be educated to distinguish between use and over use.
10. Dealers and retailers should be made accountable to the over use of pesticides.
11. The price of the pesticides can be a deterrent for farmers in selecting the needed pesticide and instead they make seek the service of cheaper and unsuitable pesticide.
12. Ensure E-surveillance for effective pest monitoring, forecasting and better implementation of IPM.
13. Cases of pesticide residue should not be treated as a local issue and a national programme should be developed. Regular monitoring, testing and stringent laws should be developed to manage this.
13. Good agricultural practices (GAP) for sustainable agriculture.
14. Discovery of green molecules.
15. Use of nano- formulations for targeted delivery of pesticides.
16. Marker assisted selection and breeding for biotic stress tolerance.
17. Pest resistant transgenic crops.
18. Novel approaches of pest management (Gene therapy, RNai-mediated gene silencing).

CONCLUSIONS

To feed the ever-growing global population, we need to produce more food and livelihood opportunities from less per capita arable land and available water. Providing ample food is only the first part of the challenge, the second and more important challenge is to produce this in a safe and sustainable manner. Most of the cultivated crops/varieties have reached their yield plateau, hence protection of crops to harvest maximum is one of the ways to meet the increasing demands of food and to attain National food security on sustainable basis. Chemical pesticides will continue to play a role in pest management because environmental compatibility of products is increasing and competitive alternatives are not universally available. Pesticides provide economic benefits to producers and by extension to consumers. One of the major benefits of pesticides is protection of crop quality and yield. Pesticides can prevent large crop losses, thus raising agricultural output and farm income. The benefits of pesticide use are high-relative to risks.

Non-target effects of exposure of humans and the environment to pesticide residues are a continuing concern. Side effects of pesticides can be reduced by improving application technologies. Innovations in pesticide-delivery systems in plants promise to reduce adverse environmental impacts even further but are not expected to eliminate them. The correct use of pesticides can deliver significant socio-economic and environmental benefits. Genetically engineered organisms that reduce pest pressure constitute a "new generation" of pest-management tools. This change in production system has made additional positive economic contributions to farmers and delivered important environmental benefits. But genetically engineered crops that express a control chemical can exert strong selection for resistance in pests. Thus, the use of transgenic crops will even

increase the need for effective resistance management programmes. The national sale of biopesticides is very little compared to the pesticide market (Kumar, 2013b). However, the market share of biopesticides is growing faster than that of conventional chemicals. Many biocontrol agents are not considered acceptable by farmers because they are evaluated for their immediate impact on pests. Evaluation of the effectiveness of biocontrol agents should involve consideration of long-term impacts rather than only short-term yield, as is typically done for conventional practices. A concerted effort in research and policy should be made to increase the competitiveness of alternatives to chemical pesticides for diversifying the pest-management "toolbox". But availability of alternative pest-management tools will be vital to meet the production standards and stiff competition is expected in these niche markets.

New scientific knowledge and modern technologies provide considerable opportunities, even for India, to further reduce current yield losses and minimize the future effects of climate change on plant health. Finding continuously new cost-effective and environmentally sound solutions to improve control of pest and disease problems is critical to improving the health and livelihoods of the poor. The need for a more holistic and modernized IPM approach in India is now more important than ever before. The IPM strategy should be implemented strictly. To achieve this, interactions between public sector research systems, farmers, private companies that conduct research in the field of plant protection and NGO's should be strengthened to assure relevance of research and appropriate distribution of responsibilities. Rising food output is vital along with slowing of population growth and maintaining the ecological balance which will ultimately enhance our purchasing power. Indian Council of Agricultural Research (ICAR), Central Agricultural Universities (CAU), Central Universities (CUs), State Agricultural Universities (SAUs), State Universities (SUs) and Deemed Universities (DUs) have to plan and should immediately transfer the recently developed scientific protection technology in form of modules to the farmers field which can increase the yield significantly. The welfare of farmers is our top priority.

Conflict of interest

The authors have not declared any conflict of interest.

REFERENCES

Agriculture Today (2014). The National Agriculture Magazine, New Delhi, India.

Bambawale OM, Singh A, Sharma OP, Bhosle BB, Levekar RC, Dhandapani A, Kanwar V, Tanwar RK, Rathod KS, Patange NR, Pawar VM (2004). Performance of Bt cotton (MECH 162) under integrated pest management in farmers participatory field trial in Nanded district, Central India. Curr. Sci. 86:1628-1633.

Bhardwaj T, Sharma JP (2013). Impact of Pesticides Application in Agricultural Industry: An Indian Scenario. Int. J. Agric. Food Sci. Tech. 4(8):817-822.

Carson R (1962). Silent Spring'. Houghton Miffin, USA.

Carpenter A, Stocker A (1992). Envirosols as post-harvest fumigants for asparagus and cut lowers. Proc. 45th N.Z. Plant. Prot. Conf. pp. 21-26.

Chaudhary SR, Nair KK, Kumar R, Gogoi R, Srivastava C, Gopal M, Subhramanyam B, Devakumar C, Goswami A (2010). Nanosulfur: potent fungicide against food pathogen, *Aspergillus niger*. Am. Inst. Phys. Proc. 1276:154-57.

Gopal M, Chaudhary SR, Ghose M, Dasgupta R, Devakumar C, Subrahmanyam B, Srivastava C, Gogoi R, Kumar R, Goswami A (2011a). Samfungin: A novel fungicide and the process for making the same. Indian Patent Application No. 1599/ DEL/2011.

Gopal M, Roy SC, Roy I, Pradhan S, Srivastava C,Gogoi R, Kumar R, Goswami A (2011b). Nanoencapsulated hexaconazole: A novel fungicide process for making the same. Indian Patent Application No. 205.

Gopal M, Kumar R, Goswami A (2012). Nano-pesticides - A recent approach for pest control. J. Plant Prot. Sci. 4(2):1-7.

Kumar S (2010a). Integrated management of maydis leaf blight of maize. Ann. Plant Prot. Sci. 18(2):536-537.

Kumar S (2013b). Trichoderma; A Biological Weapon for Managing Plant Diseases and Promoting Sustainability. Int. J. Agric. Sci. Vet. Med. 1(3):1-16.

Kumar S (2014c). Plant disease management: advances and challenges. Afr. J. Agric. Sci. 9(15):1207-1217.

Kumar S, Gupta OM (2012). Expanding dimension of Plant Pathology. JNKVV Res. J. 46(3):286-293.

Kumar S, Upadhyay JP, Rani A (2009). Evaluation of Trichoderma species against *Fusarium udum* Butler causing wilt of Pigeon pea. J. Biol. Con. 23(3):329-332.

Kumar S, Upadhyay JP (2003). Compatibility of Rhizobium and Trichoderma *in vitro* and *in vivo*. RAU J. Res. 13(1-2):61-64.

Kumar S, Thakur M, Rani A (2014). *Trichoderma*: Mass production, formulation, quality control, delivery and its scope in commercialization in India for the management of plant diseases. Afr. J. Agric. Res. 9(53):3838-3852.

Malone RW, Ahuj, LR, Wauchope RD, Rojas KW (2004). Application of the root zone water quality model (RZWQM) to pesticide fate and transport. An overview. Pest. Manag. Sci. 60: 205-221.

Marco GJ, Hallingworth RM, Dusham W (1987). Silent Spring Revisited. American Chemical Society. P 195.

Oerke EC, Dehne, HW, Schonbeck F, Webber A (1994). Crop Protection and Crop Production, Elsevier: Amsterdam.

Srivastava MP (2005a). Plant clinic in diagnosis and control of plant diseases – An Asian perspective. 2nd Asian Conference of Plant Pathology (Abstr. p. 3), Singapore pp. 25-28

Srivastava MP (2005b). Redefining the role and modalities of plant clinic. National Symposium on Plant Disease Diagnosis, Epidemiology and Management (Abstr. P 2). CCS Haryana Agricultural University, Hisar. pp. 21-22.

Srivastava MP (2008). Plant health clinic: Challenges and opportunity – a global vision. An Opening Address in Evening Session 17: Plant Health Clinic, organized by Dr. M. P. Srivastava at 9th International Congress of Plant Pathology, Torino, Italy, 27 August 2008.

Srivastava MP (2009). Role of phytomedicine and plant health clinic in plant health security. Presented in the 3rd International Symposium on Plant Protection and Plant Health in Europe, Berlin, Germany, 14-16 May 2009, In: Feldman F, Alfred D V, Furk C: Crop Plant Resistance to Biotic and Abiotic Factors pp. 222-230.

Srivastava MP (2013). Plant clinic towards plant health and food security. Esci. J. Plant Pathol. 3:193-203.

Tsuji K (2001). Microencapsulation of pesticides and their improved handling safety. J. Microencapsul. 18:137-147.