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Insect Pest Resistant Breeding in Plants

Tridip Bhattacharjee[1*], Thingreingam Irenaeus[1], Budha Ch. Thangjam[1], Tapan Kumar Maity[1] and Arup Chattopadhyay[2]

[1]*College of Agriculture, Tripura, Lembucherra, Tripura (799 210), India*

[2]*Dept. of Vegetable Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal (741 252), India*

*Corresponding email: tridip4u2@gmail.com

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ABSTRACT

Development of insect resistant cultivars has been a part of the plant breeder's tool since long time. This is especially at this juncture, when there is growing public sensitivity about the environment and residual effects on produce due to the indiscriminate use of hazardous chemicals and emergence of new races/ biotypes. The source of resistance may be present in the indigenous cultivars, land races, folk, semi-wild relatives and allied species of vegetable crops. The development of varieties with resistance to biotic (insect) stresses involves manipulation of two genetic systems *i.e.*, plants and other of the pest, not independently, but with regard to the interaction between the two systems. Resistance may be generated by mono or oligo or polygenes and effects of genes may be additive or dominant or epistatic. Methodologies of breeding for resistance may be grouped into two: conventional and non-conventional. Conventional include selection, introduction, hybridization and mutation breeding. While non-conventional include somaclonal variation, genetic engineering and molecular breeding. In spite of considerable similarities in the evolution of pathogens and insects especially in relation to plants, relatively less efforts have been directed to develop pest resistant than disease resistant varieties. Breeding for host plant resistance is switching from conventional *viz.*, introduction, selection, hybridization towards non-conventional approaches like genetic engineering and molecular approaches, as later has broadened the scope of gene manipulations at the level of specific DNA segments across wide range of organisms to produce novel genomes with enhanced levels of resistance to biotic (insect) stresses or resistance.

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INTRODUCTION

The incidence of diseases and insect pests in crop plants is usually referred to as biotic stress where living organisms like fungi, bacteria, viruses and large number of insect species induce suffering and suboptimal performance of plants (Chahal and Gosal, 2010). A wide range of chemicals are being used to eliminate the causes of such biological stresses. But the chemicals besides being

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uneconomical and health hazard do not provide a permanent solution of this problem because pathogens and pests frequently develop resistance to excessively used chemicals. The manipulation of inherent potential of plants in the form of resistant varieties is a cheap, viable and environment friendly alternative to reduce losses from biotic stresses. Though the incorporation of genetic resistance in plants is a lengthy and continuous process, especially due to multiplicity of biotic stresses and evolutionary changes in the destructive capacities of the pathogens/ pests. A systematic research on exploitation of insect resistance in crop plants started after the pioneer work by Painter (1958). In contrast to breeding for yield and other morphological characters, the development of varieties with resistance to biotic stresses involves manipulation of two genetic systems *i.e.*, one of plants and other of the pest, not independently, but with regard to the interaction between the two systems (Acquaah, 2020).

MECHANISMS OF INSECT RESISTANCE

Painter (1958) classified resistance to insects into four categories:

1. Non-Preference

A plant may have some inherent features that make it undesirable for feeding, colonization, oviposition or shelter by the insect. Such character may include colour, type of pubescence, leaf angle, odour, taste, *etc*. which act as deterrent for the insect to harbor it for feeding and multiplication. The cotton plants with thick hair on plant body are not preferred by jassids, and soybean without pubescence can be extensively damaged by potato leafhopper. The differential preference of insects to any of the following factors, which can be exploited in breeding for non-preferred varieties, (a) Morphological factors: pubescence on leaves (*e.g.*, in tomato against white fly); shape size and colour of a plant (*e.g.*, insects are particularly sensitive to green and yellow parts of the light spectrum, as red cabbage and red leaved Brussels sprouts are less favoured by butterflies and certain Lepidoptera for oviposition than are the green varieties); thickness of plant surface; deposition of silica in the epidermis and other tissues; (b) Biochemical factors: some biochemical plant compounds are repellent to pests *e.g.*, some essential oils in tomato against mite; and (c) low asparagines in rice against brown plant hopper, low sinigrin in *Brassica* against aphids and so on.

2. Antibiosis

The host plant may produce certain chemicals that adversely affect the biology of pest such as reduced size and weight, shortened life span, decreased fecundity and rate of reproduction once the insect invades the host (Table 1). It is the true form of resistance but exerts maximum selection pressure on the pest population.

Table 1: Antibiosis produces resistant to vegetable crop

Host	Insect-pest	Mechanism of Antibiosis
Pea	Pea aphid	Low amino acid content
Cole crops	Cabbage aphid	Low sinigrin content
Potato	Aphid	Gummy trichome exudates,
Carrot	*Dacus dorsalis*	Lack of thiamine, nicotinic acid and folic acid
Celery	Black shallow tail butterfly	Higher sinigrin content

(Source: Frageria *et al*., 2001)

3. Tolerance

It carries the same meaning as for disease reaction *i.e.*, host plant gives a normal performance even in the performance even in the presence of pest population of a size that would severely damage the susceptible host. Tolerant varieties may minimize damage from pest through high regeneration properties to grow more after the damage.

4. Avoidance

Pest avoidance is same as disease escape and, as such, it is not a case of true insect resistance. However, it is often as, or even more, effective as true resistance in protecting crop from insect pest damage. Most cases of insect avoidance results from the host plant being at a much less susceptible developmental stage when the pest population is at its peak. For example, in some cases, the crop may be grown in a season when the pest population is very low, *e.g.*, seed plot technique in potato to avoid aphid infestation.

GENETIC OF INSECT RESISTANCE

Genetics of insect resistance is similar to that of disease resistance. Insect resistance may be governed by oligogenes with large individual effects, polygenes with small additive effect and cytoplasmic genes (Table 2).

Table 2: Nature of inheritance of resistance of insect in vegetable crops

Sl. No.	Crops	Nature of Resistance	Insect -pest
1.	Musk Melon	Oligogenic Factor	Melon fruit fly, Melon Aphid
2.	Cucumber	Oligogenic Factor	Red Pumpkin beetle
3.	Summer Squash	Polygenic Factor	Squash bug
4.	Pumpkin	Monogenic factor	Fruit fly
5.	Cole	Low sinigrin	Cabbage Aphid
6.	Potato	Sticky trichome exudate	Potato Aphid
7.	Water Melon	Oligogenic Factor	Melon Fruit fly
8.	Tomato	Differ with each pest	Arthropod pest

(Source: Frageria *et al*., 2001)

Oligogenic Resistance

In such a case, insect resistance is governed by one or few major or oligogenes, each gene having a large and identifiable individual effect on resistance. Oligogenes may be conditioned by the dominant or the recessive alleles of the concerned gene. The differences between resistance and susceptible plants are generally large and clear-cut. In several cases, resistance is governed by a single gene (monogenic resistance).

Polygenic Resistance

Polygenic insect resistance is governed by several genes, each gene producing a small and usually cumulative effect. Such cases of resistance: (1) involve mere than one feature of the host plant, (2) are much more durable than the cases of oligogenic resistance, (3) the difference between resistance and susceptible plants are not clear-cut due to continuous variation for the trait, and (4) the transfer of resistance is relatively much more difficult than that of oligogenic resistance.

Cytoplasmic Resistance

There are at least four known cases of insect resistance that are governed by plasmagenes. While resistance to root aphid in lettuce shows cytoplasmic inheritance; in both these cases, genetic control is also reported.

SOURCES OF RESISTANCE

The best sources of genes conferring resistance to different insects can be found in places where both hosts and pathogen have co-evolved for a prolonged period, *i.e.*, the primary centers of origin of crop plants. But there are so many other sources of such genes also (Table 3). Thus, the resistance genes may be sought in the following:

a) Existing commercial varieties under immediate and direct use.

b) Old cultivars developed much before, but now obsolete.

c) Land races- the primitive cultivars developed before modern agriculture, suitable for a specific ecological niche.

d) Breeder’s collection of genetic stocks- the improved genotype which could not be released but maintained by the breeder.

e) Exotic varieties with required genes.

f) Wild relatives, the alien resources with the desired genes.

g) Induced mutants- resistant mutants can be induced, and if not suitable for direct release, can be utilized in a crossing programme.

h) Somaclonal variation.

i) Unrelated organisms.

BREEDING METHODS FOR INSECT RESISTANCE

Successful breeding for insect resistance requires the following: (1) availability of an appropriate source of resistance, (2) efficient and reliable test procedure for resistance and (3) an interdisciplinary approach. The breeding methods for insect are similar to those for disease resistance. One of the following methods may be used for this purpose: (1) Introduction, (2) Selection, (3) Hybridization, (4) Genetic engineering and (5) Molecular approaches. The choice of breeding method in a given case would depends on the sources of resistance, the mode of its inheritance and the natural mode of pollination of the crop species.

Introduction

An introduced variety resistant to the concerned insect may be released for cultivation if it performs well in the new environment and is agronomically desirable. Thus, it is the quickest and, perhaps, the easiest method of developing an insect resistant variety. But often the introduced variety may not perform well in the new environment and it may be susceptible to the biotypes of the concerned pest prevalent in the area or to a new insect pests and/or diseases of the area.

Table 3: Sources of resistant against insect-pest in vegetable crops

Crops	Name of Insect-Pest	Cultivars/ Wild species	References
Tomato	Fruit borer	Angurlata, *L. hirsutum f. glabratum*, BARI Tomato-1,4,10,11 and15	Mishra *et al*. (2019) and Amin *et al*. (2016)
	White fly and Mite	*L. hirsutum f. glabratum* and *S. galapagense*	Kashyap and Kalloo (1983) and Rakha *et al.* (2017)
Brinjal	Shoot and fruit borer	*S. sisymbrifolium* and *S. integrifolium*, Arka Mahima Hybrid Shilpa and Nirala	Srinivasan (2008) and Yousafi *et al.* (2016)
Chilli	Aphids and Mite	Kalyanpur Red and BCCH Sel -4	Tewari *et al*. (1985) and Chattopadhyay *et al.* (2011)
	Thrips	Pant C-1	Samota *et al.* (2018)
Okra	Fruit borer and Jassids	A. *tuberculatus*, *A. moschatus* and *A. angulosus*	Singh *et al*. (2007) and Prabu *et al*. (2009)
Potato	Aphids	*Solanum chomatophilum*	Pompon *et al*. (2011)
Musk Melon	Fruit fly	*Cucumis callosus*, Col-II and FSD	Gogi *et al*. (2009)
Cole crops	DBM and Cabbage looper	P1234599	Lin *et al.* (1984)
Pea	Pea Weevil	*Pisum fulvum*	Verbitskii and Pokazeeva (2015)

Selection

Insect resistant variants may be present in an existing variety of a crop. In such a case, selection for insect resistance is practiced to isolate an insect resistant variety. In self-pollinated crops, mass selection or, more generally, pureline selection is practiced for the purpose. Mass selection or, more often, recurrent selection is practiced for developing insect resistant varieties in cross-pollinated crops. Selection for insect resistance is generally more profitable in cross-pollinated than in self-pollinated crops due to the existence of large genetic variability in the former. An example of selection for insect resistance is that for resistance to potato leafhopper.

Hybridization

When the desired insect resistance is present in an agronomically inferior variety of the crop or in a related wild species, hybridization is the only course of action for the breeder. Such resistant species/ strains are crossed with an agronomically superior and adapted insect pest susceptible variety of the crop to develop a superior, well-adapted and insect resistant variety. In case the resistant variety is expected to contribute to some of the agronomic characteristics also of the new variety, the F_2 and the subsequent generations obtained from the cross are handled according to the pedigree method. This method is suitable for the resistance governed by either oligogenes or polygenes. If the resistance is governed by oligogenes, selection for resistance is effectively practiced in the F_2 generation. But in case of polygenic insect resistance, selection for resistance is delayed till the F_3 generation and a relatively large number of apparently resistant plants are selected. This is important because the differences between resistant and susceptible plants are not clear-cut, and there is a considerable effect of the environment on the expression of resistance.

In many cases, the insect resistant variety may be agronomically undesirable, or the gene for resistance may present in a related wild species. In such cases, backcross is the most suitable breeding method. The resistant variety or the related species is used as the non-recurrent parent, while the agronomically superior but susceptible variety is used as the recurrent parent. The backcrossing method is commonly used when the resistance is governed by one or few major genes. In general 5-6 backcrosses are necessary to recover the genotype of the recurrent parent. Incorporation of more resistance genes into a common agronomic base is possibly more desirable than a single gene conditioning resistance to insects (pyramiding).

GENETIC ENGINEERING FOR INSECT RESISTANCE

Recombinant DNA technology offers the possibility of developing entirely new biological insecticides that retain the advantages of classical biological control agents, but have fewer of their drawbacks. However, commercial considerations have placed this technology beyond the reach of poorer sections of society, and have generated considerable public debate about its usefulness, effects on the non-target organisms and the environment, thus preventing the use of an additional tool for increasing the production and productivity of crops. In addition to widening the pool of useful genes, genetic engineering also allows the use of several desirable genes in a single event and reduces the time to introgress novel genes into elite background (Sharma *et al.*, 2000). Several insect resistant transgenic varieties have been field tested and released in crops like tomato, potato, cotton and maize. Several approaches have been adopted to develop insect resistant transgenic plants by transferring insect-control-protein genes. While most of the insect resistant transgenic plants have been developed by using *Bt* δ-endotoxins, many studies are underway to use non-*Bt* genes for pest control. The synthesis of antimetabolic proteins, which interfere with the digestive processes in insects, is a defense strategy that plants use extensively. A number of such genes interfere with the nutritional requirements of the insects (Table 4). Such genes include protease inhibitors, chitinases, secondary plant metabolites and lectins (Jouanin *et al.*, 1998).

Table 4: Achievement of genetic engineering for biotic stress

Sl. No.	Crop	Insect-pest	Bt toxin
1.	Brinjal	Shoot and fruit borer	GY 1, Ab, Gy 1B
2.	Tomato	Fruit borer	GY 1, Ac, Gy 2Aa
3.	Cabbage	DBM	Gy 1 ab, Gy 1B
4.	Okra	Spiny ball worm	Gy1AC
5.	Pepper	Fruit borer	GY1, Ac, GY 2 Aa

(Source: Kumar, 1999)

MOLECULAR APPROACHES

Molecular approaches for insect resistance includes marker assisted selection, marker assisted backcrossing and marker assisted pyramiding. Using MAS, several genes can be combined into a single genotype. Pyramiding is also possible through conventional breeding but phenotypically testing individual plants for all traits can be time-consuming and sometimes very difficult. The most frequent strategy of pyramiding is combining multiple resistance genes. Different resistance genes can be combined in order to develop broad-spectrum resistance to diseases and insects. Either qualitative resistance genes can be combined or quantitative resistances controlled by QTLs.

CONCLUSION

In spite of considerable similarities in the evolution of pathogens and insects especially in relation to plants, relatively less efforts have been directed to develop pest resistant than disease resistant varieties. An aspect of resistance of concern to plant breeders is the durability. However, it has been a challenge to the breeders to achieve durable resistance. The exploitation of genes with known durability, the use of quantitative resistance, pyramiding of major genes, multiline, varietal mixtures and the use of spatial and temporal gene deployment can lead to the better ways of achieving durability of resistance. Breeding for host plant resistance is switching from conventional *viz.*, introduction, selection, hybridization towards non-conventional approaches like genetic engineering and molecular approaches, as later has broadened the scope of gene manipulations at the level of specific DNA segments across wide range of organisms to produce novel genomes with enhanced levels of resistance to biotic stresses.

Conflict of Interest

The authors declare no conflict of interest.

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