Developing varieties resistant to insect pest and diseases: An Eco-friendly Approach for Pest Management and Environment Protection

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Abstract

Large scale application of chemical pesticides to reduce the crop losses caused by insect pests and diseases, valued at over US$250 billion annually, has not only led to serious environmental hazards, but has also resulted in development of resistance to pesticides in pest populations. It is in this context that crop varieties capable of resisting pest damage will play a vital role in reducing crop losses and protecting the environment. Host plant resistance (HPR), is an economical and environment-friendly method of pest control. Development of crop varieties resistant to insect pests and diseases has been the major research thrust at ICRISAT for sustainable crop production. The most attractive feature of HPR is that it is the simplest seed-based technology for which farmers do not need any extra skill for application, and require no additional cash investment. Considerable progress has been made by multidisciplinary teams of scientists at ICRISAT in developing crop cultivars with resistance to the major pests of our five mandate crops (sorghum, pearl millet, groundnut, chickpea, and pigeonpea) that are largely grown under rainfed conditions. Using the conventional and molecular tools, resistance genes to major diseases and insect pests have been mapped, and some of these resistance genes have been, and are being transferred into agronomically elite and high-yielding varieties. Genes from the wild relatives of crops, and novel genes, such as those from *Bacillus thuringiensis* are also being introgressed into different crops to make “plant resistance” an effective weapon in pest management. Development and deployment of pest-resistant varieties will not only cause a major reduction in pesticide use and slowdown the rate of development of resistance to pesticides, but would also lead to increased activity of beneficial microorganisms, reduced pesticide residues in food and food products, and a much safer environment to live.

Introduction

Indiscriminate use of chemical pesticides has led to adverse effects on non-target organisms, pesticide residues in food and food products, resurgence of secondary pest problems, development of resistance in pest populations, toxic effects on human beings, and environmental pollution. Insect pests and plant pathogens (referred to as pests in the manuscript) have high reproductive rates, a fast generation turnover, wide genetic diversity, and an ability to withstand, metabolize, and avoid toxic chemicals. As a result, it has become quite difficult to control several pests through the currently available chemical pesticides. Therefore, it is important to adopt pest control strategies that are:

- Ecologically sound,
- Socially acceptable, and
- Economically viable.

Chemical pesticides (insecticides, herbicides, and fungicides) in general, are quite effective in controlling insect pests and plant pathogens. However, even if 90% of the pest population is killed with pesticides, the remaining population multiplies at a much faster rate in the absence of natural enemies (which quite often are eliminated by the pesticides) (Knipling 1979), and the farmers have to apply pesticides more frequently and at higher doses, which finally results in failure of control operations and increased environmental pollution. Heavy pesticide application has resulted in failure of pest control in several countries, and as a result, the farmers have to give up the cultivation of several crops.. Some cotton farmers have even resorted to committing suicide in India because of crop failures caused by cotton bollworm (*Helicoverpa armigera*) damage. Heavy insecticide use has led to an exponential growth in the number of insect species resistant to insecticides. Similarly, several plant pathogens causing downy mildews and late blights in various crops have developed resistance to fungicides used for their control. Therefore, it is important to place emphasis on alternative and nonchemical methods of pest management, such as host plant resistance (HPR) . The most effective strategy is to use selective pesticides at a low dosage in combination with pest-resistant varieties to slowdown the rate of evolution of pesticide-resistant populations of crop pests, reduce pesticide residues in food and food products, minimize adverse effects on non-target organisms, and avoid environmental contamination.

With the domestication of plants for agricultural purposes, farmers selected plants that were able to withstand the adverse environmental factors, including damage by insect pests and diseases. The plants that were susceptible to pests were generally eliminated, and only resistant plants survived until the crop harvest. This process led to natural selection of plants with an ability to withstand pest damage. Many landraces of crop plants selected by farmers accumulated genes conferring resistance to pests. The best examples of this process are: shoot fly resistant sorghums (landrace variety *Maldandi*) cultivated during the postrainy season in India, and head bug resistant *guinea* sorghums cultivated in West Africa (Sharma 1993); and downy mildew and rust resistant landrace cultivars of pearl millet cultivated in Asia and Africa (Hash et al. 1999). There are many such examples of existence of plants resistant to pests in wild species of various crops. Host plant resistance, therefore, should form the backbone of any pest management strategies in future, along with natural enemies, cultural practices and selective application of pesticides.

Despite the importance of HPR as a component of integrated pest management (IPM), development of cultivars with resistance to insects has not been as rapidly accepted, as has been for disease resistance. This is partly due to the relative ease with which insect control is achieved with the use of chemical insecticides. However, with the development of insect resistance to insecticides, adverse effects of insecticides on natural enemies, and growing public awareness of environmental pollution, there has been a renewed interest in the development of crop cultivars resistant to insect pests and diseases. The establishment of International Agricultural Research Centers (IARCs), such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, India; International Wheat and Maize Research Institute (CIMMYT) in Mexico; and International Rice Research Institute in Manila, Philippines, and others during the 1970's; and the collection and evaluation of germplasm for resistance to pests has given a renewed impetus to the identification and development of varieties resistant to insect pests and diseases.

Progress in development and deployment of varieties resistant to insect pests and diseases

The products of crop improvement programs have to be viable under existing farm conditions, while having the potential for increased yields under improved or high input situations. Growing pest-resistant cultivars is especially useful under subsistence farming in the developing countries. Proper understanding of biology and population dynamics of insect pests and plant pathogens, and subsequent development and standardization of techniques to identify pest-resistant plants are the key for an effective resistance-breeding program (Table 1). Delayed plantings and use of infester rows of a susceptible cultivar, artificial infestation with the laboratory cultured insects or plant pathogens, and greenhouse screening are effective to screen for resistance to insect pests (Sharma et al. 1992). Considerable progress has been made in identification and utilization of crop germplasm for resistance to insect pests and diseases of ICRISAT mandate crops. Several sources of resistance to major insect pests and diseases have been identified, and the resistance transferred into high yielding varieties in different crops. Insect- and disease-resistant cultivars have been developed in several other crops, and released for cultivation by the farmers in India (Mahajan et al. 1997, Sharma and Ortiz 2002). Cultivars with multiple resistance to insects and diseases will be in great demand in future for sustainable crop production and this requires a concerted effort from scientists involved in the crop improvement programs.

HPR in Integrated Pest Management

High levels of plant resistance, that are effective in providing optimum control of the target pests, are available against a few insect and pathogen species. However, very high levels of resistance are not a pre-requisite for use of HPR in pest management. Varieties with low to moderate levels of resistance or those which can avoid pest damage can be deployed for pest management in combination with other methods of pest management. Deployment of pest-resistant cultivars should be aimed at conservation of the natural enemies and minimizing the number of pesticide applications. Use of pest-resistant cultivars also improves the efficiency of other pest management practices, including the synthetic pesticides. Host-plant resistance can be used for pest management as:

- Principal component of pest control,
- Adjunct to cultural, biological, and chemical control, and
- Check against the release of susceptible cultivars.

HPR as a principal method of pest control

Plant resistance to insect pests and diseases as a method of pest control in the context of IPM has a greater potential than any other method of pest suppression. In general, the use of pest-resistant varieties is not subjected to the vagaries of nature unlike chemical and biological control. Use of pest-resistant varieties has contributed immensely to sustainable crop production (Panda and Khush 1995). Host plant resistance has been a major component for minimizing losses due to insect pests in sorghum, chickpea and pigeonpea (Sharma and Ortiz 2002) and diseases in sorghum (Thakur et al. 1997), pearl millet (Thakur 1996), groundnut (McDonald et al. 1998), chickpea (Haware 1998) and pigeonpea (Reddy et al. 1998). Development and release of downy mildew-resistant cultivars in pearl millet (Plate 1), wilt resistant cultivars of chickpea and pigeonpea, and midge-resistant cultivars in sorghum (Plate 2) have been the major achievements towards developing crop cultivars with resistance to insect pests and diseases. Cultivars with moderate levels of resistance to shoot fly in sorghum, *Helicoverpa* in chickpea and pigeonpea (Plate 3), and leaf diseases in groundnut have also been developed. The benefits of HPR depend on infestation levels, for example, many insects, such as aphids, whiteflies, and mites; and diseases such as downy mildews, wilts, and foliar diseases invade the crop in low numbers, and their abundance increases over several generations before reaching the economic threshold levels. For such pests, even low levels of resistance would be useful in delaying the time required to reach the damaging levels.

Compatibility of HPR with biological control

Plant resistance to insects and pathogens, in general, is compatible with biocontrol agents. Varieties with moderate levels of resistance are best suited for use in pest management in combination with biocontrol agents. The natural enemies not only help to control the target pests, but also reduce the population densities of other insect pests and pathogens within their host range. Pest-resistant varieties also increase the effectiveness of the natural enemies because of a favourable balance of population densities between the target pest and the natural enemies. Restless behaviour of the insects on the resistant varieties also increases their vulnerability to the natural enemies. Prolonged developmental period of the immature stages increases the susceptibility period of the target pest to the natural enemies or may result in synchronization of the insect developmental stages with the peak activity of the natural enemies. Moderate levels of plant resistance to the bollworm/pod borer, *Helicoverpa armigera* in cotton, tomato, pigeonpea, and chickpea in combination with natural enemies have a considerable effect on the population dynamics of this pest. The use of HPR and biological control brings together unrelated mortality factors, and thus, reduce the pest population's genetic response to selection pressure from either plant resistance or from the natural enemies. Acting in concert, they provide a density-independent mortality at times of low pest density, and density-dependent mortality at times of pest abundance. In addition to the direct and indirect effects of plant resistance on insect pests, the selection pressure imposed by natural enemies can also result in magnification of the effects of plant resistance on insect density.

Compatibility of HPR with cultural control

Pest-resistant cultivars, including those that can escape pest damage, are highly useful in pest management in combination with agronomic practices that reduce pest damage. This will have the same effect on the population dynamics of the pest species as the combined action of pesticides and resistant cultivars. For example, late planting of sorghum varieties M 35-1 during the postrainy (*Rabi*) season can reduce the shoot fly damage substantially. In contrast, late planting of pearl millet cultivars during the rainy season results in greater incidence of downy mildew, ergot and rust diseases in pearl millet and sorghum. Cultural control by itself may not reduce the pest populations to below economic threshold levels, but aid in reducing losses through interaction with plant resistance. Plant resistance in concert with cultural control can drastically reduce the need for pesticide application. Trap crops can be used to attract insect pests or other organisms so that pest incidence on the target crop is minimized. Reduction in pest damage is achieved either by preventing the pests from infesting the target crop or by concentrating them in a certain part of the field where they can be destroyed easily. Trap crops (e.g., marigold in cotton, chickpea, tomato, etc., for reducing *Helicoverpa* damage; and mustard in cabbage and cauliflower to reduce diamondback moth, *Plutella xylostella* damage) are particularly important under subsistence farming. In cotton, row strips of sesame (constituting 5% of the total area) can be used as a trap crop to attract *Helicoverpa* from the main crop of cotton. Expression of resistance to insects also changes with the availability of nutrients. Sorghum shoot fly incidence decreases, while many foliar diseases increase with an increased application of nitrogenous fertilizers (Sharma 1985). Therefore, care should be taken to apply appropriate amounts of nutrients to minimize pest damage and realise maximum crop yield. In case of plant pathogens, trap crops could be used to ascertain the presence or forewarning for a likely outbreak of a particular disease to take up a preventive action.

Compatibility of HPR with synthetic pesticides

Chemical pesticides are most effective to obtain immediate control of pests during outbreaks. However, their broad-spectrum mode of action destroys the beneficial insects as well, and thus leads to adverse effects in the environment. Because of their systemic and persistence nature, they also leave harmful residues in food and food products. The most common form of integrated control involves the use of pest-resistant cultivars and judicious application of pesticides. Even a moderately resistant cultivar in combination with pesticides can bring about a substantial reduction in pest numbers. Plant resistance may also enhance the effectiveness of the pesticides through:

- Better coverage of the plant parts with pesticide sprays through plant canopy, e.g., loose panicles in sorghum and frego-bract in cotton.
- Imbalanced nutrition or toxic substances with adverse effects on pest growth and development may increase the pest susceptibility to the chemicals, e.g., antibiotic resistance to *Helicoverpa* in cotton, chickpea, and pigeonpea.
- Easy access to the parasites and predators through open plant canopy.

Several varieties of rice, cotton, sorghum, groundnut, soybean, and vegetables have been deployed in integrated pest management in combination with pesticides (Kalode and Sharma 1995). Insect-resistant pigeonpea, chickpea, and corn cultivars require less insecticide application than the susceptible ones (McMillan et al. 1972). Chemicals in combination with HPR are more effective in reducing the shoot fly damage in sorghum and pod borer damage in pigeonpea than either the chemicals or the resistant cultivars alone. Similarly, use of moderate dosages of fungicides effectively control plant diseases on resistant/tolerant cultivars, and thus prolongs their effective commercial life, and also result in protecting the environment.

Advantages of HPR

Utilization of HPR as a control strategy has enormous practical relevance and additional emotional appeal. It is in this context that HPR assumes a central role in our efforts to increase the production and productivity of crops, and protecting the environment. Plant resistance is an important component of pest management because of:

Specificity - It is specific to the target pest or a group of pests, and generally has no adverse effects on the non-target organisms.

Cumulative - Effects of plant resistance on pest population density are cumulative over successive generations because of reduced survival, delayed development, and fecundity.

Persistence - Most of the pest-resistant varieties express moderate to high levels of resistance to the target pests, except under certain environmental conditions. In contrast, the pesticides have to be applied repeatedly to achieve satisfactory control of the pest populations.
Compatibility - HPR is compatible with other methods of pest control such as natural enemies, cultural practices, and also improves the efficiency of pesticides in pest management.
Environmental safety - There are no harmful effects of HPR on non-target organisms, humans, and the environment.
Ease of adoption - It does not involve any additional costs to the farmers. Also, the farmers do not have to have knowledge of the application techniques.

Limitations of HPR

Plant resistance is not a panacea for solving all the pest problems. Certain limitations and problems will always beset any pest control program, and HPR is no exception. Development of pest-resistant varieties requires a great deal of expertise and resources. Commitment of relatively long-term funding is a critical factor in the ultimate success of HPR. The major limitations of plant resistance are:

Time for development - It takes relatively long time to identify and develop pest-resistant cultivars. This method is not suitable to solve sudden or localized pest problems.
Genetic limitations - Absence of adequate levels of resistance in the available germplasm may deter the use of HPR for managing certain pests. Such limitations can now be overcome through the use of interspecific hybridization and genetic transformation.
Occurrence of pest biotypes - Occurrence of new biotypes of the target pests may limit the use of certain varieties in time and space. Under such situations, one has to continuously search for new genes, and transfer them into high yielding varieties.
Conflicting resistance traits - Certain plant traits may confer resistance to one pest, but render such plants more susceptible to other pests, e.g., hairiness in cotton confers resistance to jassids, but such varieties are preferred for oviposition by bollworms (*Earias vittella* and *Helicoverpa armigera*) (Sharma and Agarwal, 1983). Also, pubescence in soybean confers resistance to leafhoppers, but pod borer (*Grapholitha glycinivorella*) prefers pubescent varieties for oviposition (Nishijima 1960). Varieties with high levels of resistance to sorghum midge are susceptible to head bugs, shoot fly, and stem borer (Sharma 1993).

Conclusions

Considerable progress has been made in developing crop varieties with resistance to the target insect pests and diseases in different crops. Resistance to insect pests and diseases should be given as much emphasis as grain and biomass yield to identify new varieties and hybrids for cultivation by the farmers. Pest-resistant varieties exercise a constant and cumulative effect on pest populations, have no adverse effects on the environment, reduce the need to use pesticides, and have no extra cost to the farmers. Therefore, there is a continuous need to exploit HPR to insect pests and diseases, using both conventional and molecular tools, for their effective use in integrated pest management for sustainable crop production and environment conservation.

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Table 1. Examples of development of crop cultivars for resistance to insect pests and diseases at ICRISAT.

Crop	Trait	Screening techniques	Resistance source/ Released cultivar
Sorghum	Midge	Infester rows, Cage technique	DJ 6514 ICSV 745
Pearl millet	Downy mildew	Infector rows, Greenhouse inoculation	ICML 12 WC-C 75
Chickpea	Wilt	Sick-plot, Indicator rows	ICC 2682 ICCV 2
Pigeonpea	*Helicoverpa*	Field screening	ICP 7203-1 ICPL 332*
Groundnut	Late leaf spot	Inoculant spray	ICGV 86699 FDRS 10**

One example cited from each ICRISAT mandate crop. * = Low levels of resistance. ** = Also less susceptible to *Helicoverpa/Spodoptera*, and leaf miner.

Plate 2. ICSV 745 – A high yielding sorghum midge, *Stenodiplosis sorghicola* (inset)-resistant variety suitable for South Central India. It is also resistant to leaf diseases and ergot, and has good fodder quality. Insect resistant lines identified at ICRISAT have been used extensively in sorghum improvement in India.

Plate 1. Open pollinated pearl millet variety resistant to downy mildew (inset), *Sclerospora graminicola*. Downy mildew-resistant cultivars based on material developed at ICRISAT are widely cultivated in India.

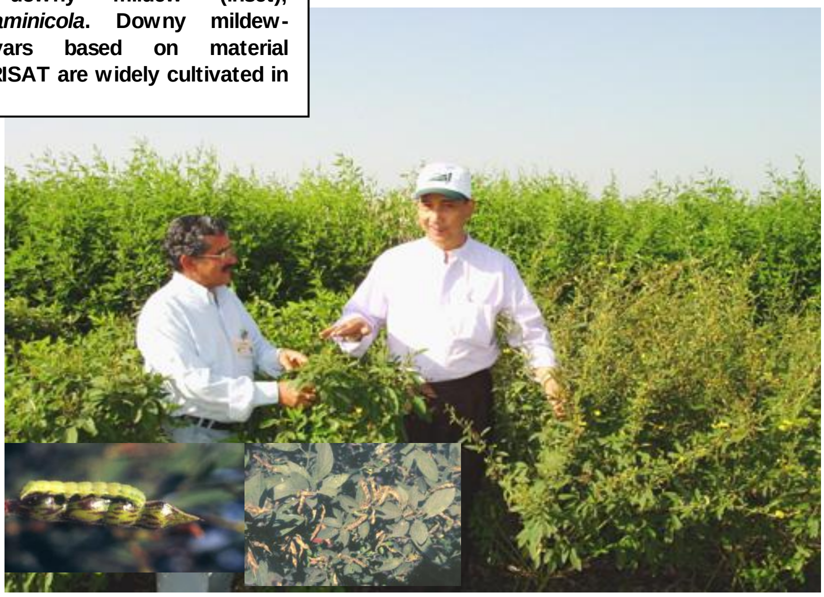

Plate 3. ICPL 88039 (right) – A short-duration pigeonpea variety with tolerance to pod borer, *Helicoverpa armigera* (inset). This variety has shown wide adaptation in Indo-Gangetic plains in North India. In the picture: ICRISAT Director General examines the variety under field conditions.